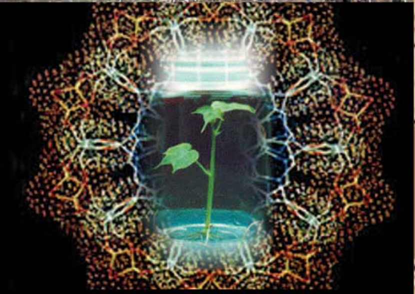
Perspectives of Agricultural Research and Development



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PERSPECTIVES OF AGRICULTURAL RESEARCH AND DEVELOPMENT

DIRECTORATE OF RESEARCH

Tamil Nadu Agricultural University

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FOREWORD

2005 is a landmark year in the history of agricultural education and research in Tamil Nadu. This year the Agricultural College and Research Institute, of TNAU Coimbatore celebrates its 100 years of glorious existence and service. It is a matter of pride that this Agricultural College is one of the four colleges established by the then Central Government during the year 1906. However, archival history indicates that prior to the Agricultural College, an Agricultural School was set up in Saidapet, Madras as early as 1868 based on the recommendations of Sir William Denison, the Governor of the then Madras Presidency, this school was later shifted to become the Agricultural College at Coimbatore. Another milestone in the development of the college was with reference to its recognition as a Centre for Post Graduate Education in 1930 by the Madras University. The AC & RI, Coimbatore which was later elevated to the position of TNAU in 1971, has lived up to the expectation that it will be an outstanding centre for education, research and extension. It is now one of the foremost Agricultural Universities in India. TNAU has become the epicenter of genetic improvement of the quality and productivity of a wide range of crop plants. TNAU can now look back with pride and satisfaction on its contributions to agricultural education, research and development which have helped the farmers of the state being identified as most progressive in this part of the country.

On this occasion of the centenary year of the AC & RI, Coimbatore, it was proposed to organize a seminar on “Recent Advances in Agricultural Research” by inviting scientific papers from eminent scientists in India and abroad. These scientific papers have highlighted the recent advances in the field of education, research management and evaluation, socio economic issues, biotechnology and crop breeding, soil and crop management, horticulture, forestry and agricultural engineering. These scientific papers have been compiled in the form of a book. This book may serve as a useful document not only to scientists in India but also in other parts of the globe. It may also serve as an informative compendium for the agricultural students too.

August 30, 2005
Coimbatore - 641 003

(C. RAMASAMY)

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AGRICULTURAL RESEARCH AND EDUCATION : 100 YEARS LATER

M.S. Swaminathan

Chairman National Commission on Farmers

2005 is a significant year in the history of India's agricultural research and education, since this year marks the centenary of the birth of organized institutions for agricultural research and higher education in the country. The Indian Agricultural Research Institute, was established at Pusa in Bihar in 1905. Steps were also taken during 1905 to establish Agricultural Colleges at Coimbatore, Nagpur, Kanpur, Pune and Lyalpur (now Faislabad in Pakistan). All these Colleges have since become Agricultural Universities. While inaugurating IARI at Pusa, Bihar, in 1905, Lord Curzon, the then Viceroy of India, referred to farming as India's greatest living industry. He also emphasized that agricultural education, particularly in villages should begin in schools. The Indian Council of Agricultural Research was established in 1929 on the basis of a recommendation of the Royal Commission on Agriculture headed by Lord Linthgow.

The Royal Commission emphasized the critical role of research in fostering sustainable advances in agricultural production in the following words:

"However efficient the organization which is built up for demonstration and propaganda be, **unless that organization is based on the solid foundations provided by research, it is merely a house built on sand".**

In the light of these remarks, it will be useful to first look at the current agricultural scenario emerging from the mid-term evaluation undertaken by the Union Planning Commission on our agricultural progress during the Tenth Five Year Plan period.

Current Agricultural Scenario: Assessment by Union Planning Commission

1. Growth Rate

- GDP growth in agriculture and allied sectors during **the first three years of the Tenth Plan averages only 1 percent per annum, in contrast to the Tenth Plan target of 4 percent.**

- The share of agriculture and allied sectors was 3.9% of the total Tenth Plan outlay, as against 4.9% in the Ninth Plan. The total share of agriculture, irrigation and rural development stood reduced from 20.1% in the Ninth Plan to 18.7% in the Tenth Plan.
- Tenth Plan expenditure of the Ministry of Agriculture during 2002-03 and 2003-04 was 27% of the total Tenth Plan outplay.

2. National Accounts

- Growth rates of livestock and crop output have averaged about 3.6% and 1.1% per annum respectively **after 1996-97,** down from 4.5% to 3.1% during 1980-97.
- Within the crop sector, only fruits and vegetables grew at over 2.5% per annum. **The output of remaining crops fell below 0.5% per annum after 1996-97** as compared to over 3% earlier.
- Growth of input use in agriculture **decelerated after 1996-97,** to about 2% per annum from over 2.5% during 1980-97.
- **After 1997-98, output prices began to fall relative to input prices.**
- Part of the deceleration in agricultural growth can therefore to attributed to lower profitability leading to a slow increase in input use. **Growth of input productivity became negligible after 1996-97.**
- During 1997-2002, agricultural prices declined **relative to prices not only of inputs** but also non-food consumer goods. Purchasing power of agriculture incomes decelerated more than GDP at constant prices. **Real farm incomes showed no per capita growth after 1996-97.**
- Real per capita food consumption declined after 1998-99, despite fall in relative food prices. **Per capita consumption declined absolutely in case of cereals, pulses and edible oils.** The growth rate in the consumption of fruits, vegetables and milk also declined,
- Input use and productivity growth decelerated from the 9th Plan onwards. **This was accompanied by low demand growth and higher farm income variability.**

3. Crop Production

- The Tenth Plan foodgrains target is 230 million tones in 2006-07. **The production was 212.9 million tones in 2001-02 and since then it has been declining.**
- Trend of rice and wheat production was less than population growth by the end of the 9th Plan. **Yield growth throughout the 1990s was about 1% per annum, as against 3% during the 1980s.** Large exports at below domestic prices and subsequent poor monsoons have now reduced the stocks to a low level.
- Yield growth in coarse cereals was about 2% per annum throughout the 1990s mainly **because of maize.**
- A Technology Mission in Pulses has been in existence since the early 1990s. Pulses yields have stagnated and the area under cultivation has also shrunk. **A sharp increase in imports of pulses has further reduced incentives for home production.**
- Oil Seeds Technology Mission started in 1986. There was a substantial expansion of area, yield and production till the mid 1990s. The production went up to 24.4 million tones in 1996-97. The production was 25.1 million tones in 2003-04 but growth continues to be negligible.
- Imports of edible oils, was less than 10% of domestic production till 1994-95. **Now the volume of imports equals domestic production.**
- There is an urgent need to **review the work of the Technology Mission on Oilseeds and Pulses, since the mission mode approach to project formulation and implementation should yield the anticipated outputs.**
- **Cotton Production** has been good during 2004-05, but yield and quality are still poor. The Technology Mission on Cotton needs to promote a symphony approach, linking the cotton producers and the textile industry in a symbiotic manner.
- **Sugarcane** yield has been either stagnating or declining - recovery of sugar from cane has not increased.

- **In fruits and vegetables, there has been no increase in yield.** Vegetable yields are declining. **Output increase in entirely through area expansion. The National Horticulture Mission will have to concentrate on increasing yield and quality.** Post-harvest processing and management need urgent attention. The National Horticulture Board needs careful restructuring and revitalization.

4. Livestock and Fish Production

- Milk and egg production has decelerated. There is however an increase in the number of crossbred cattle and poultry since 1997. Feed, Fodder and marketing need attention.
- Fish production is growing at a rate of 4% p.a. and the production was 6.4 million tones in 2003-04.

5. Overall Trends

- Almost every sector experienced lower growth after 1996-97. Even in **the excellent monsoon year of 2003-04, per capita output was less, except in horticulture.**
- Food consumption has stagnated since the beginning of the 9th Plan. National Accounts data show that real per capita consumption of cereals, pulses, edible oils, sugar, milk, fruits and vegetables was lower in 2003-04 than in 1998-99.
- Overall employment growth has been very slow. Real agricultural incomes have been stagnating or declining.
- **Agriculture will progress only if demand (both home consumption and export) increases.** Consumption should be increased through both nutrition intervention programmes and through accelerated non-farm employment.
- Cost of production should be reduced through enhanced factor productivity. The average fertilizer response of food grain output to NPK fertilization works out to 7.8 kg grain per kg NPK. This is a very low return. How can we become globally competitive if our factor productivity is both low and declining?

- Imports of pulses and oilseeds are growing. Import of pulses, which used to vary in the range of 3 to 6 lakh tonnes in the 1990s surged to over 2 million tones in 2001-02 and has remained at that level since then. Imports of edible oils increased from 1 million tonne in 1995-96 to over 4 million tonnes in 1999-2000. It is now ranging in the order of 4.2 to 5.3 million tones per year accounting for about half of domestic consumption.
- Sustainability of food production is threatened by depletion and pollution of the aquifer, soil health degradation, failure of research, extension and input supply systems and declining investment in the farm sector. In addition to being a gamble in the monsoon, farming is becoming increasingly a gamble in the market. "The fatigue of the green revolution" is due to both ecological damage and technology fatigue.
- India today has the largest number of undernourished children, women and men in the world. Maternal and foetal undernutrition is resulting in low birth weight babies. Such LBW children are handicapped at birth in brain development, the crudest form of inequity. Yet, we often hear glib talks about India becoming a Knowledge Superpower. Unless there is widespread realization among political leaders and policy makers that we are on the threshold of an unprecedented human tragedy, we will have to revert once again to the "begging bowl" phase of our agricultural evolution. Also, where hunger rules, peace will not prevail.

New Deal for Rural India

Pledging the commitment of the Government of India to providing a New Deal for Rual India, Prime Minister Manmohan Singh, a distinguished Fellow of our Academy said, **"We want India to shine, but India must shine for all".**

The steps taken to implement this commitment include the following:

- Reversing the declining trend in investment in agriculture
- 30% of increase in credit flow to farmers
- Increasing public investment in irrigation and wasteland development

- Increasing funds for agricultural research and extension by almost 40%
- Creating a “single market” for agricultural produce
- Investing in rural healthcare and education
- Investing in rural electrification ,
- Investing in rural roads
- Setting up commodities futures markets
- Insuring against risk in farming and rural business

Mission 2007: Hunger-Free India

We now have the necessary political economic, and technological capability and social infrastructure for making a major effort to eradicate poverty induced endemic hunger by 15 August 2007, which marks the 60th Anniversary of our Independence.

The following are the major components of the Food for All Movement :

1. Restructure the delivery systems relating to all nutrition support programmes on **a life cycle basis,** starting with pregnant women and 0-2 infants and ending with old and infirm persons. An illustrative list of the programmes which will benefit from a life-cycle based delivery system is in Table 1.

Table 1. Current Status of Interventions

S.No	Stage of Life Cycle	Intervention / Action
1.	Pregnant Mothers	Food for Nutrition to avoid maternal and foetal mal- and under-nutrition resulting in LBW children
2.	Nursing Mothers	Support needed for breast feeding, for at least six months
3.	Infants (0-2 years)	Not being reached by ICDS
4.	Pre-School Children(2-6 years)	Integrated Child Development Services
5.	Youth going to School(6-18 years)	Noon Meal Programme
6.	Youth out of School	Not being attended to
7.	Adults (18-60 years)	Food for Eco-Development (Sampoorn Gramin Rozgar Yojana), PDS, TPDS, Antyodaya Anna Yojana
8.	Old & Infirm Persons	Annapoorna and Food for Nutrition Programmes
9.	Emergencies	Food during natural calamities

2. Promote **community food security systems** based on an integrated attention to conservation, cultivation and consumption.

Gene Bank   Seed Bank   Water Bank   Grain Bank

This programme should be based on the principle **"store grain and water everywhere".**

The Community Grain / Food Bank system will help to widen the food security base by including a wide range of millets, grain legumes and tubers.

3. Promote the growth of **community water security systems** based on a 5-pronged strategy consisting of:

- Augment supplies through mandatory water harvesting and conservation
- Curtail demand by eliminating all sources of unsustainable use of water and promoting "more crop per drop" methodologies of crop cultivation
- Harness new technologies relating to improving domestic water use efficiency,de-salination of sea water, breeding of drought and salinity tolerant crop varieties,bioremediation, etc.
- Promote seawater farming through integrated agro-forestry and aquaculture production systems in coastal areas.
- Pay attention to water quality. The quality of drinking water is deteriorating due to pesticide and bacterial contamination in ground water. As much attention should be paid to the improvement of drinking water quality,as to the augmentation of water supplies. Bioremediation techniques will have to be used for removing arsenic and heavy metals from tube well water.

4. **Eradicate hidden hunger** caused by micro-nutrient deficiencies based on natural food cum food fortification approaches. For example, salt fortified with iron, iodine, minerals and vitamins, coupled with the consumption of beta-carotene rich sweet potato or vegetables will be very helpful to fight hidden hunger. Nutritious biscuits can also be made by local self-help groups.Nutritional literacy should be promoted at the school level.

5. New Deal for the Self-employed

The unemployment rate on current daily status was about 9.21 percent (34.85 million) in 2001-02 in rural areas. Unemployment among rural youth increased from 9 percent in 1993-94 to 11.10 per cent among males and 10.60 percent among females in 1999-2000.

Rural employment grew at 0.67% and agricultural employment at 0.02% during 1999-2000. According to the 55th round of survey of NSSO the share of self-employed in 1999-2000 was about 53%. The share of self-employed in total employment, 58% (133 to 134 million) was in the primary sector, i.e., agriculture and allied activities.

Detailed analysis of the causes of food insecurity in rural and urban India have revealed that inadequate purchasing power due to lack of job/livelihood opportunities is now the primary cause of endemic or chronic hunger in the country. Since opportunities for employment in the organized sector are dwindling, we have to create a policy environment which enlarges opportunities for remunerative self-emplovment in rural India in order to avoid an era of jobless economic growth.

Agriculture, comprising crop and animal husbandry, fisheries, forestry and agro-forestry and agro-processing is the largest private sector industry in India, providing livelihood opportunities for over 600 million women and men. There is need to intensify efforts to create more opportunities for gainful livelihood opportunities in the farm and non-farm sectors.

The menu of income earning opportunities for the self-employed needs to be enlarged. NCF has already recommended that all the existing Krishi Vigyan Kendras (KVKs) should be provided with a post-harvest technology wing. In addition, there is an urgent need for atleast **50 SHG capacity building and mentoring centers** in every State, to enhance the management and marketing capacities of Members of the Self-help Groups (SHGs). Such centers can be established in existing institutions like Agricultural, Rural and Womens' Universities, IITs, institutions operated by NGOs, etc. Village Knowledge Centres can provide SHGs with e-commerce facilities. Accounting software will have to be introduced. SHGs will be sustainable in the longer term only if they have backward linkages with technology and credit, and forward linkages with management and marketing. Sustainable Self-help Groups (SSHGs) will emerge only if we build the capacity of the key members (both women and men of SHGs). **The SHG Capacity Building and Mentoring Centres** may be financially supported by the Union Ministry of Rural Development. This will be an essential component of the New Deal for the Self-employed.

6. Enhancing the Productivity of Small Holdings

Nearly 80% of the land holdings are below 2 ha in size. Unlike in industrialized countries where only 2 to 4% of the population depend upon farming for their work and income security, agriculture is the backbone of the livelihood security system for 2/3 of India's population. **Therefore, farmers constitute the largest proportion of consumers.** The smaller the farm, the greater is the need for marketable surplus in order to get cash income. **Hence, improving small farm.productivity, as a single development strategy', can make the greatest contribution to the elimination of hunger and poverty.**

Indian soils are both hungry and thirsty. Hence, soil health enhancement and irrigation water supply and management hold the key to the enhancement of small farm productivity. The following steps are urgently needed.

- National network of advanced **soil testing laboratories** with facilities for the detection of micro-nutrient deficiencies. As a single agronomic intervention, supply of the needed micronutrients in the soil has the greatest impact on increasing yield. Hidden hunger is as widespread in soils, as in humanbeings. In fact, the two have causal relationships.
- Million Wells Recharge Programme
- Restoring Water bodies and promoting mandatory water harvesting.
- Establishment of 50,000 Farm Schools to promote farmer to farmer learning.
- Organisation of Small Farmers' Horticulture, Cotton, Poultry and other Estates, to promote group farming and to confer the power of scale to small producers both at the production and post-harvest phases of farming.

7. Proactive Advice on Land and Water Use

Farming is becoming a gamble both in the monsoon and the market. Farmers urgently need **proactive advice** on land and water use. Land use decisions are also water use decisions. (Figure) The Every Village a Knowledge Centre Movement will help to give farmers dynamic advice on meteorological and marketing conditions.

In addition to dynamic advice, farmers also need proactive advice on land and water use. For this purpose, State Land Use Boards should be restructured, retooled and reactivated on the lines indicated in Fig. This is a task of the utmost priority.

Fig : Proactive Advice on Land use

(Land use decisions are also water use decisions)

State Land Use Board

(to be located in an Agricultural University)

↓

Integrated advice

↓

Meteorological Factors | **Ecological Factors** | **Marketing Factors (Home and external markets)**

8. Designing and introducing a Food Guarantee Act

We have over a century of experience in organizing relief works (under the provisions of the Famine code in he Colonial Period) and Food for Work programmes. It is clear that our agriculture has reached a stage when farmers will grow more only if we can consume more. Hence, a **National Food Guarantee Act,** combining the features of the Food for Work and Employment Guarantee Programmes, will represent a win-win situation both for producers and consumers. Women, in particular, prefer a combination of grains and cash as wage, provided the food grains are of good quality.

National Food Guarantee Act should lead to a decentralized network of grain storage structures and would help to prevent panic purchase of food grains during periods of drought or flood. They will also help to prevent distress sales by producers at the time of harvest. In addition, it will help to enlarge the composition of the food security basket.

Brazil, Kenya and a few other countries have announced, “Zero Hunger” programmes. India can take the lead to give meaning and content to the zero hunger concept by developing a National Food Guarantee Act.

On the occasion of the Centenary of the Coimbatore Agricultural College, the mother of TNAU, let us resolve to work for reversing the agricultural decline and eliminating under and malnutrition from our country.

The Land Use Board through a virtual college should give proactive advice on the choice of crops and farming systems, so as to achieve a match between demand and supply in farm commodities and to ensure that the most efficient crops are grown in different agro-climatic and agro-ecological regions.

SEARCH NEW GENES TO AUGMENT AGRICULTURAL PRODUCTIVITY, PROFITABILITY AND RESOURCE USE EFFICIENCY

Mangala Rai

Secretary, (DARE) & Director General, I.C.A.R.Krishi Bhawan, New Delhi

The success story India's Green Revolution is well established and owes much to the introduction and adaptation of genetically improved varieties of rice and wheat. The discovery and successful transfer of dwarfing genes in wheat and rice had opened a new chapter in the history of global agriculture. The new varieties resulted in a multifold increase in foodgrain production; saved millions of lives from starvation; provided sustainability to national food security; and above all, earned pride for the nation. A major battle against hunger was thus won but the war continues.

The projections indicate that our population will be 1.5 billion by 2050. Rising population and per capita income are obviously pushing up the food demand, which needs to be met through enhanced productivity per unit area, input, time and energy. At the same time, issues of decreasing factor productivity and need for improving resource use efficiency have emerged. If we have to compete in terms of cost and quality globally, conservation and judicious utilization of prime natural resources in general and genetic resources in particular will be crucial for competitive growth and sustainability of the system.

India fortunately is endowed with a wide range of agro-climatic conditions extending from wettest areas in the east to extremely arid areas in the west and temperate climate in the north to humid and coastal areas in the south. The rainy seasons coincide with the life cycle of chief agricultural crops. There also exist wide range of soils, which support even more diverse range of life forms - floral, faunal and microbial, which has placed India among the 12 mega-centres of biodiversity in the world. There are about 45,000 species of higher plants. The number of endemic species is estimated to be close to 3470 in Himalayas, 2000 in peninsular India and 240 in the Andaman and Nicobar Islands. It is reported that the Indian gene centre has about 4000 species of medicinal value, 500 fibre yielding species, 100 aromatic and essential oil yielding species, and 400 fodder yielding species. The Western Ghats and the northeastern India are also two of the 25 hotspots of biodiversity in the world.

Besides the plant species about 114 breeds of domesticated animals are also found here.

The quest for new genes is closely linked to the 10,000 years' long history of agriculture. Over the years, nature has brought about hybridization among the closely related as well as some of the distantly related species. The development of tetraploid and hexaploid wheat are well known examples of such hybridization. In case of rice only two species i.e *Oryza sativa* and *O. glaberrima* are pre-dominantly cultivated but their wild and uncultivated species continue to be the source of genes for improved rice varieties. The gene (Gsv 1) in rice for resistance to grassy stunt virus was transferred from *O.nivara*, likewise *O. officinalis* was the source for the genes to develop resistance to brown plant hopper and white-backed plant hopper. Other important genes introgressed from wild species of rice into the cultivated species include genes for tolerance to drought from *O. glabeerrima*, resistance to rice tungro virus from *O. latifolia,* and traits of CMS, resistance to drought and high yield coming from *O.rufipogon*, and resistance to Yellow stem borer (YSB) being introgressed from *O. ridleyi.*

Wheat is the other most important staple cereal alongwith rice and probably the earliest cultivated. The genes transgressed in wheat for resistance to black rust and brown rust has come from *Aegilops speltoids* and *A. elongatum*. The research efforts directed towards achieving wheat varieties with higher yield potential, improved nutritional quality, biotic and abiotic resistance have resulted in overall enhancement of wheat germplasm. Similarly, introgression of genes from two close wild relatives of maize, *Tripsacum* and *Zea mexicana,* have resulted in higher yields in maize. The 'nobilization' of cane is well-established case of varietal improvement by harnessing the plant genetic resources. Practically every cultivated crop, field or horticultural, has got some useful quality traits through intergeneric or interspecific crossing.

The Council has accorded high priority to collection, evaluation, characterization, conservation and utilization of genetic resources and in this endeavour has established *National Bureau of Plant Genetic Resources* at New Delhi, *National Bureau of Animal Genetic resources*, Karnal, *National Bureau of Fish Genetic Resources* at Lucknow and *National Bureau of Agriculturally Important Microorganisms* at Mau. The NBAIM will help in understanding and conserving our national heritage of micro-organisms, which have not been understood and conserved so far and provide good opportunities for isolating and utilizing genes for conventional and unforeseen products of high environmental and agricultural values.

There is a little doubt that to sustain the productivity and production achieved through conventional means; to meet new, diverse and complex challenges that lie ahead of us and also to avail the technological breakthroughs that are now available for commercial use, so as to maintain comfortable position on food and nutritional fronts, agricultural research priorities and strategies will have to be revisited and new system wide system approaches will have to be developed and adopted. We will have to look for newer genes, methodologies to transfer them across the living organisms and at a much faster rate so that the variety or breed developed with the required new trait in the already well adapted background can be transferred to the field without much loss of precious time.

The Green Revolution of 1960's rallied around the input responsive, high yielding varieties grown in the early phase under near monocultures in traditionally agricultural and fertile areas. Since then, there has been significant resource degradation, culminating in further production constraints. To meet these new challenges, it will be more rewarding if the power of hitherto untapped genes is harnessed against such constraints as the resource degradation and pest-weed complexes, etc. Hence, the need is to produce crops with high input use efficiency, improvement in nutritional quality, and stability in storage. At the same time, focus will have to be made on the incorporation of traits like tolerance to various biotic and abiotic stresses for increasing agricultural productivity and profitability particularly in the rainfed and marginal environments.

The advent of biotechnology has brought the whole living world into a common gene pool and has enabled us to realize free flow of genes across the biological world.Biotechnology offers several advantages over classical breeding, in terms of precision, reducing technology gestation period, and gene transfer for specific traits even from the unrelated organisms. In the context of a holistic agricultural development and ensuring household food security, role of biotechnology is going to be much more important than ever before. Bioprospecting will have to essentially lay the foundation for effective mining and transfer of genes for specific traits. Saving on precious time and even resources is likely to become an added advantage in the changed scenario. Potential benefits could be in form of development of crops species and animal breeds that are more resistant to biotic and abiotic stresses, possess enhanced nutritional level, enhanced shelf-life of farm produce, and efficient conversion of organic waste into biofuels, etc. However, the further challenge is to characterize some focused genes from the documented sequences and harness the much-needed genes for traits like tolerance to drought, salinity, heat and cold etc., for effective use of the research results.

Application of genetic power in hybrid technology development is yet another area that is sure to give productive outcome. Since conventional hybrid breeding methods have certain limitations, biotechnological tools will have to be employed for hybridization to achieve the targetted genetic improvement through facilitated use of desirable genes across plants, animals, fish and microorganisms.

Microorganisms in the rhizosphere are known to be synergistic to crops since long. These have been essentially seen as the sustainability supporting components of traditional/biodynamic/organic agriculture in the conventional mode. Most of the chemical reactions that take place in the soil, leading to increased availability of several major and micronutrients, often have active contribution of microbes. The nitrogen-fixing bacteria, blue green algae, and phosphate solublizing bacteria are already well known to enhance availability of major nutritional elements like N and P to plants whereas the decomposer bacteria are instrumental for recycling and thereby increasing the availability of Carbon and several micronutrients from plant residues to soil.

But with the developments in genomics and gene transfer through biotechnology, their relevance and role has further increased manifolds. The agriculturally important microbes are increasingly seen to be much more dynamic and focused 'gene resource' for developing transgenics to increase productivity and quality, and incorporating resistance to biotic/abiotic stress factors in the plants and livestock. The countless microorganisms of agricultural importance hail from several taxa, such as, bacteria, actinomycetes, blue green algae (BGA), fungi, including vesicular arbuscular mycorrhizae (VAM), and viruses. They thrive in a variety of habitats/systems including soils, living body systems and dead/decayed matter, marine, snow bound mountains and desert systems, polluted land and water bodies, etc. Their genetic factors underlying the differential adaptability to such diverse habitats/systems indicate invaluable treasure of genes for the benefit of agriculture. The sectoral importance of microorganisms in agriculture has also increased with the integration of agriculture, intellectual property and services with the world trade agreement. Research efforts have to be essentially focused on prospecting and mining of the microbial genetic potential for use in crop and animal improvement. The world is keenly looking forward to harness the genic power from microorganisms through the rapid development of their institutional capacity through building up of the state of art laboratories, biosafety and other regulatory mechanisms, and human resource development.

The first transgenic plants engineered for insect resistance in cotton, corn and soybean were released for commercial cultivation in 1996. In less than a decade (1996 to 2004), area under biotech crops has increased more than 47 times globally, from 1.7 million hectares in 1996 to 81.0 million hectares in 17 countries in 2004. There has been noticeable growth in four commercialized biotech crops viz. soybean, maize, cotton and canola. Among these GM crops, soybean occupied 48.4 million hectares, maize 19.3 million hectares, cotton 9.0 million hectares and canola 4.3 million hectares. Other bio-engineered crops include Potato, Squash and Papaya and many more at the research scale, and the key traits bio-engineered are herbicide tolerance, insect resistance, etc. The developing countries have also adopted GM crops and their area is increasing steadily. The available indications are that in coming years in addition to the agronomic traits, transgenic plants will predominantly address the aspects such as improvement of product quality involving proteins, fats, carbohydrates and important nutrients such as vitamins, minerals etc. Also, transgenic plants are going to be most sought after bioreactors for producing edible vaccines, antibodies, bioplastics, highly saturated oils for industrial use, pharmaceuticals and a number of other metabolic products/byproducts of economic importance.

The issues of bio-safety and environmental safety need to be addressed along with the promotion of biotechnological applications in agriculture. Every human activity has some or the other inherent risks. Nevertheless, it is in the interest of a better future of our coming generations that the positive side of transgenics and other GM technology is rationally harnessed. We need to be more scientifically equipped so as to make sensible decisions.

The enhancement of IPRs under the TRIPS Agreement has keenly affected the area domain of scientific innovations, including the biotechnological inventions. The bioprospecting, mining and the application of genetic power in agricultural research are surely to be influenced by the capacity and skill to manage the IPRs. The international understanding has been firmed up around two basic issues i.e. ‘protection of intellectual property for exclusive use’, and ‘benefit sharing on the principles of equity’. The TRIPS Agreement and the CBD have addressed these issues and both provide the legally binding requirements. Yet there are some gaps, which need to be determined and bridged. The 10-year transition period for the implementation of TRIPS provision, which was over by 1.1.2005, appears to have been too short for the developing countries to institutionalize the whole processes so as to provide a 'level playing field' to the international players. Interdependence of countries for genetic resources for food and agriculture will continue, and the genetic power must be harnessed by the innovating scientists across the world for the global community as a whole. In relation to harnessing public good from an IPR protected technology, the IPR laws already provide the mechanism of 'compulsory licensing'. Much more needs to be done to generate public good in commodities having low commercial interest, but which are vital for food security and system sustainability.

Particular concerns, especially in the public sector research system are:

- How the whole system is to be fine-tuned in the system wide system perspective?
- How IPR portfolio is to be managed ?
- How the dissemination of research findings is going to take shape?
- How the biosafety and environmental safety concerns will be timely addressed to ?
- How the knowledge base can be used and shared with the scientific fraternity, the academia, the industry, the farmers, the end-users, and the public at large?
- How gene power through biotechnological applications in agriculture can be acclimatized to a level where it eventually becomes a way of life?
- How the vast genetic variability could be sampled and utilized ?

There is a need for every scientist to familiarize with the techno-legal requirements of IPR protection and benefit sharing, for example, entering into MOUs, MTAs, Benefit Sharing Agreements, Licensing contracts, Transfer of Technology or Know-how Agreements, Secrecy Agreements, etc. It is important to reveal the IPR related 'know-how' only in an appropriate manner and at an appropriate time. Holding of IPR titles, both quantitatively and qualitatively is a matter of pride, no doubt. But, more important is as to how we are going to disseminate the protected technologies for the cause of enhancing food security as well as the household nutritional security? In this endeavour biotechnology and IPR are going to be far more important for shaping the course of harnessing gene power and we must cope up with the developments in both areas simultaneously.

The search, characterization, isolation and utilisation of new genes from across the taxa for imparting desirable traits in crop and livestock species will remain at the core for the success of any efforts to enhance farm productivity. Natural and farm biodiversity needs to be explored as an essential prerequisite in 'search for new genes' and equally important is to conserve it for the posterity. We need to intensify the search for new genes and harness the genic power to enhance agricultural productivity, profitability and resource use efficiency for developing a prosperous India.

FROM FOOD SECURITY TO MARKET-DRIVEN GROWTH IN INDIAN AGRICULTURE : IMPLICATIONS FOR AGRICULTURAL POLICY

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INTRODUCTION

India has experienced a remarkable transition in recent decades, from food deficits in the 1960s to national food surpluses today. This has been accompanied by an equally dramatic reduction in poverty; from about 60% of the population in the 1960s to about 25% today. India seems finally to have beaten her national food problem and now producers more than enough food for all. But even as one battle has been won the agricultural sector is challenged by continuing high rural poverty levels, a rapidly changing market situation, and serious environmental problems that require a significant response if rural areas are to continue to prosper.

The very success of solving the national food problem means that market opportunities for further growth in food staples are now limited. Growth in domestic demand for food staples is now flat and India faces limited export opportunities for these crops. While there are still far too many Indians who do not get enough to eat, solving this problem now requires solutions that raise the incomes of the poor, not solutions that simply produce more food. Given these limited market prospects for food staples and declining world and domestic prices, further increases in farm incomes will have to come from diversification into higher value crop, livestock and processing activities. Fortunately, the improved performance of the national economy in recent years has raised living standards for many, and demand for higher value foods (fruits, vegetables, oils, fish, livestock products, etc.) and processed and pre-cooked foods are growing at unprecedented rates. Add to this the new export market opportunities for many of the same products that trade liberalization is bringing about, and there is a happy match between the demands of the market and the need for farmers to diversify into higher value activities. But will these markets expand sufficiently to provide the levels of income growth needed in the agricultural sector, or will they too eventually become saturated and constrain further growth?

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Agriculture's ability to contribute to additional poverty reduction is also challenged by its declining employment elasticity. The agricultural sector is no longer creating sufficient jobs or livelihoods in rural areas to absorb the growing rural labor force or to offer sufficient pathways out of poverty for the remaining rural poor. The nonagricultural sector now plays a much larger role in driving the national economy (agriculture only accounts for 25% of national GDP) and in creating jobs, but because agriculture employs 60% of the national work force it still has an important role to play. The rural work force is projected to grow at about 1.33% per year until 2020 and the numbers of small farms and near landless also seem destined to keep growing. Agriculture's role in creating jobs and reducing poverty is especially important in many of the more backward regions that missed out on the Green Revolution. But is there sufficient growth potential for productive employment in the agricultural sector?

A third challenge will be overcoming many of the environmental problems that now plague agriculture. Water scarcities will continue to grow and farmers must learn to use less water and to be less polluting. Land degradation and deforestation must also be contained. Are the needed changes in management practices compatible with future agricultural growth and continuing increases in land and labor productivity?

This paper discusses these challenges in more detail and their implications for the public policies and investments needed if the agricultural sector is to continue to play a major role in India's economic and social development.

The transition from national food shortages to surpluses

Food problems have haunted India since time immemorial. With few technological breakthroughs to increase yields, the food needs of a growing population were historically met by expanding the cultivated and irrigated area. After Independence, food production barely kept pace with population growth, leading to a fragile balance between the nation's food needs and supplies, particularly in years of low rainfall. Food imports averaged about 4-5 million tons per year, but were much higher in drought years. During the severe droughts of the mid-1960s, food imports reached 10 million tons per year and many people faced famine. This crisis proved sufficient to mobilize the Indian government to launch a national food security strategy as the heart of its agricultural development strategy. The result was a package of policy reforms, public investments, and technology development and extension that launched the Green

Revolution. This technological revolution began as a wheat-rice revolution in the main irrigated areas, but soon spread to rainfed areas relying on supplementary irrigation from tubewells and tanks, and later to other food crops in rainfed areas.

The Green Revolution made enormous contributions to national food security. In the early 1960s, India produced about 70 million tons of foodgrains in a normal rainfall year. This doubled within 20 years and has about tripled today. Rapid growth in agricultural production led to sizeable increases in rural incomes and savings, and this helped launch an economic transformation of the national economy (Mellor, 1976; Rosegrant and Hazell, 2000). By boosting rural demand for consumer goods and farm inputs and marketing services, it powerfully stimulated the rural nonfarm economy, which generated significant new income and employment of its own (Hazell and Ramasamy, 1991; Rosegrant and Hazell, 2000). The types of economic growth generated were also beneficial to the poor. Pro-poor growth was helped by the facts that many small farmers widely adopted the new technologies, and because more intensive use of land increased agricultural employment and wages (e.g. Hazell and Ramasamy, 1991). Moreover, the additional food production helped keep food prices low, and this was enormously beneficial to poor people in urban and rural areas alike.

Despite these impressive gains, the green revolution was not equitable everywhere. It was most equitable in regions where small farms were major participants, and that required an equitable distribution of land as well as equitable access to modern farm inputs, credit and markets (Hazell and Ramasamy, 1991; Rosegrant and Hazell, 2000). It also bypassed many areas that lacked access to sufficient water. Evidence suggests that villagers in these regions did obtain important indirect benefits through increased employment, migration opportunities, and cheaper food (David and Otsuka, 1994). Many poorer regions also benefited later from higher yielding varieties of coarse grains and pulses. But these benefits rarely prevented the widening of regional income differentials.

Moreover, despite very significant gains to the poor in general, including the urban poor, from lower food prices, there are still some 250 million Indians living in poverty who do not get enough to eat. These people do not have the means to buy all the staple foods they need despite their ready availability in the market. Food security is now a distribution problem and that requires a different solution than simply growing more food. It requires a more focused and targeted effort to raise the incomes of the poor, most of whom are rural (75%) and reside in rainfed, often backward areas (Fan, Hazell and Haque, 2000).

India now has large surpluses of rice and wheat and to support declining farm incomes, the government is procuring and storing grains to shore up farm gate prices. Per capita demand for cereals declined during the 1990s (Table 1), and with limited exports and a slowing of population growth, the total value of cereals produced also declined during the 1990s (by 1.18% per year, Table 2). Even if poverty were eliminated through a better distribution of income, it would not add that much to total food staple demand; perhaps about 8 million tons per year (Bhalla and Hazell, 2003). Any significant growth in domestic cereal demand is more likely to come from livestock feed, and that means more maize and coarse grains rather than rice and wheat (Bhalla, Hazell and Kerr, 1999). While India could be competitive in world markets as an exporter of rice and wheat, opportunities are restricted by the continuing distortions in OECD agricultural markets as well as by government policies (Gulati and Kelley, 1999; Kalirajan *et al.,* 2001).

Table 1. Average per capita consumption, India

(Rupees, constant 2000 prices)

Commodity	***1993/4***	***2001/2***	***Annual growth rate: 1993/4 – 2001/2***
Cereals and gram	*1197*	*1139*	*-0.69*
	(20.81)	*(15.70)*	
Pulses	*203*	*215*	*0.84*
	(3.53)	*(2.97)*	
Edible oils	*255*	*242*	*-0.70*
	(4.42)	*(3.34)*	
Fruits & nuts	*119*	*139*	*1.21*
	(2.07)	*(1.79)*	
Vegetables	*336*	*426*	*3.46*
	(5.83)	*(5.87)*	
Milk and milk products	*553*	*601*	*1.22*
	(9.60)	*(8.29)*	
Eggs, meat and fish	*193*	*226*	*2.24*
	(3.36)	*(3.11)*	
Other foods	*604*	*668*	
	(10.49)	*(9.23)*	
Total foods	*3,459*	*3647*	*0.76*
	(60.11)	*(50.30)*	
Nonfoods	*2,296*	*3,604*	*6.66*
	(39.89)	*(49.70)*	
Total expenditure	*1,201*	*1,383*	*3.36*

Source: NSS data

Figures in parentheses are percent shares in total budget

Table 2. Changes in value of Indian Agricultural Output

(Crores Rupees, constant 2000 prices)

Commodity	***1991-93***	***2000-02***	***Annual growth rate: 1991 – 2002***
Cereals	*134,113*	*131,488*	*-1.18*
	(39.0)	*(32.1)*	
Pulses	*17,693*	*20,158*	*0.47*
	(5.1)	*(4.9)*	
Oil crops	*52,275*	*39,278*	*-3.82*
	(15.1)	*(9.6)*	
Fruits	*32,443*	*45,645*	*5.84*
	(9.4)	*(11.1)*	
Vegetables	*31,160*	*56,592*	*5.65*
	(9.1)	*(13.8)*	
Milk	*58,459*	*92,373*	*4.94*
	(17.0)	*(22.6)*	
Eggs	*2,248*	*4,272*	*6.00*
	(0.7)	*(1.0)*	
Meat	*15,969*	*19,601*	*2.98*
	(4.6)	*(4.8)*	
Total	*344,361*	*409,408*	*1.57*

Source: FAO data base

Figures in parentheses are percent shares

With national surpluses and downward pressure on farm gate prices, it is getting difficult for many farmers to support their families through production of food staples. The pressure on land is also increasing, and small farms are becoming more numerous and smaller in size (Table 3). India has seemingly not yet reached the point in her economic transformation where the absolute number of farms and agricultural workers decline, so there is still need to find ways of increasing both land and labor productivity in agriculture.

New opportunities

In this context, future growth in agricultural income will be constrained if the country does not move beyond its concerns with national food self-sufficiency to better exploit its comparative advantage. This will also be essential if agriculture is to again become a major contributor to rural employment and poverty reduction. Fortunately, new growth opportunities for agriculture are arising from a number of sources:

Table 3. Size Distribution of Operational Holdings, All India

Size Category of Holding (acres)	***Number and Percentage[a] of Total Operational Holdings (millions) Year***				
	1953/54	***1961/62***	***1971-72***	***1981-82***	***1991-92***
Sub. Marginal	*8.74*	*8.70*	*12.13*	*22.69*	*35.24*
(0.01 - 0.99)	*(19.7)*	*(17.1)*	*(21.3)*	*(32.3)*	*(37.7)*
Marginal(1.0 2.49)	*8.62*	*11.14*	*13.99*	*16.31*	*23.45*
	(19.4)	*(21.9)*	*(24.5)*	*(23.2)*	*(25.1)*
Small (2.5 – 4.99)	*9.25*	*11.48*	*12.77*	*13.72*	*16.63*
	(20.9)	*(22.6)*	*(22.4)*	*(19.5)*	*(17.8)*
Medium (5.0 – 14.99)	*12.19*	*14.09*	*13.77*	*13.85*	*14.74*
	(27.5)	*(22.8)*	*(24.1)*	*(19.7)*	*(15.8)*
Large (>15.0)	*5.56*	*5.36*	*4.41*	*3.68*	*3.40*
	(12.5)	*(10.6)*	*(7.7)*	*(5.2)*	*(3.6)*
Number holdings	*44.35*	*50.77*	*57.07*	*70.26*	*93.45*
(millions)	*(100)*	*(100)*	*(100)*	*(100)*	*(100)*

a. Percentages are in parentheses

Source: - National Sample Survey on Land HoldingNSS 8th round, no.36 1954-55: NSS 17th round no. 144 1961-62; NSS 26th round no. 215 1971-72, NSS 37th round, nos.330 and 331 1982, 48th round no.388, 1992.

§ Changes in the national diet. With the accelerated national economic growth achieved in recent years and the rising affluence of the middle classes, per capita consumption of livestock products (especially eggs, milk and milk products), fish, fruits, vegetables, flowers and vegetable oils) has grown rapidly in recent years (Table 1). This is creating new growth opportunities for farmers to diversify (even specialize) in higher value products, especially those farmers who have ready access to markets, information, inputs and so forth. It is also accelerating demand for feed grains, especially maize, which is providing additional opportunities for some grain farmers.

§ The ongoing national policy reforms are also slowly opening up export markets for Indian farmers. This, together with the removal of restrictions on inter-state trade within India, should enable more farmers to specialize in those crops in which they have comparative advantage and can best compete in the market. These opportunities should also improve if the Doha Round of the world trade negotiations succeeds in freeing up more agricultural markets around the world, especially in rich countries. Exports of higher value agricultural products (fresh and processed fruits and vegetables, meats, and poultry and dairy products) have grown rapidly in recent years (Table 4), though they still remain relatively small in total value. In 2002/03, the export of these commodities was worth Rs. 3,155 crores in 2000 prices, or about 10% of total agricultural exports. This was up sharply from Rs. 436 crores in 1990/91, equivalent to 3.3% of total agricultural exports at that time.

Table 4. Changes in India's Agricultural Exports

(Crores Rupees, constant 2000 prices)

Commodity	***1990/91 – 1991/1992***	***2001/02 - 2002/03***	***Annual growth rate, 1990/91 to 2002/03 (%)***
Pulses	*NA*	*334.6*	*12.95*
Cereals	*1,349.5*	*5,552.2*	*16.96*
Poultry and dairy	*NA*	*180.7*	*10.85*
Fruits	*150.3*	*908.8*	*17.48*
Vegetables	*NA*	*775.0*	*6.86*
Meat	*370.0*	*1,208.1*	*12.65*
Oils	*1,738.3*	*2,273.4*	*1.54*
Spices	*603.0*	*1471.8*	*9.56*
Traditional export crops	*2,089.7*	*6,313.3*	*10.96*
Total agricultural exports	*13,887*	*29,724*	*7.50*
Total national exports	*76,674.2*	*218,232.9*	*10.62*

Note: NA means not available

§ There are also good opportunities for generating greater value added in agroprocessing, particularly if agroindustry were liberated from current protective policies and became more competitive with imports (World Bank, 1999; Gulati and Kelley, 2000). Oil seeds processing, for example, is still protected, making domestically produced vegetable oils non-competitive with imports. Many producers can compete as growers of vegetable oils, but they are penalized when competing in the vegetables oils market because their products have to be processed by a highly inefficient domestic industry (Gulati and Kelley, 2000).

These trends offer significant and growing opportunities for India's farmers to move into higher value products that can increase their returns to land and labor. Growing opportunities for food processing and retailing also offer significant possibilities for adding value and employment in rural areas and market towns.

During the 2-year period 2000-02, the output of high value crops and livestock averaged Rs. 218,483 crores (53% of the total value of agricultural output), up from Rs. 140,279 crores in 1991-93 (about 40% of total output) (Table 2). This increase (Rs. 78,204 crores) was equivalent to about Rs 8,232 for every operational holding in India, or Rs 4576 per hectare of total crop land. These are large enough numbers to have significantly affected the average farm income in India. Nearly all of this output was consumed domestically. Despite recent impressive growth in high value exports, they still only account for less than 2% of India's total high value production[2].

Projections to year 2020 using IFPRI's global food model (IMPACT[3]) suggest future growth rates for high value commodities in India will fall in the 2-3% range (Table 5). Although more than double the projected growth in cereals consumption, it nevertheless implies a significant slowing from the 5-6% per year growth rates achieved between 1991/3 and 2000/2 (Table 2)[4]. These projections may prove conservative if national GDP grows more rapidly than the 5.8% assumed in the IMPACT model projections, or if there is a structural shift in consumers' preferences that expands per capita consumption of high value foods[4]. But otherwise it seems that the domestic market will progressively become a break on the speed of growth for high value production. Increased exports offer some hope of relieving this market constraint, but with a starting point of less than 2% of the total value of production, even rapid growth in exports will not add significantly to total national demand for at least another decade. If these projections are about right then, despite the real benefits to be reaped from expanding high value agriculture, there is little basis for any "excessive exuberance" about their potential to solve all of India's rural income problems.

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[3]The total value of production of fruits, vegetables, milk, eggs and meat averaged Rs. 218,483 crores in 2000/01 – 2001/02 (Table 2) while exports of these commodities averaged Rs. 3,072.6 crores in 2001/02 – 2002/03 Table 4).

[4] IMPACT is the International Model for Policy Analysis of Agricultural Commodities and Trade developed by Mark Rosegrant and colleagues at IFPRI. See for example, Rosegrant *et al.,* (2005).

Table 5. Projected changes in value of agricultural output, 1997 to 2020

(US$ billion in constant 1997 prices)

Commodity	*1997*	*2020*	*Annual growth rate (%) 1997 – 2010*	*Annual growth rate (%) 1997 – 2020*
Cereals	*28.69*	*36.88*	*1.60*	*1.10*
	(31.8)	*(25.2)*		
Oils	*4.00*	*6.78*	*2.58*	*2.32*
	(4.4)	*(4.6)*		
Fruits	*1.33*	*2.18*	*2.30*	*2.16*
	(1.5)	*(1.5)*		
Vegetables	*26.96*	*44.42*	*2.57*	*2.19*
	(29.9)	*(30.4)*		
Milk	*20.02*	*37.92*	*3.11*	*2.82*
	(22.2)	*(26.0)*		
Eggs	*1.39*	*2.91*	*3.80*	*3.26*
	(1.5)	*(2.0)*		
Meat	*7.71*	*14.98*	*3.27*	*2.93*
	(8.6)	*(10.3)*		

Source: IFPRI's IMPACT model
Figures in parentheses are percent shares

Agricultural growth that is increasingly led by high value crops and livestock production should increase the employment elasticity for the sector. During 1973/74 to 1993/94, the sector wide employment elasticity was about 0.5, but it had fallen to virtually zero by 1993/94 to 1999/2000, largely as a result of more capital intensive farming (Bhalla and Hazell, 2003).[5] High value farming activities can increase labor use per hectare by a factor of 2 to 3 (Joshi *et al.,* 2003) and this will make a useful contribution to employment creation. However, since high value activities only account for a small share of the total cropped area (e.g. fruits and vegetables accounted for about 10% of the cropped area in 2002-04, Table 6), one should not expect any large increase in the employment elasticity for the agricultural sector

[4] Some question the accuracy of the official estimates of fruit and vegetables production over the past decade, suggesting that they may have resulted from a change in the way the data were collected (Bhalla and Hazell, 2003, footnote 2).

[5]Bhalla and Hazell (1999) have suggested that such a structural shift might occur as per capita incomes rise and as retailing services and advertising improve, bringing per capita consumption of livestock products more into line with other Asian countries. At present India consumes far less livestock products per capita than almost any other country with her level of per capita income.

Table 6. Changes in Crop Areas, India (million Hectares)

Commodity	*1990-92*	*2002-04*	*Annual growth rate (%): 1991 - 2002*
Cereals	*100.7*	*95.9*	*-0.47*
	(58.9)	*(56.1)*	
Pulses	*23.5*	*22.2*	*-0.13*
	(13.7)	*(13.0)*	
Oil crops	*33.9*	*35.1*	*1.38*
	(19.8)	*(20.5)*	
Fruits	*2.8*	*4.1*	*3.55*
	(1.6)	*(2.4)*	
Vegetables	*4.7*	*6.7*	*2.81*
	(2.7)	*(3.9)*	
Other crops	*5.4*	*6.9*	
	(3.2)	*(4.0)*	
Total	*171.0*	*170.9*	

Source: FAO data base
Figures in parentheses are percent shares

as a whole. Additional jobs will be created in marketing, processing and distribution, but these will need to be very substantial if the increases in total employment in agriculture and allied activities are to achieve the scale needed to absorb the growing rural labor force.

The Transition to High Value Agriculture; what needs to be done?

Successful growth of high value agriculture will require policy changes that enhance market competitiveness. This requires appropriate investments in rural infrastructure and technology (roads, transport, electricity, improved varieties, disease control, etc.) and improvements in marketing and distribution systems for higher value, perishable foods (refrigeration, communications, food processing and storage, regulation of food quality and safety standards, etc). Trade barriers that protect inefficient domestic agro-industries also need to be removed. The government should not attempt to provide many of these key investments and services itself, but rather create an enabling environment in which the business sector can take up many of the needed investments and market functions. This will require changes in government regulations, tax breaks and subsidies that favor state and cooperative enterprises at the expense of private firms. It will also require a fundamental shift in thinking about the changing roles of the private sector and the state.

High value agriculture could make important contributions to income and employment growth in rural India. But left to market forces alone, such growth is likely to leave many poorer regions and small farmers behind. It will take pro-active policy interventions to ensure an equitable outcome.

Smallholder farmers will need to be organized more effectively for efficient marketing and input supply. While smallholders are typically more efficient producers of many labor-intensive livestock and horticultural products, they are at a major disadvantage in the market place because of a) poor information and marketing contacts, and b) their smaller volumes of trade (both inputs and outputs) lead to less favorable prices than larger-scale farmers. Contracting arrangements with wholesalers and retailers has proved useful in some contexts, but for the mass of smallholder farmers in India, farmer associations probably offer the more realistic option. Operation Flood is a good example of what can be done. This project uses dairy cooperatives to collect, treat and market milk collected from millions of small scale producers, including landless laborers, women and smallholder farms, many of whom produce only 1 or 2 liters per day. In 1996, Operation Flood reached 9.3 million farmers yet still accounted for only for 22 percent of all marketed milk in India (Candler and Kumar, 1998). The Government assists the program through technical support (e.g. research and extension, veterinary services and the regulation of milk quality), but otherwise the program is run by the cooperatives themselves with no direct financial support from government.

Less Favored Areas

Spreading the benefits of new growth opportunities to less-favored areas will also require targeted policies and investments. While many of these areas do not have comparative advantage in growing foodgrains for market, they could compete in the production of many high value products (e.g. milk, eggs, fruits and flowers). These areas will need greater public investment in research, infrastructure and human development. Indeed, without such investments, many less-favored areas will lose out even further as agricultural markets become more liberalized and competitive. They will become victims of market liberalization, not beneficiaries, with worsening poverty and environmental degradation.

Does investing in less-favored areas have to mean less growth per dollar of investment compared to investing that money in high-potential areas? Few would dispute the possibility of achieving bigger direct reductions in poverty by investing in less-favored areas, but are there significant tradeoffs against long-term growth and poverty reduction? IFPRI research on India suggests not. In fact, many investments in less-favored areas now offer a "win-win" strategy for India, giving more growth and less poverty (Fan, Hazell and Haque, 2000). This is not true for all types of investments in all types of less-favored areas, but for enough that more serious regional targeting is justified. This is even true for some types of R&D investments.

Environmental Issues

The green revolution played a key role in achieving national food security and in reducing rural poverty. By raising yields, it also saved having to make large increases in the total cultivated area, thereby helping to preserve remaining forest and avoiding rapid crop expansion into other environmentally fragile areas (e.g. hillsides and drylands). Even so, there is no question that the green revolution was also environmentally destructive in many of the areas in which it occurred. The problems include salinization of some of the best irrigated lands, fertilizer and pesticide contamination of waterways, pesticide poisoning, and declining water tables. The problems began in the 1970s and seem to be getting worse. There is mounting evidence showing that yield growth in many of the intensively farmed areas has now peaked and in some cases is even declining (Rosegrant and Hazell, 2000). There are growing voices arguing that Indian farmers should revert back to the low external-input farming technologies of pre-green revolution days (e.g. Vandana Shiva, 1991). This would be disastrous for yields and food supplies, and would destroy the environment on an even larger scale because of the need to rapidly expand the cultivated area.

There are realistic prospects for making modern technologies more environmentally benign and reversing resource degradation problems on a national scale (Pingali and Rosegrant, 2000). But it will take significant and determined action by the government. Needed actions should include:

- Development and dissemination of technologies and natural resource management practices that are more environmentally sound than those currently used in many farmers fields. Some of these technologies already exist and include precision farming, crop diversification, ecological approaches to pest management, pest resistant varieties, and improved water management practices. The challenge is to get these technologies adopted more widely in farmers' fields. Managed properly, some of these technologies can even increase yields while they reduce environmental damage. Further agricultural research is needed to create additional technology options for farmers, and this should include inter-disciplinary work on pest control, soil management, and crop diversification, but also use of modern biology to develop improved crop varieties that are even better suited to the stresses of intensive farming but with reduced dependence on chemicals (e.g. varieties that are more resistant to pest, disease, drought and saline stresses).

- Reform of policies that create inappropriate incentives for farmers in the choice of technology and natural resource management practices. The prevailing subsidies for water, power, fertilizer and pesticides lead farmers to undervalue the true cost of these inputs and encourage excessive and wasteful use with dire environmental consequences. Pricing these inputs at their true cost would save the government much money whilst also improving their management. This would reduce environmental degradation and, in the case of scarce inputs like water, lead to important efficiency gains. Improvements in land tenancy contracts would also improve the incentives for many smaller farmers to take a longer term view in their choice of technologies and management practices. Strengthening community rights and control over common property resources like grazing areas, woodlots and water resources could also improve incentives for their more careful and sustainable use. Additionally, the farm credit system needs to offer more medium and long term loans for investment in the conservation and improvement of natural resources, especially for smallholders and women farmers.

- Reform of public institutions that manage water to improve the timing and amounts of water delivered relative to farmers' needs, and the maintenance of irrigation and drainage structures. When farmers have little control over the flow of water through their fields they have reduced capacity to prevent waterlogging or salinization of their land, or to use water more efficiently. Forestry departments also need to work more closely with local communities, devolving responsibilities where possible, to improve incentives for the sustainable management of public forest and grazing areas.

- Assist farmers in diversifying their cropping patterns to relieve the stress of intensive monocultures. Investments in marketing and information infrastructure, trade liberalization, more flexible irrigation systems, and so forth, can increase opportunities for farmers to diversify. Unfortunately, the kinds of diversification that the market wants are not always consistent with the kinds of on-farm diversification that are needed for sound crop rotations, but they likely offer better prospects than monoculture cereal systems.
- Resolve widespread "externality" problems that arise when all or part of the consequence of environmental degradation is borne by people other than the ones who cause the problem (e.g. pollution of waterways and siltation of dams because of soil erosion in watershed protection areas). Possible solutions include taxes on polluters and degraders, regulation, empowerment of local organizations, or appropriate changes in property rights. Effective enforcement of rules and regulations is much more difficult to achieve than the writing of the new laws that create them.

Renewing Productive Public Investment in Agriculture for the New Agenda

Government spending on agriculture ("development" expenditure on agriculture, irrigation, transportation, power and rural development) has slowed badly in recent years. It grew at 15.1% per annum during the 1970s, but slowed to 5.1% per annum in the 1980s, and to 1.3% per annum in the early 1990s (Fan, Hazell and Thorat, 1999). Despite an increase in private investment in the early 1990s, there is little evidence to suggest that it is substituting for public investment, either in its level or composition. To make matters worse, the government is wasting a good deal of the resources it does spend on agriculture by paying far too much to provide basic services to agriculture (power, fertilizers, water, credit, etc). Fan, Thorat and Rao (2004) estimate that the subsidies for power, irrigation, fertilizer and credit cost the Government about Rs 27,130 Crores in 2000 (1993 prices), equivalent to about 8% of the value of agricultural output that year. This is squeezing out the funding of additional public investments in the kinds of rural infrastructure, technologies and institutional reforms needed for high value activities.

Conclusions

India has made impressive gains in agricultural growth, food security and rural poverty reduction since the crisis years of the

1960s. Agricultural growth continues to be critical for addressing the livelihood needs of large numbers of rural people, including most of the country's poor. But future growth will need to be different from the past. It will be less driven by growth in foodgrains production and more by new growth opportunities for higher value livestock, fish, horticultural and agroforestry products for the domestic market, by increased value added opportunities in agro-industry, and by export opportunities. Moreover, if future agricultural growth is to benefit the poor, then it will need to be more focused in rainfed areas than in the past, including many of the less-favored and backward regions that gained relatively little from the green revolution.

Diversification is already happening, but it needs to move ahead much more rapidly if the Indian agricultural sector is to continue to grow and generate sufficient income and employment to meet the growing needs of the rural population.

Future agricultural growth will also need to be more environmentally sustainable than in the past, with greater attention to the problems of intensive farming areas. This will require policy reforms to change incentives in favor of more sustainable technologies and natural resource management practices, as well as appropriate types of agricultural research.

Meeting these challenges will require serious policy and institutional reforms, including the phasing out of input subsidies, trade liberalization (including removing trade protection for agroindustry), reform of public institutions serving agriculture, and increases in productive investment in agriculture and the rural sector. India has been flirting with some of these changes for over a decade, but faces difficult problems with entrenched interests in the farm, agro-industry, banking and the public sector that are politically very difficult to resolve at the present time. It may take the same kind of vision to surmount these problems and to rejuvenate the agricultural sector as it did to launch the green revolution some 35 years ago.

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CHALLENGES TO INDIAN AGRICULTURE IN THE LIBERALIZED TRADE ECONOMY – IMPLICATIONS FOR CROP DIVERSIFICATION AND RURAL POVERTY

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The Challenges

(i) Declining Total Factor Productivity Growth

India achieved social and economic gains due to government policies, scientific discoveries and public and private investments in rural areas particularly in agricultural research, irrigation, credit and farm inputs leading to a substantial reduction in poverty and improved food security. Appreciable growth in agricultural production was achieved due to technological advancements as a result the country reached not only self sufficiency in food production but also becomes a net exporter of agricultural products. Total Factor Productivity (TFP) growth has contributed roughly 1.1 to 1.3 per cent per year to the growth of crop production in the country. Conventional inputs have contributed about 1.1 per cent per year since 1956. TFP and conventional inputs have thus contributed 2.3 per cent per year to the growth of crop production. Total factor productivity in India grew at an average rate of 0.69 per cent between 1970 and 1995. In 1970s, total factor productivity grew at 1.37 per cent per annum. But it grew fast in 1980s, at 1.99 per cent annum. Since 1990s, total factor productivity in Indian agriculture declined at the rate of 0.59 per cent annum (Fan, 2002). Growth (or decline) in total factor productivity (TFP) results predominantly from public investment (or lack of investment) in infrastructures (irrigation, electricity, roads) and in agricultural research and extension, and from efficient use of water and plant nutrients. The observed decreases in the rate of increase of TFP are in large part a consequence of a substantial lessening of investments notably public sector investments in agriculture (Table 1).

Increase in urbanization, increase in marketed surplus on account of not only increase in output also changes in cropping pattern in different regions due to comparative advantage, opening up of trade in agricultural commodities, increase in consumer's income and higher demand for processed, packaged and branded commodities poses various challenges and opportunities. Land degradation in the form of soil erosion, salinity/alkalinity and water logging are also posing serious threat to the sustainable agricultural development. Gains from the green revolution areas have been plateauing, apparently growth rate in production of many crops has come to stagnate in recent years and contribution of technological change to agriculture declined over the period (Ramasamy, 2004). In the 1970s, agricultural production growth was comparatively low, growing at an average annual rate of 1.95 per cent. In the 1980s, it grew at 3.82 per cent per annum. Since 1990, production growth has slowed, growing at only 2.09 per cent per annum (Fan, 2002).

Table 1. Factor Productivity Growth in Agriculture and Its Contribution to Economic Growth

Sector	1950-51 to 1979-80	1950-51 to 1964-65	1965-66 to 1979-80	1980-81 to 2003-04	1980-81 to 1991-92	1992-93 to 2003-04
Total factor productivity growth						
GDPfc: Total	0.90%	1.90%	0.10%	3.00%	2.50%	3.60%
Agriculture	0.20%	1.00%	-0.50%	2.10%	2.20%	2.10%
Growth rate of NDP per worker						
GDPfc: Total	1.10%	1.90%	0.50%	4.10%	3.30%	5.00%
Agriculture	0.00%	0.40%	-0.40%	2.50%	2.50%	2.60%
Contribution of sector TFPG to sector growth						
GDPfc: Total	0.26	0.41	0.04	0.52	0.46	0.59
Agriculture	0.05	0.21	-0.18	0.36	0.39	0.34

Source : Virmani (2004). Source of India's Economic Growth: Trends in Total Factor Productivity. Working paper No. 131. http://icrier.res.in/wp131.pdf as on 28.10.2004

(ii) Rainfed Agriculture

Policies, so far, have been focused more towards irrigated agriculture to increase agricultural production through public investment. Less-favoured areas in India cover 70 per cent of cropped area, contributing nearly 40 per cent of the total production and account for most of the commodities which are in short supply. About 90 per cent of coarse cereals, 90 per cent of pulses, 81 per cent of oilseeds and 69 per cent of cotton are grown under rainfed conditions in India, (Kanwar, 1991; Rao, 1991). Population size continues to grow in many less favoured areas outstripping agricultural growth rate despite some migration to agriculturally better off and urban areas. Large areas of less-favoured regions are characterized by resource-poor, small and marginal farmers and tend to be backward in infrastructure, amenities and supporting services for agriculture and particularly suffer low investments on technology and inputs. Droughts and crop failures are also quite common in dry areas.

Studies suggest that dry land technologies are still inadequate to get small and marginal farmers out of poverty trap in dryland regions. Performance of both the public and private extension agents (farmers' organizations, producers' co-operatives, input firms,media and voluntary organizations) vary widely and their presence is more skewed towards well endowed regions. Even in those regions where there is some significant presence, there has not been any integration of effects by the various agencies. The head count index and per cent of population below poverty line reveals that incidence of poverty is higher among the rainfed farmers compared to their counterparts in the irrigated region due to lack of resource endowments (Table 2). It is also reported by many studies that incidence, depth and severity of poverty are substantially lower in the technologically developed region viz., irrigated ecosystem compared to rainfed region due to various risks (Janaiah, *et al.,* 2000).

Table 2. Incidence of Poverty and Inequality among Different Household Groups

Household Groups	Gini Coefficient	Head Count Index	Per cent Distribution to Rural Poor	Per cent Distribution to Total Population
All Households	0.302	39.17	100.00	100.00
Land Ownership Groups				
Landless Household	0.32	41.92	14.39	13.44
Small Farmers(<1.0 ha)	0.280	45.80	57.48	49.16
Large Farmers (>= 1.0 ha)	0.309	29.47	28.13	37.40
Land Quality Groups				
Small Farmers (Irrigated Region)	0.277	45.0	30.22	26.31
Small Farmers (Rainfed Region)	0.283	46.72	27.25	22.85
Large Farmers (Irrigated Region)	0.307	23.58	9.63	16.00
Large Farmers (Rainfed Region)	0.305	33.87	18.50	21.40

Source: India Development Report (2002)

(iii) Marginalization of Land Holdings

There is a marginalization of land holdings and farmers have to rely on his piece of land for growing crops (Table 3). Due to high population pressure the per capita land area is alarmingly at the decreasing rate. A tiny landholder cannot rotate his land to avoid over-farming. Over farming leads to plateauing of agricultural productivity and environmental problems. There is also increasing pressure on land for non-agricultural uses because of the rising level of urbanization and geographic spread of industries. Preponderance of small and marginal uneconomical land holdings limits any attempts to introduce mechanized farming. Raising agricultural productivity is constrained primarily by the small size of holdings as a results productivity enhancing technologies and management methods become unaffordable and uneconomical. Consequently, the productivity is low and the total production varies substantially.

Table 3. Zone-wise Average Size of Holdings

(ha)

Zone / State	1970-71	1976-77	1980-81	1985-86	1990-91	1995-96
South Zone						
Tamil Nadu	1.45 (5.31)	1.25 (6.11)	1.62 (7.19)	1.01 (7.71)	0.93 (8.00)	0.91 (8.01)
Andhra Pradesh	2.51 (5.42)	2.34 (6.15)	1.91 (7.37)	1.72 (8.23)	1.56 (9.29)	1.36 (10.60)
Karnataka	3.2 (3.55)	2.98 (3.81)	2.54 (4.31)	0.40 (4.40)	2.13 (5.78)	1.95 (6.22)
North Zone						
Punjab	2.89 (1.38)	2.74 (1.50)	- (1.02)	3.77 (1.09)	4.74 (1.12)	3.74 (1.09)
Haryana	3.7 (0.91)	3.58 (1.00)	- (1.01)	2.76 (1.35)	2.43 (1.53)	2.13 (1.72)
Uttar Pradesh	1.16 (15.64)	1.05 (16.97)	1.75 (17.82)	0.93 (18.99)	0.90 (20.07)	0.86 (21.52)
East Zone						
West Bengal	1.20 (4.22)	0.99 (5.27)	0.88 (5.88)	0.92 (6.13)	0.90 (6.28)	0.85 (6.55)
West Zone						
Madhya Pradesh	4.00 (5.30)	3.58 (6.06)	3.38 (6.41)	2.91 (7.60)	2.63 (8.40)	2.28 (9.60)
Maharashtra	4.28 (4.95)	3.66 (5.76)	3.14 (6.86)	2.64 (8.10)	2.21 (9.47)	1.87 (10.65)
India	**2.30** (70.50)	**2.00** (81.55)	**2.43** (88.88)	**1.69** (97.16)	**1.55** (106.64)	**1.41** (115.58)

(Figures in parentheses denote number of holdings in million)

India's agricultural productivity is amongst the lowest in the world. Though there is considerable regional variation, India's best productivity levels are some 30-40 per cent lower than world best levels, country wide averages for most crops are some 50-80 per cent lower than world best levels (Table 4).

Table 4. Productivity of Crops in India and the World

Crops	*India (kg/ha)*		*World average yield (kg/ha)*	*India' s average yield to world's average yield (per cent)*	*India's highest yield to world's average yield (per cent)*
	Average yield	*Highest yield*			
Wheat	*2770*	*4103*	*4123*	*67.18*	*99.51*
Rice	*1913*	*3506*	*3970*	*48.19*	*88.31*
Maize	*1792*	*2727*	*4279*	*41.88*	*63.73*
Cotton	*198*	*408*	*1027*	*19.28*	*39.73*
Sugarcane	*68200*	*108480*	*165532*	*41.20*	*65.53*
Sunflower	*549*	*1429*	*1225*	*44.82*	*116.65*
Soybean	*941*	*1733*	*2253*	*41.77*	*76.92*
Groundnut	*977*	*1471*	*1367*	*71.47*	*107.61*
Banana	*34*	*53*	*113*	*30.19*	*46.64*

(iv) Imbalances in Use of Inputs and Declining Input Use Efficiency

Alleviation of physical and chemical constraints in soils is the prime concern in today's agriculture since unfavourable side effects of green revolution are slowly now experienced. Incremental responses to inputs are declining fast and prices of purchased inputs increasing, thus reducing the profitability of agriculture. Further, the law of diminishing returns from the increased use of production factors has reduced the farmer's interest in intensification of agriculture. However, it is essentially important to dispel any impression about the overuse of fertilizers in India. A comparison with other countries reveals that there is much lesser consumption in India and evidences indicate that economic responses continue to be obtained even in high fertilizer – consuming states like Punjab and Haryana. Chemical fertilizers, being the sources of high nutrient content, have obvious uses, but there are possible areas of risk in the use of chemical fertilizers. According to Sankaran (1990), the Fertilizer Use Efficiency (FUE) was 17.1 in 1970-71, but decreased to 10.3 in 1980-81 and 8.1 in 1988-89 for the additional food grains production (base year 1951-52). He further calculated that for obtaining 240 million tonnes of foodgrains, the estimated quantity of fertilizer would be 20 million tonnes and its use efficiency would be only 6.5. This was further reiterated by Kanwar (1991) that dramatic changes in agricultural productivity had been recorded through the use of fertilizers, but the overuse and unbalanced use of fertilizers in the assured areas of irrigation is leading to declining output/input ratio and increasing micronutrient deficiency. Fertilizer consumption was 25.75 kg per ha during 1970s and it increased to 78.43 kg per ha during 1990s registering a growth rate of 3.94 per cent between 1990-91 and 2000-01 (Table 5). There was however notable disparity in fertilizer use among the States during 1970s and 1980s and variation has declined marginally during 1990s (Gini ratio is 0.46, 0.49 and 0.43 during 1970s, 1980s and 1990s, respectively) (Ramasamy, 2004).

Pattern and Trends in Crop Diversification

Cropping pattern is monotonically biased towards few crops especially rice and wheat in the early green revolution period. Of the total cultivated area in the country, more than 30 per cent of area was under rice and wheat. Demand for high value products is on the rise in the 1990s due to increasing population, high income growth in rural and urban areas, changing food habits, realization of high nutritional value and great emphasis on value addition and export. The forecasts are that by the 2030, the urban population in India will account for 41 per cent of total population (UN, 2002). To meet the demand for High value crops in the urban areas, the agriculture is transforming from food grain based system to high-value agriculture. Further, economic liberalization policies as well as globalization process exerted strong pressures on the area allocation decision of the farmers essentially through the impact on the relative prices of inputs and outputs. Such transformation in the economy is leading to changes in production portfolio from cereals- based system to high- value commodities, such as fruits and vegetables and livestock products. Diversification of agriculture in favor of more competitive and high-value enterprises is reckoned as an important strategy to overcome the emerging challenges of globalization (Joshi et. al., 2004). Although the objective of diversification may vary depending on the level of agricultural development, overall diversification is a strategy for poverty alleviation, employment generation, environmental conservation, and augmentation of farm income through better use of available resources (Satyasai and Vishwanath, 1996; Ryan and Spencer, 2001).

Table 5. Fertilizer Consumption and Imbalance in Use of Fertilizer - Select States

(Kg/ha)

Zone / State	*1970s*				*1980s*				*1990s*				*Growth Rate (per cent) (1990-91 to 2000-01)*			
	N	***P***	***K***	***Total***	***N***	***P***	***K***	***Total***	***N***	***P***	***K***	***Total***	***N***	***P***	***K***	***Total***
South Zone																
Tamil Nadu	*34.9*	*9.6*	*11.3*	*55.8*	*37.6*	*10.9*	*14.7*	*63.2*	*72.82*	*28.07*	*35.05*	*135.94*	*3.71*	*3.44*	*-0.21*	*2.61*
	(3.65)	*(1.00)*	*(1.18)*		*(3.45)*	*(1.00)*	*(1.35)*		*(2.59)*	*(1.00)*	*(1.25)*					
Andhra	*27.9*	*8.9*	*2.7*	*39.4*	*31.9*	*10.4*	*3.6*	*45.9*	*90.99*	*37.69*	*11.37*	*140.02*	*4.38*	*6.23*	*9.15*	*5.24*
Pradesh	*(10.19)*	*(3.24)*	*(1.00)*		*(8.86)*	*(2.89)*	*(1.00)*		*(8.00)*	*(3.31)*	*(1.00)*					
Karnataka	*15.6*	*5.9*	*5.2*	*26.7*	*17.5*	*7.4*	*6.3*	*31.2*	*45.94*	*24.41*	*14.27*	*84.62*	*8.13*	*6.30*	*6.00*	*7.17*
	(3.01)	*(1.15)*	*(1.00)*		*(2.78)*	*(1.17)*	*(1.00)*		*(3.22)*	*(1.71)*	*(1.00)*					
North Zone																
Punjab	*59.2*	*19.1*	*3.9*	*84.2*	*81.1*	*32.3*	*4.5*	*117.9*	*128.13*	*36.97*	*2.36*	*167.46*	*1.63*	*-1.90*	*7.22*	*0.84*
	(15.11)	*(4.86)*	*(1.00)*		*(18.02)*	*(7.18)*	*(1.00)*		*(54.27)*	*(15.66)*	*(1.00)*					
Haryana	*27.2*	*4.5*	*1.6*	*33.3*	*34.5*	*5.8*	*2.2*	*42.5*	*96.72*	*27.84*	*0.78*	*125.31*	*6.24*	*5.32*	*5.87*	*6.04*
	(17.35)	*(2.88)*	*(1.00)*		*(15.68)*	*(2.64)*	*(1.00)*		*(123.47)*	*(35.54)*	*(1.00)*					
Uttar	*28.7*	*6.0*	*2.9*	*38.0*	*36.9*	*9*	*3.4*	*49.3*	*80.94*	*20.15*	*3.45*	*104.55*	*4.26*	*6.91*	*1.70*	*4.67*
Pradesh	*(10.01)*	*(2.08)*	*(1.00)*		*(10.85)*	*(2.65)*	*(1.00)*		*(23.45)*	*(5.84)*	*(1.00)*					
East Zone																
West Bengal	*16.2*	*5.7*	*4.2*	*26.1*	*21.2*	*9*	*5.7*	*35.9*	*58.05*	*28.34*	*18.74*	*105.21*	*3.65*	*5.04*	*6.90*	*4.59*
	(3.90)	*(1.36)*	*(1.00)*		*(3.72)*	*(1.58)*	*(1.00)*		*(3.10)*	*(1.51)*	*(1.00)*					
West Zone																
Madhya	*4.7*	*2.2*	*0.5*	*7.4*	*5.7*	*2.8*	*0.7*	*9.2*	*24.26*	*13.90*	*1.84*	*40.07*	*1.90*	*3.90*	*2.60*	*2.65*
Pradesh	*(9.47)*	*(4.40)*	*(1.00)*		*(8.14)*	*(4.00)*	*(1.00)*		*(13.20)*	*(7.56)*	*(1.00)*					
Maharashtra	*11.3*	*3.7*	*3.1*	*18.1*	*13.3*	*4.6*	*3.3*	*21.2*	*42.43*	*18.42*	*8.91*	*69.76*	*4.15*	*5.59*	*2.42*	*4.27*
	(3.66)	*(1.18)*	*(1.00)*		*(4.03)*	*(1.39)*	*(1.00)*		*(4.76)*	*(2.07)*	*(1.00)*					
India	***17.60***	***5.18***	***2.85***	***25.75***	***21.4***	***7***	***3.6***	***32.0***	***52.68***	***18.79***	***6.96***	***78.43***	***4.22***	***3.71***	***2.62***	***3.94***
	(6.18)	***(1.82)***	***(1.00)***		***(5.94)***	***(1.94)***	***(1.00)***		***(7.56)***	***(2.70)***	***(1.00)***					

There is a substantial area shift form cereals to non-cereals. Area under cereals declined from 61 per cent to 53 per cent, while area share of oilseeds increased to 13 per cent from 9 per cent between the 1970s and 1990s (Table 6). Farmers prefer to grow oilseeds in rainfed / dry land conditions setting apart irrigated and better land to rice, sugarcane, cotton, vegetables, etc. Although expansion of area under oilseeds is at the cost of coarse cereals and pulses and even rice and wheat in certain areas, the fact remains that farmers find oilseeds cultivation not an attractive proposition as evident from their share in the total cropped area. The share of oilseeds in total cropped area increased very marginally for the last three decades. Area under fruits and vegetables increased over the last three decades particularly during the 1990s. Share of area under fruits and vegetables jumped to 5 per cent in the 1990s from 2 per cent in the 1970s. Higher income elasticity of demand for these high value commodities pushed up the demand as a result these sectors grew faster than the other sectors. Crop sector grew at the rate of 3 per cent during the 1990s, while livestock and fruits and

Table 6. Compositional Changes in Cropped Area

(Per cent)

Year	*HI*	*Cereals*	*Pulses*	*Oil seeds*	*Fibres*	*Sugar Cane*	*Fruits & Vegetables*	*Others*
1970-71	*0.07*	*61.3*	*13.9*	*8.7*	*5.5*	*1.6*	*2.2*	*1.1*
1980-81	*0.08*	*60.6*	*13.3*	*9.0*	*5.5*	*1.8*	*2.8*	*1.3*
1990-91	*0.08*	*56.5*	*13.0*	*12.9*	*4.7*	*2.0*	*3.6*	*1.4*
2000-01	*0.07*	*53.3*	*11.4*	*12.8*	*5.2*	*2.2*	*5.2*	*1.5*

Source: National Accounts Statistics of India *HI – Herfindhal Index*

vegetable sectors grew faster than the crop sector and recorded 4 and 6 per cent growth respectively during the same period (Tables 7 and 8). During the nineties to meet the growing demand, the livestock sector grew faster than the crop sector in most south Asian countries. This is reflected in an increase in the share of livestock sector in the agricultural sector (Birthal and Rao, 2002; Rao et. al., 2004). The promotion of Operation Flood to boost milk production and augment income of rural small holders uniformly promoted dairy sector irrespective of their proximity to the urban center (NDDB, 2002; Parthasarathy, 2002).

Table 7. Growth Trends in Output Value of Crops Sector

(Per cent)

Year	*Cereals*	*Pulses*	*Oilseeds*	*Sugars*	*Fibres*	*Drugs & narcotics*	*Condiments & spices*	*Fruits & vegetables*	*Other crops*	*Total agriculture*
1970s	*2.4*	*0.0*	*-0.1*	*2.2*	*2.5*	*3.7*	*2.9*	*2.9*	*0.7*	*1.8*
1980s	*3.0*	*1.2*	*5.3*	*2.2*	*2.3*	*1.8*	*4.8*	*2.4*	*-0.5*	*2.5*
1990s	*2.3*	*1.2*	*2.6*	*2.7*	*2.8*	*3.7*	*4.6*	*6.2*	*0.8*	*3.1*

Source: National Accounts Statistics of India

Table 8. Growth Rates in GDP of the Economy and Agriculture Sub sectors at 1993-94 prices

(Per cent)

Period	**GDP Total**	**GDP Non-agric ulture**	**GDP Agri culture**	**GDP Fishing**	**Value of Output**		
					Crop sector	**Live stock**	**Fruit/ Veg**
1970/71 to 1979/80	3.45	4.72	1.94	2.9	1.79	3.92	2.88
1980/81 to 1989/90	5.38	6.78	3.13	5.82	2.47	4.99	2.36
1990/91 to 1999/00	6.19	7.4	3.28	5.46	2.99	3.82	5.97
1990/91 to 1995/96	5.56	6.63	3.16	7.49	2.65	4.25	4.93
1996/97 to 2001/02	5.53	6.85	1.75	2.72	1.28	3.47	4.55
1990/91 to 1995/96	5.56	6.63	3.16	7.49	2.65	4.25	4.93
1990/91 to 1996/97	6.01	7.04	3.69	7.41	3.22	4.12	5.92
1990/91 to 1997/98	6.09	7.26	3.35	6.9	2.92	3.95	5.91
1990/91 to 1998/99	6.16	7.33	3.43	5.9	3.1	3.89	6.14
1990/91 to 1999/00	6.19	7.4	3.28	5.46	2.99	3.82	5.97
1990/91 to 2000/01	6.12	7.38	3.01	5.07	2.66	3.76	5.88
1990/91 to 2001/02	6.06	7.29	2.95	4.96	2.58	3.73	5.78

Source: National Accounts Statistics of India

Area under rice, which was 11 per cent of the gross cropped area in Punjab during 1970s increased to 29 per cent during 1990s. Similarly, in most of the irrigated areas except Tamil Nadu area under rice registered positive growth rate. However, in the rainfed rice ecosystems, the share of rice area in gross cropped area declined during 1990s compared to the 1970s. Herfindhal Index[1] for irrigated environment particularly for Punjab and Haryana was 0.27 and 0.15 respectively during 1990s. This shows that there is a gradual diversification of crop sector in favour of high value commodities especially fruits and vegetables (Tables 9 and 10). Punjab plans to diversify crops in 1.5 million acres in next 4 years through contact farming. Already 3 lakh acres under contact farming have been diversified from paddy and wheat to commercial crops like maize, barley, white mustard, Basmati rice and oil seeds. Wide varieties of vegetables, gherkins, lime, pomegranate, grapes for resins, pearl onions, asparagus and mangoes for pulp are already covered under contact farming in Karnataka. Contact farming in gherkins, cotton, maize etc. is coming in Tamil Nadu. Rallis formed an alliance with Hindustan Lever (HLL) for a contract farming project for wheat in Madhya Pradesh. This is mainly intended to help farmers grow and sell wheat for making atta and basmati rice for export. Sami Labs also come in a big way for contract farming in medicinal plants in Karnataka, Tamil Nadu and Kerala. Estimates of Location Quotient method of Crop Concentration Index[2] imply that crop concentration is shifting towards maize, sunflower and banana from the traditional crops in most of the States(Table 11).

Table 9. Crop Diversification in Selected States (Herfindahl Index)

Zone / State	*1970s*	*1980s*	*1990s*
South Zone			
Tamil Nadu	*0.14*	*0.12*	*0.13*
Andhra Pradesh	*0.10*	*0.11*	*0.13*
Karnataka	*0.03*	*0.03*	*0.03*
North Zone			
Punjab	*0.19*	*0.25*	*0.27*
Haryana	*0.07*	*0.15*	*0.15*
Uttar Pradesh	*0.13*	*0.20*	*0.18*
East Zone			
West Bengal	*0.46*	*0.55*	*0.43*
West Zone			
Madhya Pradesh	*0.07*	*0.08*	*0.10*
Maharashtra	*0.02*	*0.03*	*0.03*
India	*0.07*	*0.08*	*0.08*

Table 10. Crop Diversification in Pre and Post Reform Periods (Herfindahl Index)

States	Pre Reform Period	Post Reform Period
South Zone		
Tamil Nadu	0.131	0.131
Andhra Pradesh	0.123	0.124
Karnataka	0.032	0.032
North Zone		
Punjab	0.268	0.266
Haryana	0.157	0.151
Uttar Pradesh	0.180	0.178
East Zone		
West Bengal	0.413	0.410
West Zone		
Madhya Pradesh	0.103	0.103
Maharastra	0.031	0.030

Pre Reform Period: 1980-81 to 1990-91

Post Reform Period: 1991-92 to 2002-03

Table 11. Crop Concentration in the Pre and Post Reform Periods

State	Rice		Groundnut		Cotton		Maize	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Andhra Pradesh	1.30	1.26	4.26	4.11	1.10	1.77	0.77	4.40
Karnataka	0.42	0.47	0.14	0.14	0.61	1.27	6.01	8.92
West Bengal	2.75	2.66	0.26	0.28	0.20	0.11	1.17	1.52
Maharastra	1.09	1.50	2.42	3.05	1.18	3.09	0.01	0.08
Punjab	1.24	1.22	3.17	2.78	0.91	0.59	1.76	1.63
Uttar Pradesh	0.90	0.91	2.47	2.36	1.35	1.30	5.98	10.15
Tamil Nadu	1.29	1.40	3.72	4.24	1.48	1.61	3.87	3.08
Haryana	0.50	0.66	2.46	2.40	1.61	2.06	1.01	1.03

Diversification of cropping pattern particularly from high water consuming crops like rice to other lower water consuming crops is not much reflected as the Herfindhal index found almost same in the rainfed areas. In rainfed areas cultivation of wide range of commodities is limited and the farmers have to rely on traditional and backward crops. Based on the rainfall distribution and availability of ground water farmers change their cropping pattern and mitigate the risk of rainfall failure. Among the rainfed environments, West Bengal and Madhya Pradesh show less diversity as compared to irrigated states. The decision of the farmers to allocate more resources would much depend on price expectation and productivity of the concerned crop in relation to prices and productivity of substitute crops. Farmers are willing to undertake diversification only when food production can provide adequate food for their family. Therefore, it is necessary to increase the productivity of rice and wheat based production system to successfully promote crop diversification. However, there are some apprehensions about the sustainability of small farmers producing high value crops due to small and scattered production, price risk associated with high value crops and need to maintain stiff quality standards as the size of processing units increase to reap economies of scale (Pingali and Khwaja, 2004). Small farmers are willing to diversify towards fruits and vegetables after meeting their food security needs provided suitable technology and marketing outlets at remunerative prices for high value crops are readily available (Shanmughasundaram, 2003).

Factors Influencing Diversification

Several forces influence the nature and speed of agricultural diversification from staple food to high value commodities. Earlier evidences suggest that the process of diversification out of staple food production is triggered by rapid technological change in agricultural production, improved rural infrastructure, and diversification in food demand patterns. These are broadly classified as demand and supply side forces. The demand side forces that are hypothesized to influence the diversification include per capita income and urbanization. On supply side forces, the diversification is largely influenced by infrastructure (markets and roads), technology (relative profitability and risk in different commodities), resource endowments (water and labour) and socio-economic variables (pressure on land and literacy rate). Several demand and supply variables were considered to examine their influence on crop diversification (Joshi *et. al.,* 2004).

Studies have indicated that the income elasticity of demand for high value crops was high not only in urban areas but also in rural areas (Kumar *et. al.,* 2003). In all South Asian countries the income elasticity of demand for fruits, vegetables, milk and meat is high compared to staples like cereals, pulses etc (Paroda and Kumar, 2000). Kumar and Mathur (1996) found that structural shifts (urbanization) had a positive impact on demand for vegetables, fruits, meat, fish and eggs. Available estimates reveal that by 2020 the developing countries of Africa, Asia and Latin America will be home to some 75 per cent of all urban dwellers (CGIAR, 2002). This common observation is attributed not only to changing incomes and prices, but also to structural shifts in demand. Such structural changes can be explained by a number of factors: a wider choice of foods available, exposure to a variety of dietary patterns of foreign cultures, more sedentary occupations, and the move away from food production for household consumption. These trends are highly associated with the general pattern of urban migration(Barghouti *et. al.,* 2003). Decline in cereal consumption during 1990s was much higher than what was accounted for by dietary diversification (Chand *et.al.,* 2003). In recent years demand side factors are driving agricultural diversification in India, as also in most South Asian countries. Higher economic growth and consequent income growth in both urban and rural areas are translating into higher demand for high value commodities (Tables 12 and 13) like fruits, vegetables, and livestock products like milk, meat and fish (Dorjee *et. al.,* 2002; Pokharel, 2003; Wickramasinghe, 2003; Joshi *et. al.,* 2004).

Table 12. Food Consumption in India

(cal/person/day)

Item	**1979-81**	**1989-91**	**1999-01**
Total	3142.1	3603.7	3736
TotalAnimal Product	119.7	162.7	195.9
Total vegetable product	3022.4	3440.9	3540.1
Cereals	1367.8	1507.5	1470.2
Pulses	119.5	132.7	109.1
Rice (Milled Equivalent)	669.6	778.4	751.4
Sugar& sweeteners	192.7	221.3	247

Source: FAOSTAT

Table 13. Per capita Consumption Pattern of Foods

(Kg/Person/Annum)

Item	1977	1987	1993	1999
Rural				
Rice	86.5	88.1	85.4	81
Wheat	49.4	61.6	53.5	53.9
Coarse cereals	56.7	29.8	24.1	17.7
Total cereals	192.6	179.5	163	152.6
Pulses	8.7	11.5	9.2	10.1
Milk & Milk products	24.6	58	51.4	50.5
Edible oils	2.7	4.3	4.6	6
Vegetables	24.7	50.8	53.2	66
fruits	2.6	10.3	9.8	17
Meat, Eggs, fish	2.7	3.3	4.1	5
Sugar and gur	13.5	11	9.2	10.1
Urban				
Rice	67.6	68.1	64.2	62.5
Wheat	64.6	60.4	57.4	55.4
Coarse cereals	14.8	10.6	7.7	7.1
Total cereals	147	139.1	129.3	125
Pulses	11.7	12.2	10.5	12
Milk & Milk products	39.7	64.9	68.3	72.4
Edible oils	4.8	6.8	6.3	8.6
Vegetables	39.7	66.4	63.1	70
fruits	5.9	18.8	20.1	19
Meat, Eggs, fish	4.8	4.9	6.3	6.8
Sugar and gur	17.1	12.3	11.8	12

Source: Kumar (2002)

Econometric results showed that rainfall had a positive effect, though not significant for many states, on crop acreage diversification except Maharashtra revealing that good rainfall is expected to encourage diversification. Irrigation intensity (ratio of gross irrigated area to net irrigated area) had a positive and significant effect on acreage diversification suggesting that availability of irrigation water all round the year is expected to promote crop acreage diversification. Coefficients of whole sale price index and productivity index reveal that farmers in the irrigated environments except Haryana prefer to diversify cropping pattern if they fetch higher income either through increase in productivity or product price. However, realization of higher level of productivity of crops and better product price discourage acreage diversification in rainfed environments since farmers in these fragile environments have limited option to choose crops for cultivation (Tables 14 and 15). The results further indicate that if the yield level increases, crop specialization also increases. Higher the yield level more is the incentive to cultivate the crop. There is no incentive to diversify when the output from the crop is increasing. Cropping intensity has negative sign. This shows that when cropping intensity increases, the value of Herfindahl index goes down, which means that crop diversification is taking place (Table 16).

Table 14. Factors Determining Crop Diversification (Auto Correlation Adjusted Linear Estimates)

Dependent Variable= Herfindahl Index

States	Intercept	GIA/GCA	Fertilizer (kg/ha)	Productivity Index	Rainfall (mm)	WSPI	Size of Holding (ha)
South Zone							
Tamil Nadu	5.191	0.0917**	-0.0001	0.0070	0.0004	0.0029***	-0.4343
Andhra Pradesh	-2.759	-0.1301	-0.0027	0.0649***	0.0022***	0.0060***	-0.7547
Karnataka	0.9534	0.0063	0.0019	0.0007	0.0002	0.0004	0.2554
North Zone							
Punjab	-1.9668	0.3578**	0.0255	0.0374	0.0032	0.0022	-0.0448
Haryana	4.861	0.1087	0.0247	-0.6719**	0.0027	-0.0014	6.277*
Uttar Pradesh	9.2183	-0.2602	-0.2252	-0.0168	0.0019	0.0305**	0.1723*
East Zone							
West Bengal	-17.0199	3.9874	-0.2942	0.4112	0.0261	0.0258	0.4416
West Zone							
Madhya Pradesh	3.653	0.1919***	-0.0355**	-0.0075	0.00004	0.0014	0.7342*
Maharashtra	3.566	0.0547**	-0.0047***	-0.0081	0.0002***	0.0006***	-0.2194***

**** Significant at 1 per cent level, ** significant at 5 per cent level, * significant at 10 per cent level,GIA/GCA: Ratio of Gross Irrigated Area to GrossCropped Area expressed in percentage. WSPI: Whole Sale Price Index*

Table 15. Determinants of Crop Diversification of High Value Crops– Log linear Estimates

Ratio of value of production to AgGDP	*GIA/GCA*	*Fertilizer consumption (kg/ha)*	*Productivity Index*	*Rainfall (mm)*	*Whole sale Price Index*	*Average size of land holding (ha)*	*Intercept*	*Adj R^2*
Vegetables	0.10 (1.363)	0.0055 (0.826)	-0.0014* (-2.202)	-0.0068 (-1.142)	0.0026 (1.200)	0.13** (2.535)	-0.008 (-0.076)	0.73
Fruits	-0.18 (-1.279)	-0.015 (-1.220)	0.025 (0.198)	0.0036 (0.316)	0.0026 (0.626)	-0.057 (-0.545)	0.28 (1.291)	0.36
Sugar	0.11 (1.361)	0.0008 (0.010)	-0.0036 (-0.479)	-0.0011 (-1.707)	-0.0037 (-1.505)	-0.10 (-1.758)	0.38 (2.936)	0.71
Oilseeds	0.13* (1.814)	-0.0083 (-1.309)	-0.030*** (-4.827)	-0.0030 (-0.526)	-0.0025 (-1.213)	0.027 (0.531)	0.53*** (4.878)	0.98
Total of High Value Crops	0.16 (1.175)	-0.018 (-1.473)	-0.046*** (-3.736)	-0.0017 (-1.596)	-0.0010 (-0.252)	-0.0018 (-0.002)	1.18*** (5.567)	0.95

(Figures in parentheses are t values)

**** Significant at 1 per cent level, ** significant at 5 per cent level, * significant at 10 per cent level. GIA/GCA: Ratio of Gross Irrigated Area to Gross Cropped Area expressed in percentage*

Table 16. Determinants of Crop Diversification-Log Linear Estimates

	Pre-Liberalization (1980-81 to1990-91)	*Post-Liberalization (1991-92 to2002-03)*
Constant	*-17.40**	*-6.49***
	(-1.66)	*(-2.46)*
Cropping Intensity	*-3.09**	*-0.05***
	(-1.66)	*(-2.21)*
Yield Index	*0.12***	*0.88**
	(2.20)	*(1.61)*
R^2	*0.69*	

(Figures in parentheses denote t values)

** Significant at 1 per cent level of probability,*

*** Significant at 5 per cent level of probability*

Trade Reforms and Diversification

With liberalization of trade and providing the market access for agricultural produce among the different countries throw many challenges and opportunities. Liberalization of trade in agriculture is likely to benefit developing countries to the extent of additional $ 60 billion by way of trade. Empirical evidences, however, show that there has not been much change in the pattern of world agricultural production and exports and there was a little change in the volume of exports or diversification of products and destination. Several researchers felt that as economic reforms focused mainly on price factor and ignored infrastructure and institutional changes the overall impact on growth of agricultural sector has not been favourable. This argument is supported by citing deceleration in output of agriculture sector (Table 17) after reforms were started in the year 1991 (Chadha, 2002; Mujumdar, 2002; Bhalla, 2002; Kumar 2002). Evidences show that India had benefited from joining the General Agreement on Tariffs and Trade (GATT) and its successor, the World Trade Organization (WTO). India's exports have almost doubled in less than a decade with exports going up from $26.33 billion in 1994-1995, when India joined the WTO, to $51.70 billion in 2002-03. India's share in total world exports of goods and commercial services increased from 0.61 per cent in 1995 to 0.86 per cent in 2001 whereas its share in total world imports of goods and commercial services increased from 0.78 per cent to 0.99 per cent during the same period. Being a WTO member, India also avails of the Most Favoured Nation (MFN) treatment and National Treatment for its exports to other WTO members.

Table 17. Performance of Crops during Pre and Post Reform Periods – Estimated Compound Growth Rates

(Per cent)

Crops	*Area*		*Production*		*Yield*	
	Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*
Rice	*0.62***	*0.12*	*3.4**	*0.98*	*7.2**	*2.3****
Wheat	*0.7**	*0.07*	*3.5**	*0.64*	*6.1**	*2.2***
Pulses	*-0.4*	*-1.06*	*9.6*	*-0.4*	*10.1*	*0.6*
Oilseeds	*2.33 ****	*-3.45 ****	*4.05 ****	*-5.12*	*1.84****	*-1.45**
Groundnut	*1.65*	*-1.88*	*2.97*	*3.92*	*1.89*	*2.45*
Rapeseed	*6.45*	*-5.75*	*8.90*	*-0.05*	*1.23*	*0.08*
Sunflower	*4.07 **	*-10.60 ****	*6.00 ***	*-12.90 ****	*1.63***	*-1.21****
Soybean	*17.78 ****	*4.03 ****	*27.09 ****	*8.08 ****	*1.85***	*0.94**
Castor	*4.43 ****	*4.72 ****	*16.03 ****	*0.25*	*4.02****	*0.05*
Vege tables	*4.5**	*3.23**	*4.3**	*3.31**	*-0.02*	*0.6*
Fruits	*-0.7****	*1.14****	*4.2**	*2.9**	*14.01**	*7.9****

India's export of agricultural commodities has been on the increase and agricultural exports grew at the rate of 11.58 and 7.16 per cent in rupee and dollar terms respectively at current prices in the period between 1970-71 and 1990-91. Agricultural export growth was found higher in the 1990s and export of agricultural commodities recorded over 17 and 10 per cent respectively at current prices in rupee and dollar terms. Agricultural exports also grew significantly in the post reform period and this could be attributed to the trade liberalisation policies followed in agriculture. There is a rising trend in export of high value horticultural products (fresh and processed) during the post liberalization period (Table 18). However, there is no steady trend in export of other commodities including livestock and marine products. Steady trends in imports of agricultural commodities are also noticed in the post liberalization period particularly in the case of vegetable oils. The increase in export and import raised the proportion of trade in agricultural GDP from less than 5 percent in the beginning of reforms to close to nine and a half percent by 1995-96. After 1996-97, value of export started shrinking as international prices started falling (Chand and Pal, 2003).

Table 18. Production and Export of Select Agricultural Commodities

Commodities	*Production (lakh tonnes)*				*Export Qty ('000 tonnes)*			
	1970s	***1980s***	***1990s***	***2002-03***	***1970s***	***1980s***	***1990s***	***2002-03***
Rice	*672.02*	*897.18*	*1200.79*	*1076.00*	*66.86 (0.10)*	*414.09 (0.46)*	*2009.41 (1.67)*	*5053.24 (4.70)*
Maize	*61.72*	*74.60*	*99.27*	*111.66*	*0.33 (0.01)*	*2.76 (0.04)*	*13.40 (0.13)*	*78.18 (0.70)*
Wheat	*266.06*	*429.58*	*612.57*	*727.66*	*185.03 (0.70)*	*87.12 (0.20)*	*270.16 (0.44)*	*3671.25 (5.05)*
Cereals	*1219.13*	*1625.46*	*2124.13*	*2064.97*	*277.20 (0.23)*	*521.86 (0.32)*	*2511.01 (1.18)*	*9569.86 (4.63)*
Pulses	*112.85*	*119.01*	*135.00*	*134.38*	*11.33 (0.10)*	*6.27 (0.05)*	*75.55 (0.56)*	*151.92 (1.13)*
Oilseeds	*1.26*	*1.61*	*1.72*	*1.70*	*6.20 (4.88)*	*8.22 (5.09)*	*14.25 (8.27)*	*37.36 (21.98)*
Spices	*2.69*	*4.45*	*8.05*	*16.00*	*20.74 (7.71)*	*29.16 (6.54)*	*48.18 (5.98)*	*84.70 (5.29)*
Sugarcane	*1407.15*	*1760.88*	*2570.33*	*2972.08*	*378.20 (0.27)*	*127.12 (0.07)*	*134.70 (0.05)*	*1469.88 (0.49)*

(Figures in parentheses are percentage to production)

Indian exports need to grow at the rate of 18 per cent annually, if the target of $75 billion in 2004-05 is to be achieved for cornering one per cent of world trade from the present level of 0.7 per cent. India exports a wide range of agricultural and allied commodities. Of the various agricultural and allied items, tea and mate, cashew kernels, spices and coffee were the dominant exportable items during 1970-71, but their share declined in the later period due to the increase in the share of non-traditional commodities. These traditional agricultural commodities constituted about 93 per cent of the total value of agricultural and allied products exported in 1970-71 and its share increased to 96 per cent in 1980-81. The share of these commodities declined during 90s. Diversification of export basket of agricultural commodities comprising of marine products, oil-cakes, floriculture products, castor oil, rice, guargum meal etc. increased substantially during 1990s (Tables 19 and 20).

Table 19. Export Performance of Agricultural and Allied Products

Commodity	1960-61	1970-71	1980-81	1990-91	1999-00	2002-03
Agricultural and allied products	284 (100.00)	487 (100.00)	2057 (100.00)	6317 (100.00)	24576 (100.00)	35119 (100.00)
Coffee	7 (2.46)	25 (5.13)	214 (10.40)	252 (3.99)	1364 (5.55)	1773 (5.05)
Tea and mate	124 (43.66)	148 (30.39)	426 (20.71)	1070 (16.94)	1766 (7.19)	2295 (6.53)
Oil cakes	14 (4.93)	55 (11.29)	125 (6.08)	609 (9.64)	1603 (6.52)	2083 (5.93)
Tobacco	16 (5.63)	33 (6.78)	141 (6.85)	263 (4.16)	993 (4.04)	1290 (3.67)
Cashew kernels	19 (6.69)	57 (11.70)	140 (6.81)	447 (7.08)	2451 (9.97)	3186 (9.07)
Spices	17 (5.99)	39 (8.01)	11 (0.53)	239 (3.78)	1702 (6.93)	2212 (6.30)
Sugar and molasses	30 (10.56)	29 (5.95)	40 (1.94)	38 (0.60)	38 (0.15)	(0.14)
Raw cotton	12 (4.23)	14 (2.87)	165 (8.02)	846 (13.39)	81 (0.33)	105 (0.30)
Rice	- -	5 (1.03)	224 (10.89)	462 (7.31)	3105 (12.63)	4036 (11.49)
Fruits, Vegetables and pulses	6 (2.11)	12 (2.46)	80 (3.89)	216 (3.42)	1212 (4.93)	1575 (4.48)
Miscellaneous processed foods	1 (0.35)	4 (0.82)	36 (1.75)	213 (3.37)	760 (3.09)	988 (2.81)

(Figures in parentheses indicate percentage)

Table 20. Trends in Agricultural Exports in the Reform Period

(Per cent)

	1990-91	1994-95	1999-2000	2003-04
Cereals and preparations	8	10.3	14.1	19.4
Tobacco	4.5	1.9	4	2.9
Sugar	0.6	0.5	0.1	3.2
Cashew	7.6	9.4	9.8	5.1
Oilseeds	2.5	1.8	3	3.5
Guargum	0	1.1	3.2	1.4
Oil Meals	10.6	13.6	6.5	8.8
Fibres	0	1.1	1.1	3.3
Tea	18.3	7.4	7.1	4.3
Coffee	4.3	8	5.7	2.9
Spices	4	4.6	7	4.1
Fresh fruits and vegetables	3.7	3.5	2.9	4.7
Processed fruits and vegetables	3.6	2.7	3.4	4.8
Floriculture Products	-	0.2	0.5	0.6
Meat & Preparations	16.3	3	3.2	4.9
Marine Products	14.6	26.7	20.3	16.4

India has been exporting over 80 per cent of its coffee production and domestic production is around 60,000 tonnes for the last few decades. India's share in the world coffee exports increased from one per cent in 1970s to 3 per cent during 1990s. Coffee exports witnessed year-wise fluctuations in the reform period and it constituted 4 per cent in total value of agricultural exports in 1990-91, increased to 8 per cent in 1994-95 and declined to 5 per cent during 2002-03. These fluctuations are mostly attributed to trade reforms that have been taking place in coffee trade. India has lost a substantial portion of its market share in world trade of tea and mate, with a decline from 33.4 per cent in 1970 to 22.1 per cent in 1990. In the post-liberalization period also declining share of India's tea exports in the world trade continued and it further declined to 16.4 per cent in 1998. The share of tea exports in India's agricultural exports also declined from 30.39 per cent in 1970-71 to 16.94 per cent in 1990-91. It reached an all time low of 4.28 per cent in 1996-97 and further improved to 6.53 per cent in 2002-03. The growth rates revealed that tea exports in quantity and unit value terms in constant rupees as well as dollar terms have made only very low growth in the post reform period.

Traditionally India exported basmati rice but since 1991-92 export of non-basmati rice has increased and it dominated the rice trade since 1995-96. During late eighties, non-basmati export constituted less than 2 per cent of the total rice export and during the recent triennium its share has risen to above 80 per cent of total quantity of rice export. India was net importer of rice whereas since 1990-91 imports have dwindled almost to nil. The big boost to export of non-basmati rice was witnessed during 1995-96 when export touched 4.5 million tonnes. India exports rice to wide range of countries and Saudi Arabia is the major export market for Indian basmati rice and it consumes nearly 60 per cent of India's basmati rice exports. Bangladesh, Saudi Arabia, South Africa and Russia are the major export markets for non-basmati rice and 27 per cent of India's export goes to Bangladesh.

India is the largest producer, consumer and exporter of spices. Pepper, chilli, ginger, and turmeric form major spices exports from India. Pepper contributed around 18 per cent of spices exports in quantity and value terms respectively during 2002-03. Spice oils and oleoresins constituted about 16 per cent of export earnings from spices. About 75 per cent and 40 per cent of the world requirement of oleoresin and pepper respectively is met by India. India's share in the world spices trade was 20.5 per cent in 1970s, which declined to 7.7 per cent in 1998. Liberalised environment, heavier emphasis on value added products and supportive trade policies of the government resulted in remarkable growth in export of spices. Spices recorded a high growth rate of more than 8 per cent in 90s in quantity term.

Cashew is primarily an important export oriented commodity and production of raw cashew nut in the country is far below the requirement of the processing sector (production meets hardly 50 per cent of the demand). Since it is one of the most important commodities of international trade, many countries are involved in export of cashew kernels. As the largest producer of cashew kernels, India has taken the lead in establishing grade specification for cashew kernels. Availability of raw cashew nuts to traditional processors and exports in India have shown signs of a decline over the years. This is mainly because many former raw cashew producing and exporting countries have turned processors and exporters of cashew nuts. Depressed demand condition are also said to be main reasons for the low growth in exports. Performance of India in export of cashew kernel was impressive during the reform period. Export in quantity terms recorded over 5 per cent growth which was almost similar to that of 1980s and in value terms it increased at the rate of over 15 per cent per annum.

India is world's largest producer of sugar with annual production of 17.4 million tonnes of which 16.6 million tonnes of sugar is consumed. Due to rise in domestic demand and production volatility, export of sugar follows a sort of cyclical pattern. Although India is world's largest producer of sugar and has freight advantages because of its geographical proximity to the major importing nations, Indian exports is less and due to regular cycles of surplus and deficit of sugar production in India, in certain years India tops the list of importers. Erratic behavior in domestic production is reflected in export growth as it is noticed that there was 11 per cent decrease in exports during 80s and 2 percent decrease in 90s in quantity terms. In the case of cotton India ranks third in production next to US and China with an annual production of over 13 million bales. The share of cotton export to the total agricultural exports declined sharply over the years from 8 per cent in 1980-81 to less than one percent currently. Exports of cotton in the reform period declined substantially at the rate of over 16 per cent per annum.

Among the fruits and vegetables mango, grapes, banana and onion have high export potential. During 2002-2003, 96,000 tonnes of mango pulp valued at Rs. 297 crores was exported from India. India produces more than 500 varieties of mango. Among them 52 varieties are popular among the consumers. The Alphonso variety of mango is well known in American and European market. In the recent past, the quantum of grapes exports, has witnessed an annual growth rate of over 23 per cent. Indian grapes are highly export competitive and India has been able to achieve a good market penetration with grapes currently being exported to about 30 markets. Currently, the Middle East, UK and South Asian Countries are the main importers of Indian grapes with the UK and Bangladesh markets growing rapidly. In India, Maharashtra state is the largest banana producing state followed by Tamil Nadu, Gujarat, Assam, Andhra Pradesh and others. The 'Poovan' variety has good market potential in the Middle East and Japan provided it is free from blemishes. Nigeria is exporting a variety called 'silk' which is similar to the Rasthali variety. The 'nendrans' have a market potential in the Middle East where ethnic population form the bulk of the consumers. Nendran 'chips' will also be a favourite as long as it is packed scientifically. The Red Banana will also be a success since it is a Cavendish variety with a different flavour and colour. Among processed onions, dehydrated onion powder has a good market potential. The important floricultural crops in the international cut flower trade are rose, carnation, chrysanthemum, gerbera, gladiolus, gypsophila, liastris, orchids, archilea, anthurium, tulip, lilies. During 2002-03, India earned about Rs. 165 crores by export of cut flowers as against Rs. 115 crores in 2001-2002 and Rs. 123 crores in 2000-01.

Impediments to growth of international trade of India include restrictive import policy regimes of the developed countries, unrealistic standards, testing, labeling and certification including phytosanitary standards, export subsidies (including agricultural export subsidies, preferential export financing schemes), barriers on services, government procurement regimes and other barriers including anti-dumping and countervailing measures. There is also concern about the persistence of high rates, escalation, complexity and the gap between applied and bound rates. India is willing to reduce the

Table 21. Tariffs and Bound Rates on Major Agricultural Commodities

Commodity	*Basic Customs duty (%) (As on 01.03.2004)*	*Bound duty (%) (As on 01.03.2004)*
Pulses other than peas	*10*	*100*
Wheat	*50*	*100*
Rice in the husk	*80*	*80*
Husked rice, broken rice	*80*	*80*
Milk powder	*60*	*60*
Tea	*100*	*150*
Coffee	*100*	*100*
Coconut	*70*	*100*
Copra	*70*	*100*
Fish	*30*	*Unbound*
Sugar	*60*	*150*
Apples	*50*	*50*
Garlic	*100*	*100*
Onions	*5*	*100*
Mushrooms	*30*	*100*
Potato	*30*	*100*
Sweet potato	*30*	*150*
Frozen vegetables – peas, beans, spinach, sweet corn etc	*30*	*150*
Edible oils (Refined)		
Soyabean oil	*45*	*45*
RBD palmolein	*70*	*300*
Palm oil	*70*	*300*
Groundnut oil	*85*	*300*
Sunflower / Safflower	*85*	*300*
Coconut oil	*85*	*300*
Rapeseed oil	*75*	*75*
Mustard oil	*75*	*75*
Castor oil	*100*	*100 / 300*

protection on certain farm goods where there is a substantial difference between their customs duty and bound duty. By offering these products, India is hopeful of getting in return more export opportunities in other countries. The actual custom duty is on an average less than half of existing bound rate in commodities like some fruits and vegetables, live animals, nuts, some pulses, cashewnuts, copra, processed foods, wheat flour, sugar, and cocoa. The country has to protect all those farm products where the current duty is already equal to the existing bound rate, or more than 75 per cent of it. These include meats, poultry products, potato, rice, wheat, cereal preparations, coarse grains, soyabean oil and rapeseed oil (Table 21).

Trade Liberalization and Rural Poor

In recent studies, the growth effects of trade were more systematically analyzed using a large sample of developed and developing countries. A large body of literature has examined the effects of trade on growth and many of these studies have found substantial growth effects of trade. The important question is that how could increased participation in international trade affect the economic growth rate, and what implications will this have for the distribution of income and the incidence of poverty? Experiences suggest that rapid economic growth translates into sustainable reductions in poverty because there is a significant association between trade liberalization and long run improvements in economic growth. Thus, there is likely to be a positive link between liberalization and eradication of poverty in the long run. Incidence of poverty fell by half from 26 per cent to 13 per cent of the population, just five years after trade was liberalized in the mid 1980s in Morocco. Studies shows that countries with open economies (those integrated into the world economy) in developing regions grew, on an average by 2.5 per cent points more than those with closed economies. This, in turn, would have a positive impact on poverty reduction in the absence of an anti-poor bias in domestic policies and investment pattern.

The years of rapid growth in the Indian economy coincided with reduction in poverty. As average annual increases of more than 3 per cent in GDP in the first half of the 1970s accelerated to rates of 6 per cent in the last of the 1980s (World Bank, 1989) and 7 per cent in the early1990s, the incidence of poverty recorded notable decline and there is considerable potential towards reducing poverty in India. According to Planning Commission (1998), the annual average rate of decline of the poverty ratio in India during the period 1973-74 to 1993-94 has been 2 per cent in rural areas and on the basis of the growth rate experienced between 1993-94 and 1996-97, the incidence of poverty has been worked out to 30.55 per cent in 1996-97 and 18.61 per cent in 2001-02. Rural poverty shows a slow decline in the 1970s and a faster decline in the 1980s till 1990-91. There was reduction in poverty during the post reform period. Percentage of rural persons below poverty line during 1993-94 was 37.27 and it declined to 27.09 per cent during 1999-2000 in spite of slow down in the growth rate of agricultural production during 1990s (Tables 22 and 23).

Table 22. Population below Poverty Line, All India

Year	1983	1993-94	1999-00
Rural			
No. of Persons (Lakh)	2519.56	2440.31	1932.43
% of persons	45.65	37.27	27.09
Poverty Line (Rs)*	89.50	205.84	327.56
Urban			
No. of Persons (Lakh)	709.40	763.37	670.07
% of persons	40.79	32.36	23.62
Poverty Line (Rs)	115.65	281.35	454.11
Combined			
No. of Persons (Lakh)	3228.97	3203.68	2602.50
% of persons	44.48	35.97	26.10

Source: Agricultural Statistics at a Glance, 2002; * - *Percapita per month*

International trade has grown twice as fast as income worldwide during 1990s. In India, per capita GDP growth in agriculture in the 1990s accelerated from 9 percent a year in the early 1990s to 13 per cent at current prices. This acceleration in growth is even more remarkable given the inflation rate. At constant prices, per capita GDP grew at the rate 2.15 per cent in the post reform period, while in the earlier period the growth was less than one per cent (0.80). There was a sizable reduction in poverty in the post reform period and it was estimated that rural population below poverty line declined by 3 per cent in the 1990s, while it was less than one per cent in the early 1990s. Similarly, percentage of population below poverty line also declined in the reform period, which is almost 2 per cent more than the earlier period.

Empirical evidences indicate that the trickle down mechanisms have weakened considerably in the later time periods. In the process of weakening of trickle down mechanism, growth in agricultural production alone will not bring about a large reduction in the incidence of rural poverty and there are other important factors that directly influence the living conditions of the rural poor. Although rural poverty is found to be inversely associated with agricultural income per capita of rural population in all the time points, the strength of the relationship between poverty and agricultural growth are found to have declined considerably (Ramasamy, 2004). In the context of weakening of trickle down effect, among the other factors improving trade orientation is found to be one of the most important in alleviating the poverty (Table 24). Agriculture still needs to play a key role in supplying adequate food at affordable prices to ensure that poverty remain low. Therefore, large-scale production of exportable crops and identification competitive crops for exports would enhance the income entitlements of the farmers. Obviously there will be gainers and losers from liberalization of agricultural trade. There may be inadequacy of the trickle effect of reforms, which are due to regional imbalances, profitability of crops and zonification of cropping pattern and these factors may impede the equalizing effect of distribution of income.

Table 23. Growth in Poverty, Income and Prices

Year	*1970-71 to 1990-91*	*1991-92 to1999-00*	*1970-71 to 1999-00*
Per capita AgGDP (Current Rs)	*1025.38*	*4648.66*	*2112.36*
	(8.89)	*(12.59)*	*(10.48)*
Per capita AgGDP (Constant Rs)	*906.64*	*1100.96*	*964.94*
	(0.80)	*(2.15)*	*(1.16)*
Rural Population (000')	*534868.38*	*682198.00*	*579067.27*
	(1.77)	*(1.37)*	*(1.70)*
Rural Population (BPL 000')	*256484.06*	*227170.36*	*247689.95*
	(-0.63)	*(-3.01)*	*(-0.81)*
Rural Population (BPL %)	*48.69*	*33.43*	*44.11*
	(-2.35)	*(-4.32)*	*(-2.47)*
Agrl. Production (Index)	*106.41*	*163.88*	*123.65*
	(2.84)	*(2.37)*	*(2.94)*
Food Articles (WPI)	*104.01*	*345.22*	*176.38*
	(7.97)	*(8.39)*	*(8.59)*
Agrl. Labour (CPI-General)	*74.95*	*233.10*	*122.39*
	(6.84)	*(8.49)*	*(7.79)*
Agrl. Labour (CPI-Food)	*76.41*	*241.03*	*125.79*
	(6.97)	*(7.61)*	*(7.91)*

(Figures in parentheses denote compound growth rate in per cent). WPI - Whole Price Index; CPI - Consumer Price Index Source: *Ramasamy (2004)*

Table 24. Agricultural Growth and Poverty

Year	Intercept	PCSGDP agri	t value	R^2
1972-73	89.462	-0.090	-5.241	0.696
1977-78	83.113	-0.069	-4.121	0.586
1983-84	68.333	-0.055	-3.809	0.547
1986-87	52.330	-0.031	-3.281	0.473
1999-00	32.286	-0.003	-3.821	0.422

Source: Ramasamy (2004)

Implications

There is a need for expanding agricultural production to meet growing demand. How to achieve the target when rai sing the agricultural productivity is constrained by several factors. Income entitlements of majority of people in India are directly linked to domestic agricultural production and the ability of the farmers to respond to market signals by a shift in the cropping pattern or by reallocating their resources in order to maintain their income entitlements is very much limited due to various reasons. The internal constraints, which severely limit the capacity to increase cost effective domestic production to at least a certain minimum percentage of their requirement in order to avoid domestic market distorting imports, need to be addressed on priority basis. Conglomeration of hundreds of small farms is the key to raising agricultural productivity? Whether this would be the right direction to capitalize India's comparative advantage of agricultural commodities under open trade? These need further debate and thorough assessment. Agriculture still needs to play a key role in supplying adequate food at affordable prices to ensure that poverty remain low. Therefore, large-scale production of exportable crops and identification competitive crops for exports would enhance the income entitlements of the farmers. Obviously there will be gainers and losers from liberalization of agricultural trade. There may be inadequacy of the trickle effect of reforms, which are due to regional imbalances, profitability of crops and zonification of cropping pattern and these factors may impede the equalizing effect of distribution of income.

Without discounting post harvest losses total demand of about 130 million tonnes of vegetables has been projected for the country in the coming years showing sample scope for vegetable farming. Similarly, the demand for fruits is also expanding in the country apart from export demand. Considering the scope existing in this sector, it is proposed to launch National Horticulture Mission in April 1, 2005 with the budget allocation of Rs. 630 crores for the year 2005-06. It is proposed to implement Accelerated Irrigation Benefit Programme (AIBP) with a budget allocation of Rs. 4800 crores for the year 2005-06, which is 71 per cent higher than the previous year allocation. These measures will kick start the horticulture industry to attain a faster growth in the coming years. However, overall development of the horticulture in the country would require substantial improvement in productivity and quality of the produce and reduction of post harvest loss of perishable commodities through better handling and organized marketing. Since the scope for expansion of area is limited, further growth of horticulture industry and its sustainability will largely depend on the new and emerging technologies. Further, in the era of globalization, produce has to be of international quality and globally competitive.

Export potential of horticultural products is unlimited. Providing infrastructure would boost export of these items. Market development and promotion with an assurance of continuity in supplies of horticultural products will be a long-term strategy for increasing the exports of these commodities. The several factors like acidic nature, strong astringent taste, poor quality, improper post harvest techniques and poor packaging are the major bottlenecks in export. Low exportable surplus, protective tariffs, stiff competition in the global market, poor market intelligence, lack of brand status to the commodities, lack of publicity and export in the form of raw materials are the major market related constrains inhibiting exports of fruits. Technical standards, environmental and social concerns and non trade barriers like anti dumping duties, countervailing duties, safe guard measures and sanitary and phyto sanitary measure have affected market access for export of horticultural commodities like floricultural produce.

Notes

1. Herfindhal Index is defined as:

$$\mathrm{H} = \sum_{i=1}^{n} p_i^2$$

P_i = Proportion of area under ith crop

The value of H-index varies between zero to one. It is one in case of perfect specialization and zero in case of perfect diversification.

2. Crop Concentration

Crop concentration means the "variation in the density of crops in an area or region at a given point/period of time". The concentration of a crop in an area largely depends on its terrain, temperature, moisture, price and income, social factors, government policy, type of soils and many others. The most commonly used method to study crop concentration is the Location Quotient method.Location Quotient Method of Crop Concentration is algebraically defined as:

$$LQ = \frac{A_{ij} / A_j}{\sum_{i=1}^{n} A_{ij} / \sum_{j} A_j}$$

A_{ij}= Gross cropped area under i th crop in j th state,

A_j= Gross cropped area in j th state.

$\sum_j A_j$ = Gross cropped area in the country

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DESIGNING AGRICULTURAL RESEARCH WITH A HUMAN FACE : CHALLENGE TO AGRICULTURAL UNIVERSITIES

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Our country, currently in the threshold of entering an era of sustained agricultural and industrial development and become a strong economic power to contend with, is addressing many grass-root level issues that contribute to the development of the Millennium Development Goals. In planning such economic and social development in a holistic manner, especially in the rural sector, the importance of appropriate agricultural technologies cannot be overstated. Science and technology have made a remarkable contribution to increasing production and productivity of not only agricultural goods but also to products and services in ways difficult to imagine a few decades ago. Despite various factors like achievement of self-reliance in food grains production due to Green Revolution, the problem of rural poverty remained as acute as ever before. As seen from the various surveys, though on a proportional basis, there has been a reduction in rural poverty, in absolute numbers, the number of poor people has increased over the years. The responsibility of finding solutions to problems in the rural areas not only results with the planners and progressive thinkers, but also with public institutional structures like agricultural universities with mandates to provide food, nutritional and livelihood security to them.

The ultimate goal of research in agriculture and rural development is to benefit the farmers, helping them to improve their life by increased production and productivity, enhancement of income, meaningful reduction in drudgery, improved quality of life and sustained growth. The main concern should be to indicate the correct way to environmental protection, conservation and management to achieve a lasting benefit and sustainable production aimed at reducing poverty and under-development. Any research that does not concern itself with social, cultural and ethical issues largely remains bookish and is not relevant.

It has long been believed that economic growth is the specific remedy for the ills of poverty. Some economists argue that for a country like India, which is largely agrarian in character, a seven to eight percent rate of growth per year over a period of 15-20 years can help in reducing poverty. Economic growth certainly reduces poverty. But growth alone does not provide sufficient conditions for reducing poverty. The argument that a good growth rate will have a trickle down effect, down to the lowest layers of poverty is not necessarily correct, as evidenced by our own experiences as well as several other less developed countries coping with the problem. Again, while agricultural growth is an important factor to alleviate poverty, it has to be developed as a unified strategy broad-basing the issue with greater and more meaningful participation of small and marginal farmers, as well landless resource poor. It is not sufficient to focus attention on low income alone, but on the entire marginalization processes that push many to the brink of subsistence.

Fifty years of development experience in our country have yielded some valuable and critical lessons :

1. Macroeconomic stability is an essential pre-requisite for achieving growth needed for development.
2. Economic growth should ensure employment generation and livelihood opportunities.
3. Growth does not trickle down; development should address human needs directly.
4. The development orientation should be sustainable; it should be rooted in processes that are socially inclusive and responsive to changing circumstances and institutional structures that are locally developed and empowered.
5. A synergy need to be developed between the institutions and individuals through linkages and partnerships with the government, NGOs and private sector so that people are not regarded as beneficiaries but partners in progress.

Lately, I have been working in the rural areas with the perspective of alleviating poverty through employment generation, and provision of multiple livelihood opportunities. This meant using scientific agriculture not only for increasing agricultural production and productivity, but income enhancement and livelihoods, both on-farm and off-farm. Despite the enormous success that we have achieved in food production, and the fact that many new technologies have been developed, I was disturbed to find how few of these technologies were really focused on the poor and landless farmers and farm workers, taking into account their resource and social constraints. Even though the entire production system was dependent on the basic natural resources of soil and water, not many resource-neutral technologies were available and even among them, very few contributed to employment generation, improvement of labour productivity and reduction of drudgery in work.

The National Policy on Agriculture seeks to actualize the vast untapped growth potential of agriculture to generate income and employment opportunities for the rural communities. It recognizes that agriculture is and will continue to be central to all strategies for planned socio-economic development in the country and its rapid growth is essential not only to achieve self-reliance at national level but also for household food security and to bring about equity in distribution of income and wealth. Towards this end, it promotes technically sound, economically viable, environmentally non-degrading, and socially acceptable use of country's natural resources to promote sustainable development of agriculture, ensure food security, and a fair standard of living of the rural poor and minimizing inter-regional disparities in development.

"Development with a human face", which I am emphasizing as the theme of this paper, addresses various issues of inter and intra household food security, nutrition security, equity issues - especially gender, social concerns and economic disparities - employment generation and livelihood security. The social responsibilities of science get recognition as important criteria in planning development activities.

Phases in the agricultural development of our country

Agricultural development, which has been the mainstay of economy of our country, had witnessed major ontogenesis in the latter part of the last century.Broadly speaking, it has gone through five phases of development.

In Phase 1, when subsistence farming was most common, farmers essentially relied on their traditional wisdom of growing crops, handed to them over generations, which was preserved by folklores, predictions based on vital climatic signs, suitability of crops to seasons and regions, and by selection procedures based on shrewd observations and analysis.Domestication of plants was done to suit varying needs and changes and consumption patterns, and eco-friendly practices which primarily insisted on returning to the soil what it got out of it. Native soil fertility was preserved by depending on the soil's resilience and ability to recoup when minimal disturbances were applied. Since there was no pressure either of population or on land, the system had a harmony of natural adjustment with nature and its functions.

When pressures on land increased, and agriculture started developing as an occupation that has to be designed for profit, Phase 2 which could be broadly termed as "Exploitative agriculture" developed. There was increased discrimination in the production processes, as well as in the choice of crops and varieties. More productive seeds and animals were introduced through careful selection processes, and external inputs like manures, fertilizers, and other agricultural chemicals were used to increase productivity. The first signs of scientific agriculture were evident and several new technologies were developed; these were still dependent on low inputs and eco-friendly practices. Since there was pressure on land, there was an attempt at increasing the land area under cultivation and marginal lands were also brought under the plough. The adverse influence of these practices on the natural ecosystem started showing up by way of loss in native soil fertility, decreased production from the same land, water use problems leading to drop in water table levels, and a host of associated limitations. Many regions of the world were not able to fully meet the food requirements of their own population, and widespread production constraints were recorded. There was intense pressure on both scientists and farmers to produce more, and demand for new technologies grew.

A major change in the production systems, appropriately termed as "Green Revolution" marked the beginning of Phase 3 of agricultural development. Plant breeders developed newer plant varieties with high yield potential, and with chosen desirable characteristics. High external input agriculture developed, and careful nutrient and pest management became critical inputs. Agriculture became a commercial venture. Globalization facilitated exchange of materials and technologies and most parts of the globe witnessed dramatic increase in production levels of food grains, milk and milk products, meat and meat products etc., which people could never even conceive of earlier. Developments in many spheres of science influenced evolution of agricultural technologies. Technology spread was far and wide, and pockets of intense production, and consequent affluence developed. This was indeed the golden period of agricultural development from the point of production and productivity. However, this was also the period when the true dangers of exploitative agriculture were noticed. Small and marginal farmers with limited resource potential could not benefit from the 'high external input agriculture'. The technologies developed largely depended on high use of fertilizers, agricultural chemicals for control of weeds, diseases and pests, mechanized tillage practices and post harvest care. Many of these practices interfered with the natural resilience ability of the soil while over-exploitation of land caused problems like salinity, alkalinity, water-logging, fall in water table, decline in Total Factor Productivity etc. More serious than all these were the wide regional disparities in production, socio-economic problems and environmental concerns that fringed on the sustainability of ecosystems.Many social scientists saw this as a sad phase of development that created more problems than it sought to solve, though they recognize the fact that the food needs of the world could never have been met but for this production revolution.

We are now passing through Phase 4 of this development, which has to sustain the fruits of this production revolution. Called the Doubly Green Revolution (Gordon Conway) and Ever Green Revolution (Swaminathan), the concept underscores environmentally friendly and equitable agriculture, where the emphasis is on ecologically friendly and environmentally safe agricultural practices. The importance of appropriate natural resources management is recognized and extensive use of Integrated Management of pests and nutrients is the key. Marker-aided selection procedures, use of biotechnology and gene manipulation for breeding of crops and animals with desired characteristics supplements conventional breeding and selection procedures, are extensively adopted.The social responsibilities of science are recognized and development of technology takes into account employment generation and providing livelihood opportunities. Minimizing regional disparities in development and social and economic inequities are given greater attention, and in Amartya Sen's words, a 'balanced set of rules' are developed.This phase attempts to balance between development for production and productivity with ecologically sound and socially relevant agriculture.

As we move into Phase 5 of development, the emphasis will be on socially conscious futuristic agriculture that is compatible with ecology and environment. The opening up of the world's borders for trade will bring a high element of competitiveness in agriculture. Agriculture will be designed for increased prosperity and expansion of livelihood opportunities.Consumption patterns will drastically change in keeping with greater affluence and purchasing power of people and in deference to food preferences, selective consumption of articles of food will be noticed. Nutrition and food sanitation will receive greater attention. In the development of transgenic crops, breeding will emphasize addition of genes that have little commercial value, but are nutritionally important. This will include protein enrichment with essential amino acids, incorporation of Vitamin A, bio-available iron etc. in the grains, so that supplementation through drugs and chemicals are not needed.The value of the ecosystem services will be increasingly recognized.Sustainability rather than profitability will be the primary goal and the importance of eco-economy will be realized. Future agricultural research will have to focus to service this phase of development.

Agricultural development challenges of Agricultural Universities

The Acts of the Agricultural Universities specify that one of the prime objectives of the university is "undertaking the extension education of such sciences and technologies specially for the rural people of the State". In view of this specific mandate, at one time, it was even suggested that agricultural universities should be renamed as rural universities. Under this objective, the Universities have a mandate of research and training that will help the rural population in overcoming many of their problems of overall development increasing agricultural production, income enhancement and drudgery removal. Besides, these institutions can perform a vital role in planning and monitoring of several ongoing activities of the rural development plans, both on the basis of expertise and from penetrating insights and experiences it has acquired. It is axiomatic that sensitizing the rural population and evoking their conscience, coupled with their organization is the basic requirement of any rural development plan that addresses the techno-economic and socio-cultural problems. Further, this mandate assumes special significance in view of the changing social environment and the increased importance that the Government is paying to rural development activities.

Three important factors that have concerned planners of agricultural development are:

1. Decline in Total Factor Productivity in most areas, notably in the Rice-Wheat production system, which is not only the most fertile and productive systems, but also the most popular in the region.
2. Increase in cost of production with no concomitant increases in the prices of primary agricultural commodities.
3. Stagnation or decline in capital formation in agriculture both in the public and private sector.

These are techno-economic and socio-cultural issues which will require the attention of multidisciplinary approaches, specially the involvement of social scientists.

Role of agricultural research in developing benign technologies

Research should play both a reactive and proactive role and should be designed to solve farm problems practically and pragmatically. The ultimate inputs of agricultural research are to improve agricultural production brought about in a benign environment.A comprehensive systems approach to the development and adoption process is needed. The viability of such technological innovations depends on the changing circumstances, which critically covers, need, market trends, input and resource availability and above all support policies.

Enhancing sustainability of agricultural production systems, promoting sustaining and equitable use of natural resources, protecting environment, meeting diversified consumption needs, achieving regionally balanced growth, alleviation of poverty, strengthening food and nutritional security shall be major development concerns. While agriculture will become internationally more competitive, care has to be taken to ensure that the interests of small holders, landless labour and the disadvantaged sections of the community are not bypassed. Deliberate attempts should be made to protect them by focusing on cost-reducing technological innovations, creating employment and income generating opportunities and realizing economies of scale. The strategies for development will focus on rural technologies that would be resource neutral, while at the same time, adequate attention will also be paid to cutting edge technologies that will promote capital formation in agriculture. Anticipatory and impact-oriented research that transforms societies towards better health and standards of living will receive high attention. This may include monitoring changes in climate and agricultural scenario, developing prediction models and developing technologies for effective management of such changes. These may be formidable challenges.

Advances in Information technology is transforming even our rural areas into knowledge-intensive societies. Many of our programs will have to be tailored to mainstream IT into our development programs. The experiences of the M. S. Swaminathan Research Foundation in establishing ‘knowledge centres’ and virtual universities in the rural areas is worth emulating. It is high time that agricultural universities developing innovative methods and techniques of knowledge spread which can be used for the dissemination of not only agricultural extension information, but also work towards social good.

Thrust area for development with a human face

As has been pointed out earlier, sectoral plans of development have not had the desired effect at rapid development. What is required is a holistic emphasis on 'Human Development'. This term is a widely pervasive one that covers improving the quality of life, removal of drudgery, development of multiple livelihood opportunities contributing to income enhancement, better health and nutrition brought about by more favourable environmental sanitation, empowerment of people leading to evolution of better social structure, improvement of literacy and education that brings in awareness for development, encouragement of self-help etc. Reorienting research programs towards the fulfillment of these goals will require a paradigm shift and change in outlook on the part of researchers in understanding and defining problems and in finding suitable and appropriate solutions. Research programs should be developed on a 'participatory' mode and development plans need to be meshed with existing organizational structures and social norms.

The role of the Universities in making significant contribution to the welfare of the rural poor can be broadly grouped as under:

I. **Technological options for increased production:** Increasing agricultural production with stability, sustainability and environment protection is one of the primary objectives of research by Universities. The approaches may be in the development of genetically improved crop varieties suitable for the region, a more suitable crop rotation, better land use and soil conservation techniques for more efficient land management, integrated water management system etc. Further the effort will be to maintain resource neutrality to the extent possible. Most of these options will be highly location specific and need to be site-tested before wider adoption.

II. **Diversification of agriculture:** Traditional agriculture needs to be diversified so as to improve farmers' income. Crop-efficient zones should be identified and their production in these areas should be intensified by the use of appropriate technological packages. Where relevant practices such as cultivation of fruits and vegetable crops, dairying, poultry, goat rearing, sericulture and mushroom cultivation, either as additional activity or even replacing existing practices should be encouraged.Experiences are galore where farmers' income has substantial increase by an appropriate choice of crops as well as diversification of activities.

III. **Primary processing and value addition:** Most agricultural commodities require several stages of processing before they are in the hands of the consumers. Every activity involved in these processing stages is also a value addition of the product. It has been estimated that, at the farm gate level, the price of agricultural produce is only 40% of the price of the product that the consumer pays. The rest is the middle men's earnings, the cost of the processing steps, processing, packaging and marketing expenditure as well as the costs of storage and a series of losses that occur from harvest to sale. While there are conscious efforts to minimize the cost involved in these steps, there will be a wide difference between the price of the primary commodity that the farmer gets, and the finished products that the consumer buys. Some of the storage and processing steps, specially those that do not require a high degree of sophistication, can be handled at the farm level itself so that the benefits of increased income can reach the farmer himself. Universities can play an active role in making available these services including the training required to acquire the specific skills needed.

IV. **Increased livelihood opportunities:** Enhanced income from diversification of crop and commodities will be the main approach to improve the lot of the rural poor. Besides the primary product a number of by-products from the same plant or crop can also be produced at the rural level provided appropriate technologies are available. Numerous examples can be cited where such diversification of products is possible for example cashew is mainly grown for its nuts but the cashew apple which is normally thrown away can be processed for a delightful and nutritious drink provided it is made more palatable and packing ensures maintenance of quality. The juice can also be processed for alcohol. The department of food processing at the University as well as the Department of Agriculture can play a significant role in bringing home such knowledge.

V. **Conservation of Biodiversity:** Even though rural folk and villages continue to be the storehouse of wisdom in biodiversity, there is a grave threat to it because of the lack of a coordinated mechanism to conserve both the species and the knowledge about them. A large number of rare plants with many divergent uses have been identified, but a lot more need to be chronicled and studied. Universities, in general, have not taken the required initiative to understand and document indigenous technical knowledge that seeks to preserve the disappearing information about the plants and the traditional practices. The scientific rationale of these practices should be studied so that the benefits of modern sciences are available in interpreting them more diligently. The benefits from conservation of biodiversity and traditional knowledge should be available to not only individual farmers but also to the communities which have painstakingly and steadfast preserved them. Modern technology provides ample scope for such documentation and quick dissemination. Universities can play a very significant part in this activity.

VI. **Health and Nutrition:** Health and nutrition education should form an essential component of rural development. Protein and Calorie malnutrition is fairly widespread. The problem can be solved only by knowledge on appropriate nutrition needs. Malnutrition, especially micronutrient malnutrition, also known as the hidden hunger, is also a chronic problem. Vitamin A, iron, and iodine deficiency are the most serious problems.

Research-Extension Linkages

The success of Indian agriculture from 1960s to 2000 is the product of a partnership between the research and extension systems. However, field level adoption of far-reaching technologies has not kept pace with rapid advances in technology generation. The most serious institutional problem impeding the flow of improved technologies to farmers is Research-Extension linkage and interface. While the farmer is the key element in the agricultural production process, research and extension support these activities with improved technologies and methods. The ultimate adoption decision is made by the farmers, who assess the technological information resulting from research, together with a set of other factors that affect the suitability and profitability of their enterprise such as price support, input distribution, subsidies credit, taxes and marketing policies and their own resource base, particularly capital, land and labour. The sustainability of the technology system in the long run depends on such critical decisions made by the farmer and this is not a static measure, but is a scenario that encompasses the entire system and the changing complexities that go with it.

In the light of changes in the rural agricultural scenario, priorities in research undergo some major changes as outlined earlier in the paper. Participatory approach gives credence and recognition to all the parties involved in the development chain, the farmers, researchers, extension workers and planning functionaries. The primary emphasis is on the farmer not as a beneficiary of a program, but as partner in progress. The National Policy on Agriculture seeks to strengthen research and extension linkages to improve quality and effectiveness of both the systems. The extension system needs to be more broad-based .

Epilogue

Human development as an all pervasive purpose would demand a high degree of social mobilization, participatory involvement at the grassroots level and location-specific technologies which blend indigenous knowledge with advances in modern science. This requires a paradigm shift and attitudinal change. While resources will always be limiting for such endeavors, commitment of individuals and groups, innovativeness in action and a visionary zeal for accomplishment will pave the way for success.

EMERGING ISSUES IN MANAGEMENT OF AGRICULTURAL RESEARCH IN THE CHANGING GLOBAL PERSPECTIVE

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Prologue

Food production, hunger, poverty, economic growth, and natural resource degradation will continue as the major challenges through out the world especially in the less developed and developing nations. As the global population climbs to an expected 8,000 million by 2025, these problems are going to be more acute than ever before. Today at least 800 million people suffer from chronic hunger. Pervasive poverty remains largely rural.

Ensuring a competitive agricultural economy is critical for reducing poverty, enabling food security, and managing natural resources in a sustainable fashion. Agriculture continues to be the major livelihood option for more than 60 percent of people in developing country, and in many countries farm families make up 80 percent or more of the population (World Bank, 1990). Agriculture has already reached the limits of land and water, thus future increases in food production must exploit biological yields on existing land (World Bank, 1997). Hence, these challenges put tremendous pressure on agriculture to change from the way it used to be practiced earlier and practiced even today. Agriculture of next generation has to go beyond mere food production to be a propellant of economic development by being sustainable, environmental friendly and market oriented. One of the prime movers of agricultural development – agricultural research has to play a crucial role in ushering in such a transformation in agriculture to meet the challenges and emerging issues.

Agricultural Research Management – Concept and Importance

In the context of this paper agricultural research management is operationalized as a comprehensive process of planning, conducting, monitoring and evaluating agricultural research. Essentially, it refers to how exactly the research is planned and managed to achieve the objectives set. The reorientation of agricultural research in management perspective is the outcome of

1-Director and 2-Senior Scientist

developments in the area of operations research, which again evolved as a specialized subject and profession in the post-World War II years. An assessment of evolution of agricultural research reveals that what started as curiosity experiments today stands as a distinct area attracting substantial investments nationally and globally and contributing in equal measures to ensure food, nutritional and livelihood security of millions of rural poor and farmers. With increasing population, there was a necessity to increase food production, which was the prime accelerator of agricultural research. Then as more and more investments started pouring in for agricultural research, there was compulsion on better focusing of research efforts and also its systematic management.

Today, we are a part of a highly complex and competitive world. While the challenges to agricultural research are becoming more complex, the funding has started to decline. This is leading to a situation where the entire process of agricultural research right from identifying problem, planning, conducting to the spread of the outcomes, has to be managed more professionally. Hence professional management of agricultural research has become both a necessity as well as order of the day.

The need for professional management of agricultural research on the basis of scientific theories and principles of management is aptly highlighted by Arnon (1968) as follows: "The management of the research organization, at all its levels, is, in most cases, in the hands of veteran agricultural research workers who have risen from the ranks. This is as it should be. However, here we have people who, by training and inclination, have usually been conditioned to averseness to administration in all its manifestations. They are then made responsible for managerial activities in an extremely complex field, for which they have had little or no training whatsoever and for which their only qualifications are their individual character traits and standing with their research colleagues. Administrative understanding is usually incidental and rarely present".

Emergence of Management Perspective in Agricultural Research

Agricultural research is probably the first and the most widespread form of organized research in the world. It is also a major professional activity in which the entire world including nations from developed, developing and underdeveloped world are interested and engaged in for various reasons and objectives. If research is construed as a human process of constantly improving life and life processes by innovating then human beings even in the most primitive civilization qualify as researchers as they were compelled to explore new flora and fauna for the purpose of meeting hunger. Then, we may say that agriculture research is as old as human civilization itself. However, with human civilizations settling for a more organized way of life, agriculture and agricultural research saw drastic changes insofar as domestication and culture of plants and animals was considered. Individuals were making conscious and systematic attempts to apply scientific knowledge to improve agriculture by the middle of the eighteenth century (Asopa and Beye, 1997).

During the 18th century, agricultural research was characterized by gifted individuals working on their own initiative, establishing and recording unrelated findings which had little impact on agriculture. A management innovation occurred in the nineteenth century, when learned farmers began to form societies with the objective of defining and solving their problems. Interacting with interested chemists, these societies took the initiative in setting up laboratories and field experiments. Agricultural science began to grow and develop in a systematic fashion, mirrored by improved farming methods and practices. By the middle of the 19th century, organized agricultural research started taking better shape in the mid-19th century with the establishment of institutions like the Agricultural Chemistry Association of Scotland, and the Agricultural Experiment Station, Möckern, Saxony (Asopa and Beye, 1997).

Looking back, the major questions addressed seemed to have concerned the nature and structure of the new organizations, the setting of priorities, the proper source of support, the relationship of research to the farmer, the relative emphasis to be placed on research and diffusion of research results, the degree of appropriate autonomy for the research organization, and other issues of management. It was only through effectively dealing with these management issues in industrialized economies that agricultural research was able to grow and lead agricultural development into the last quarter of the twentieth century.

In India too, organized efforts at agricultural research date back to early 20th century when the erstwhile British government established Imperial Agricultural Research Institute at Pusa in Bihar in 1905. Subsequently, this pioneering institute became known as Indian Agricultural Research Institute and was shifted to the national capital of Delhi. Establishment of Imperial Council of Agricultural Research, which was subsequently renamed as Indian Council of Agricultural Research (ICAR) as an apex body to coordinate agricultural research, is the major landmark event. The real impetus for regionalizing agricultural research was seen from 1960s onwards when a series of State Agricultural Universities (SAUs) were established on the pattern of the Land Grant Colleges of USA with trifunctional responsibilities of agricultural education, research and extension. Today, the ICAR and SAU systems constitute one of the largest National Agricultural Research Systems in the world in terms of both size and diversity of institutes.

Prior to independence, agricultural research in many economies was largely focused on crops of economic significance for the colonial powers. The research institutions and experiment stations that emerged usually focused on plantation crops, and were staffed by expatriate scientists. Following independence, it was normal for governments to initiate research on improving agriculture to attain food self-sufficiency. This transition - from colonial to national agricultural research systems (NARS) - often started with fairly good research facilities and equipment, and some technicians. It was rare, however, to find a national who had been trained and nurtured to the level of a scientist, and rarer still to find such a person with managerial experience. Establishment of International Service for National Agricultural Research (ISNAR) was an effort to bridge this gap. Meanwhile, in India too a need was being felt of the importance of human resource development for better management of agricultural research. Creation of a national level Agricultural Research Service in 1976 and starting of the National Academy of Agricultural Research Management (as Central Staff College for Agriculture) were the manifestations of this need. Since then, agricultural research has been receiving good deal of management perspective in terms of its planning, conducting, monitoring and evaluating.

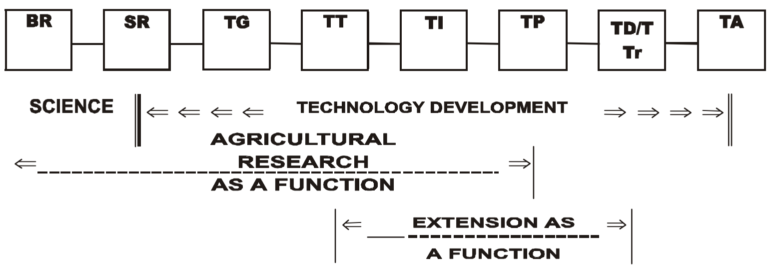
Agricultural Research Continuum – Implications for Management

Agricultural research primarily has been applied and adaptive research. However, with rapid development in science and technology on the one hand and complexities of the problems confronted in the farm sector on the other, led to initiation of basic and strategic research in agriculture. Conceptualized as essentially technology development process, agricultural research has now come to be visualized and practiced in a vast continuum with its scope extending up to technology transfer and adoption. This continuum of research in agriculture is illustrated in figure 1. It is necessary to note that the agricultural research is one vast subsystem (extending the main objective of agricultural research is to solve the farm and farming related problems of farmers by developing appropriate technologies. Research management primarily involves perception/identification and articulation of the research problem, project prioritization, selection and resource allocation, planning of research activities, monitoring and review of the project, and utilization of research results.

The technology development and transfer processes form a continuum on which our research and extension activities are carried out (figure 1).

Stakeholders of Agricultural Research

The primary stakeholders of agricultural research are the farmers. Besides, a host of other interest groups have their own stakes in agricultural research. Figure 2 illustrates the possible stakeholder groups in agricultural research process.



Key BR = Basic research; SR = strategic research; TG = technology generation; TT = technology testing; T1 = technology integration; TD/TTr = technology dissemination and technology transfer; TA = technology adoption;

Figure 1. Continuum of agricultural research – technology development, transfer and adoption

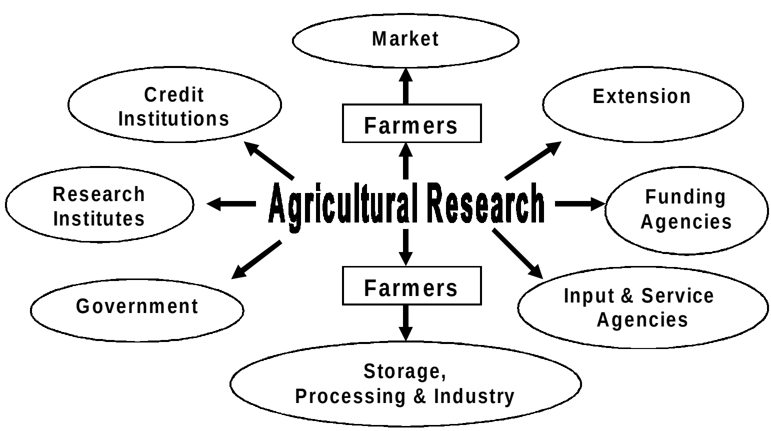


Figure 2. Stake holders of agricultural research

Changing Global Perspective of Agricultural Research

As mentioned elsewhere, agricultural research has come to ages in terms of its content, form and nature. Today, it attracts a substantial international funding as food and nutritional security haunt human civilization even in this 21st century characterized by rapid advancements in science and technology. The real drastic changes in the nature of agricultural research began to happen in the second half of the bygone millennium when we had agricultural revolutions – green, white, blue and now rainbow. With advancements in genetic and cytogenetic research farm scientist began to evolve new strains, hybrids and varieties of both crops and livestock, which tremendously helped in at least partially overcoming the challenges of hunger and poverty. This period also saw the birth of a number of institutions nationally and internationally specializing on different commodities and systems of agriculture. Meanwhile, strides made in molecular biology, biochemistry, biotechnology, informatics and bioinformatics started to significantly infuse considerable research efforts of basic nature in agriculture too. There was rapid growth in agricultural sciences with several new specializations taking root and consequent developments in human knowledge and skills leading to availability of qualified and trained manpower in both conventional and emerging areas of agriculture.

However, all these spectacular developments and achievements could not help in fully overcoming the challenges of poverty, hunger and malnutrition. Then slowly but steadily a few question marks started appearing on the contribution of agricultural research, especially to those international donors of agricultural research. Simultaneously, the developments like General Agreements on Trade and Tariff (GATT) and World Trade Agreements (WTA) added new dimensions to agricultural research in terms of protection of intellectual property rights, movement and trade of commodities, subsidies, etc. posing newer challenges to agricultural research. Growing concern over environmental implications of agricultural research/ technologies, depletion/degradation of natural resources, rising regional and socio-economic disparities, sustainability of farm production together with shrinking resources and fast changing expectations of stakeholders have started exerting influence in further alteration of the nature of agricultural research.

Mudahar et al. (1998) have summarized 'some of the changes occurring in agricultural research systems around the world' in terms of a) increased emphasis on the cost effectiveness of agricultural research, often requiring reductions in staff and streamlining of bureaucracies, b) resource commitments based on anticipated applied research outcomes, c) increased involvement by users in decision making, d) more access to research resources by those likely to benefit from its outcomes, including farmers, processing firms and seed producers, etc. e) responsibility and substantial autonomy for management of research in main centres, with policy and funding bodies providing only overall guidelines on programmes and outcomes and f) shift from basic to applied research while ensuring public good linkage between basic and applied research.

Based on the above discussion, the points presented in box 1 below emerge as the significant changes that have happened in agricultural research over the years, which will have a critical impact on the way we are going to manage agricultural research in the days to come.

- Change in orientation from disciplinary to multidisciplinary and interdisciplinary research
- Availability of specialized manpower to carry out all forms of research in agriculture
- Growth in number of research institutions and research infrastructure
- Change in stakeholders' expectations from domestic consumption to international trade, value addition, processing, packaging, change in food habits, etc.
- Need for accountability of agricultural research
- Payoff to agricultural research
- Private investments and interests in agricultural research
- Evolution of participatory appraisal methods
- Changing nature of farm problems
- Availability of high-tech knowledge and skills in frontier areas
- Growing concerns on the implications of WTO on agriculture

Box 1. Significant changes in Management of Agricultural Research

Needless to say, today's requirement is to manage agricultural research in the most professional manner using the principles and practices of management science. It is in this backdrop that an attempt is made to both identify and analyze the emerging issues that need to be addressed by agricultural research of today and tomorrow.

Emerging Issues in Management of Agricultural Research

Stakeholder related issues : Agricultural research of yesteryears had relatively less number often farmers and state, stakeholders than it has today. With advances in agricultural sciences vis-à-vis developments in industry and other sectors, the stakeholder gamut has changed significantly. Today, agricultural research is seen as a means to achieve the overall development of human society. The increasing stakeholder spectrum means wide and varied expectations from the research system. These expectations are reflected in the multiple and sometimes conflicting objectives set for agricultural research, like production and productivity concerns, sustainability, equity, etc. Hence, agricultural research has to work under a more dynamic and fast changing environment, which makes the task of research manager and scientist very challenging. However, the fast evolving methodologies for stakeholder participation in agricultural research like the rapid/participatory rural appraisal (R/PRA), participatory research, participatory technology development (PTD), etc. offer new and renewed hope and interest to research community. The emphasis of these alternative approaches is to recognize stakeholders as equal partners in research process, so that they own the system, process and outputs of agricultural research. The recent innovation of Strategic Research Extension Plan (SREP) tried under NATP acknowledges the importance of multiple stakeholders for agricultural research and has all the potential to involve them in voicing their research needs.

Issues related to research funding : Global trends of investment in agricultural research reveal gradual decline in public funding. As policy reform continues, concerns are increasing that the rapid growth in agricultural production is waning. These concerns are heightened by a perception that the returns to agricultural research may be declining over time because the “easiest” gains from the Green Revolution have already been reaped through the rapid spread of modern varieties of wheat and rice, leading to high levels of modern variety adoption and high input use in many regions of India, and by the failure of domestic and foreign research to generate crop varieties with higher maximum yields than varieties produced in the 1960s (Rosegrant and Pingali, 1994). Public investments in agriculture are declining, and the annual increment to gross capital formation in agriculture is now lower than in the early 1980s. This decline appears to be happening in all states, not just the poorer ones. At the same time, increasing shares of total public expenditures on agriculture have been allocated to input subsidies, rather than to productivity enhancing investments. The share of input subsidies in public expenditures in agriculture increased from 44 per cent in the early 1980s to 83 percent by 1990 (Rao, 1994). During this period private investment in agriculture did not compensate for the decline in public investment. Because of the apparent high complementarity between public and private investment, and the adverse terms of trade for agriculture during the 1980s, private investment also declined through much of the 1980s before recovering modestly during the early 1990s (Rao and Gulati, 1994). Based on a thorough analysis of funding and organization of agricultural research in India, Suresh Pal and Byerlee (2003) remarked that the efficiency and effectiveness of public sector agricultural research will depend on critical policy changes and institutional and management reforms like autonomy, decentralization, financial flexibility, and accountability.

The implications of decline in public funding for agriculture research are far too serious. While, there is a dire need to pragmatically assess our research priorities at both macro and micro levels, greater financial discipline has to be exercised to ensure proper utilization of scarce research budgets. Duplication in research efforts needs to be avoided by more concerted efforts like research in network and collaborative modes. Signals are also strong towards cost sharing by the stakeholders so that their participation and accountability sharing in agricultural research are enhanced.

Environmental issues: While the 'green revolution' and its aftermaths leading to 'rainbow revolution' in agriculture contributed substantially to achieve the primary objective of ensuring enough food reserves, it also brought in high external input use in Indian agriculture. Consequent indiscriminate use of agri inputs like fertilizers, plant protection chemicals, growth promoters, herbicides, etc. have started causing alarms to natural resources like soil, water and environment. Shift in cropping patterns in favour of cash crops even though desirable were accompanied by overuse of external inputs threatening sustainability of natural resources on the one hand and leading to build up pest resistances on the other. Mishandling of some of the farm research outcomes have come in for sharp scrutiny under the environmental concerns. Growing concern for environment is calling for eco-friendly farming practices. Under these circumstances, agricultural research has to reorient itself to address these emerging concerns of natural resource degradation and environmental safety.

Sustainability issues: Agricultural research during its sojourn has successfully addressed pressing needs of time. Barely a decade and half after independence, the seeds of 'green revolution' were sown and we could harvest its benefits in ensuring self sufficiency in food grain production. What followed green revolution in the form of white and blue revolution was still more spectacular in earning valuable foreign exchange through trade of milk, milk products, fish and marine products. However, the real success of agriculture is determined by the extent to which it can continue to provide adequate and reliable food supplies to the growing population (Evans, 1993). In spite of its growing importance, there seems to be a general lack of precise conceptual framework for understanding and practising sustainable agriculture. Such a lacuna arises primarily due to multiple and hierarchical levels at which agricultural systems can be defined for example, soil-plant system, cropping system, farming system, agro-eco system, and so on to higher regional, national and global systems (Lynam, 1994). It, therefore, follows that any attempt to fully comprehend sustainability requires the system level to be specified. For effective formulation and implementation of research management strategies aimed at sustainable agriculture, various issues need to be addressed at least at two levels namely farming system and agro-eco system. Then at these two levels appropriate linkages can be worked out to strike a balance between the two contradictory dimensions of sustainability – profitability and environmental/social welfare concerns. Sustainability thus has physical, ecological, socio-economic, cultural and ethical dimensions that operate differently at different levels. Based on a critical examination of the concept of sustainability, Rao et al (2002) offered the following three components of a sustainability driven research perspective: i) crop production system perspective to address production and profitability concerns at the farm level (to accommodate the biophysical dimension), ii) regional natural resource management perspective with a relatively short term focus on regional resources, production, income and their distribution (to accommodate the social dimension) and iii) regional ecosystem health perspective with a long term focus to address ecological and environmental concerns (to accommodate ecological, ethical and aesthetic dimensions). Therefore, in order to successfully address the issue of sustainability, we have to change our approach from commodity to system orientation. This is easier said than done, as it calls for structural and functional modifications in our institutional set up.

Gender Issues : The realization of the importance of women in agriculture vis-à-vis their role and contributions has come a rather late in to the focus of agricultural research. History has it that women played key role in domestication of animal and plants and thereby laid the foundation for 'settled' agriculture. In today's modern technology driven era too women continue to play vital role in many a farm operation. In fact, several studies have revealed that decisions on technology use in agriculture are joint-decisions with equal say by spouses of farmers. There are many specific farm operations, like sowing/planting, weeding, fertilizer application, harvesting, post-harvest processing, marketing, etc., which are exclusive domains of farmwomen. Similarly, in animal husbandry feeding, cleaning, milking, processing and marketing are done by women. In fisheries too, women play a major role in marketing. However, agricultural research, by and large, failed to recognize such contributions of women and most of the farm technologies emerging from conventional research have had orientation towards masculine gender. Of late, however, there has been growing realization of the gender issues. There are well evolved methodologies to study the role of gender issues in agriculture like 'gender-analysis', which can be made use of to identify technology/information needs of farm women and then developing appropriate gender-friendly technologies. Hence, the emerging context of agricultural research requires focusing considerable attention on ensuring gender equity in agriculture by suitable research efforts.

Issues related to research-extension-farmer linkages: Building effective linkage among the research (technology development) system, extension (technology transfer) system and client (technology user) system is a strategic issue in management of agricultural research. If investment in agricultural research has to be judged in terms of its outcome's impact on the society, there has to be a strong interface among the three major systems of agricultural development viz., research, extension and client systems. Further, the participatory approaches that have seen a lot of evolution over the past couple of decades aim at increasing the stakeholders demands on the research agenda of research systems. World wide a great deal of attention is being given to explore the intricacies involved in forging strong functional linkages among the various stakeholders of agricultural research so that research efforts lead to better technology adoption and thereby achieving goals of agricultural development. The recently experimented approaches like Institution Village Linkage Project (IVLP), SREP approach piloted in the NATP are fairly successful in addressing the issue of R-E-F linkage. However, given the diversity of conditions and contexts prevailing in our country linkage issue needs to be looked more as a micro level issue to foster context specific linkage mechanisms. Acknowledging and analyzing pluralism in agricultural extension systems, Samanta and Sontakki (2005) suggested measures like institutional revitalization, decentralization, fiscal, organization and management reforms, stakeholder analysis, corporate marketing strategies like segregation, targeting and positioning and corporatization of work culture to improve performance of extension in the plural context vis-à-vis its linkage with research and client systems.

Trade and intellectual property related issues: With our country being a signatory to the WTO and its agreements like Technical Barriers to Trade (TBT), Trade Related Intellectual Property Rights (TRIPS) and Agreement on Agriculture (AoA), guarding of our indigenous knowledge (IK) and management of intellectual property assume critical importance. Research is essentially an intellectual pursuit and research outcomes – new knowledge, process, products, etc. become intellectual property and need to be protected by appropriate means like licensing, copyrighting, patenting, etc. In the liberalized global trade scenario, agriculture has to be competitive from the point of both domestic and international markets and trade. This implies that a great deal of effort has to go into not only documenting and protecting our IK and quality management in food and fibre production. All these developments have thrown open a wide spectrum of areas for research endeavours to generate empirical data and models on various farming systems. While the government has initiated action by enacting Plant Variety Protection Bill in 2001, the scientific fraternity in farm sciences has to be proactive in not only better focusing of their research efforts but also in protecting the research outcomes. The first step in this direction would be to sensitize the National Agricultural Research System (NARS) scientists to various issues of WTO and their implications for research and technology transfer. NAARM has initiated efforts in this direction by conducting policy level deliberations as well as capacity building programmes. Rao and Sastry (2004) observed that in the past few years the need for specific policy guidelines for managing intellectual property is being increasingly felt in the public agricultural research systems in India and such a policy must be based on a framework comprising the institutional vision, mission and stakeholder interests and an assessment of the present global scenario with respect to the impacts of intellectual property rights on agricultural research and the overall social mission of public agricultural research systems. They proposed a set of guiding principles for managing IP in the premier public agricultural research system of India, the ICAR at three specific levels namely ICAR, institute and individual scientist. These guidelines are consistent with the declared vision and mission of ICAR and keep in view the interests of its different stakeholders.

Issues related to human resource management: Human resource management forms an integral component of systematic management of agricultural research. In its broadest sense, HRM means having right type of people to do right kind of jobs at right times so as to achieve the organizational goal and objectives. However, this has a low priority area in the whole spectrum of agricultural research management. But with new recruitments becoming sparse, there is going to be increased pressure on existing stock of human resource in agricultural research. It is being argued that in the next couple of years, NARS is going to be depleted of its scientific manpower by 30-40%. Measures like outsourcing, contractual services, manpower retention, etc. are going to be very critical in the years to come. As a measure of manpower retention, a strategic approach to capacity building of NARS scientists is essential. NAARM again initiated a modest beginning in this direction by developing guidelines for HRD in ICAR institutes.

Issues related to information technology: One of the most fascinating developments of this century is the information technology, which pervades all human endeavours. Agricultural research is no exception to absorb the benefits of IT revolution. The agricultural scientists of 21st century need to be IT-literates to make good use of various IT applications in reducing the space and time barriers in development and dissemination of agricultural technologies. IT applications like Geographic Information System (GIS), Remote Sensing (RS), Multimedia, Decision Support Systems, Modeling, Web, Internet, etc. hold immense potential in enhancing the research effectiveness and efficiency and therefore need to be well integrated in to the agricultural research management perspective of 21st century. NAARM has pioneered in capacity building of NARS scientists in this area and has identified IT applications in agriculture as a major priority area to focus research and training efforts in the years to come.

Organization and management reforms: The National Agricultural Technology Project (NATP) laid major emphasis on institutionalizing O&M reforms like Priority Setting, Monitoring and Evaluation (PME), human resource development for research management, information systems and management, etc. These measures need to be augmented by the Indian NARS institutions with other measures like project based budgeting, accountability enhancement and nurturing performance oriented work culture.

New Paradigm of Agricultural Research Management

In order to successfully address the above issues and challenges, ARM needs to be looked in to an altogether new perspective. This calls for a paradigm shift in both concept and practice of management of agricultural research. World wide, good

Table 1. Shifts in dimensions of agricultural research management – new paradigm

Dimensions of ARM	Existing Paradigm	New Paradigm
Focus	Commodity	Farming systems
Orientation	Disciplinary	Multi/Interdisciplinary
Approach	Business as usual	Professional
Goal	Food and nutritional security	Livelihood security including food, nutrition, employment to alleviate poverty, Sustainability and Environmental Safety
Philosophy	Good management in response to global changes	Good governance to anticipate change by institutional learning and change management
Emphasis	Information management	Knowledge management and sharing
Key processes	Research planning and management	Priority setting, monitoring and evaluation, Collaboration and Networking to achieve synergy among various actors, Project based budgeting
Actors	Mostly public institutions	Pluralistic with public, private and non-governmental institutions
Mode	Mostly on-station	Integration of client oriented on-farm participatory research
Critical areas	Improvement, production, protection and processing of crops and livestock products	Biotechnology, Bioinformatics, Decision support systems, Genomics, Social audit, Crop-livestock interactions, Value addition, Market intelligence, Client group processes, etc.
Critical inputs	Money and material	Human and information
Impetus	Supply driven	Demand driven
IP management	Less concern	Systematic and professional management of IP
Accountability	Mostly to donors	All the stakeholders
Work culture	Individualistic and mechanistic	Team and performance oriented

management is giving way to good governance, which emphasizes performance oriented work culture to achieve the organizational goals and objectives to meet the stakeholder expectations and thereby achieve greater accountability.

Earl *et.al.,* (2001) listed the substantive research challenges as i) addressing access, production and nutritional aspects of sustainable food security; ii) integrating natural resources, forestry and fisheries into sustainable food security research; iii) addressing resource poor agriculture in marginal areas - integrating new areas of science (e.g. biotechnology, communication and information technology); iv) addressing household food security in the context of livelihood and food systems strategies; v) adapting to changing population demographics - particularly rapid urbanization; vi) integrating local knowledge and transfer mechanisms; vii) integrating non-agricultural food security research issues; viii) addressing sustainable food security in light of trade liberalization, decentralization, diversification and property rights; and ix) incorporating nutritional considerations in food and agricultural research. They also listed research process challenges as implementing participatory, demand-driven and people-centered research approaches; integrating agricultural, ecological and social sciences into an interdisciplinary research paradigm; integrating gender, age, ethnicity, poverty and other dimensions of exclusion; enhancing linkages between research and policy-making related to sustainable food security; changing relationships between research, education and extension; identifying mechanisms for integration of various actors, institutions and their roles; developing private sector research partnerships; seeking mechanisms to improve human and financial resources for more effective research programmes; decentralizing research and bringing smaller research units closer to producers; research planning and priority setting; improving institutional capacity and management; and informing policy on research, agriculture and development.

Suresh Pal and Byerlee (2003) called for greater realization at the policy level of the need for reform in order to keep pace with global changes. They also recommended that the public research system itself requires an internal paradigm shift that links funding to performance of research providers, improves relevance of research through participatory approaches, and institutes a performance-based incentives and reward system.

Norton (2004) remarks that in recent years it has been accepted that traditional ways of carrying out agricultural research and extension are no longer satisfactory; that in spite of their apparently high returns, these systems can perform better under new approaches that lead to different institutional arrangements and that respond to a new operational philosophy. He indicated identification and implementation of the research agenda, management and institutional structures for agricultural research, financing of agricultural research, agricultural research and poverty alleviation and gender approaches in agricultural research as the new directions in management of agricultural research.

Based on diagnosis of the emerging issues in the context of changing global perspective, a new paradigm for conceptualizing and operating agricultural research is evolved. This new paradigm indicating shifts in its dimensions is diagrammatically represented in table 1. Since the suggested changes in the new paradigm of managing agricultural research are already discussed in some form or the other elsewhere in this paper, they are not elaborated further. Moreover, these are only a few indicative changes and are gradually evolving. Yet, it is important to realize that these changes are happening. Therefore, by regular debates and discussions these issues are likely to become practices in the suggested new paradigm.

Epilogue

In the context of the rapidly changing global scenario, agricultural research must emerge as a major policy instrument to address the growing challenges of hunger, malnutrition, unemployment and poverty. Indian NARS has successfully steered the nation in earlier crisis moments. However, the future is more complex and even more challenging. It is in this context that the Task Group constituted by the Planning Commission of India under the chairmanship of Dr. M. S. Swaminathan, in its report notes that "**Unfortunately, agricultural research institutions are yet to work in an integrated manner to achieve the triple goals of 'more food, more income and more jobs", all in an environmentally sustainable and socially equitable manner"**. It is, therefore, high time that our planners, managers and scientific fraternity of Indian NARS gears up itself to achieve the above 'triple goals'. As is rightly said, there is a need not to do different things but to do things differently. It is the change in our approach and thinking that will make us strong enough to successfully march ahead towards achieving higher glory and green in the coming years. A cognizance of the suggested paradigm shift might just be the right starting point in this direction.

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MEETING CHALLENGES OF FOOD SECURITY AND SOIL QUALITY

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India with a geographical area spreading over 329 million hectares is endowed with a complex diversity of climate, soils, flora and fauna offering both a blessing and a challenge for agricultural development. In the post-independence era, our agricultural production saw a radical boost mainly due to the 'green revolution' triggered by intensive use of high-yielding varieties of crops coupled with other inputs like chemical fertilizers and irrigation water. The country's foodgrain production witnessed a four-fold growth from 52 million tonnes in 1951-52 to the record 212 million tonnes achieved in 2001-02 (**Table 1**). It is a vivid demonstration of the nation's greatest achievement, because it has occurred against the onslaught of rising demographic pressure. This impressive growth in foodgrain production enabled India to have a sizeable buffer stock of about 60 Mt with some export potential. Against this reality, hunger still persists in many parts of the country. Today more than 200 million people are below the poverty line and suffer from the food insecurity as the economic access to food is a constraint with them.

Table 1. Growth of foodgrain production and human population in India

Year	Foodgrains Production (Mt)	Population (million)
1951-52	51.9	361
1961-62	82.7	439
1971-72	105.2	548
1981-82	133.3	683
1991-92	168.4	846
2001-02	212.0	1027

Source: FAI (2003)

Not withstanding the very heartening progress in agricultural growth, there is hardly any room for complacency because the unabated surge in population will continue to mount pressure on all natural resources, and the complex problems of food security and sustainability of resource base (particularly soil and water) will continue to be main cause of concern for agriculturists in the years to come. This complexity is understandable with the recognition of the fact that the additional stress on the resource base is inevitable as it would be required to enlarge its carrying capacity to meet the multiple demands of growing population. Achieving food security while maintaining soil quality/health will, therefore, be a formidable and continuing challenge before Indian agriculture in future. In this context, it is pertinent to quote Dr. Norman E. Borlaug (2000), who in his September 8 speech to the Nobel Institute in Norway marking the 30th anniversary of his 1970 Nobel Peace Prize said:

(i) "Despite the success in implementing Green Revolution technology to increase grain crop yields, the battle to ensure food security for millions of miserably poor people is far from won, especially in South Asia"

(ii) "Producing sufficient food in environmentally and economically sustainable ways is a daunting task. Equally or even more daunting is to distribute food equitably"

This paper begins by exploring concepts of food security and insecurity, and highlights some issues relating to food security scenario in India. It goes on to examine the threats to food security and opportunities to alleviate food insecurity. It also provides some insights into soil quality and its management as a key component strategy to ensure sustained high productivity and thus food security.

What is Food Security?

Concern with food security can be traced back to the world food crisis of 1972-74 - and beyond that at least to the Universal Declaration of Human Rights in 1948, which recognized the right to food as a core element of an adequate level of living. Food security as a concept emerged at the United Nations Food and Agriculture Organisation (FAO) World Food Conference in 1974. It is centred around two sub-concepts; food availability and food entitlement. The first, food availability refers to the supply of food available at local, national or international levels. The second, food entitlement refers to the capability of individuals and households to obtain food. It suggests that people do not usually starve because of an insufficient supply of food but because they have insufficient resources, including money ('entitlements'), to acquire it (Sen, 1981). Thus, food security in a single country, or in the world as a whole, reflects the ability of food-deficit countries, or food-deficit regions within countries, or food-deficit households within them, to meet target consumption levels on a year-to-year basis. The most widely used definition of food security is that of the World Bank: 'Access by all people at all times to enough food for an active, healthy life'. The term "access" here is inclusive of both the supply side (availability) and the demand side (entitlement).

What is Food Insecurity?

Food insecurity refers to a lack of access to enough food. There are two kinds of food insecurity: chronic and transitory. Transitory food insecurity is a temporary decline in a household's access to enough food. Chronic food insecurity is a continuously inadequate diet caused by the inability to acquire food. It affects households that persistently lack the ability either to buy enough food or to produce their own. Hence, poverty is considered the root cause of chronic food insecurity.

Famines are the worst form of transitory food insecurity. They can result from several causes: wars, floods, drought, crop failures, the loss of purchasing power by groups of households, market failures including sometimes high food prices and grain hoarding, and natural disasters such as earthquakes and Tsunami. All of these types of disruptions to food supplies can 'trigger' subsistence crises by threatening a population's access to food. They are the immediate causes of famine. The most vulnerable include: small-scale subsistence farmers, landless agricultural workers, other workers who are affected by a drop in real income in famine regions, pastoralists, children, and the elderly.

Measuring Food Security and Insecurity

There are a number of ways, and levels, at which food security and insecurity can be measured. These levels include: continental, regional, sub-regional and households levels.

- At the continental and sub-regional levels, food security can be measured by comparing regional nutritional requirements with availability of dietary calories per head. The ultimate goal is to meet the food requirements of the population at all levels. At the country level, the most widely used indicators are quantities of available food compared with needs, as well as import requirements compared with the country's capacity to import.
- At the household level, food security is measured by actual dietary intake of all household members using household income and expenditure surveys. It is important that changes in socioeconomic and demographic variables be monitored continuously over time.

Food Security Situation in India

Famines in India are "a nightmare of the past". The green revolution witnessed in late 1960s has contributed immensely over the years to cereal production in India and hence a substantial increase in the net per capita availability of foodgrains was registered (**Table 2**). This has led to a nationwide sense of complacency that, in a way, slowed down the growth rate in agricultural production during 1990s, while the population continued to grow at high rate. **The net result was a decline in the per capita foodgrain availability in the terminal decade of 20th Century**. Even with present level of production, there is enough food in the country to meet energy and protein requirements of the current population, if the food were distributed equitably according to needs. But as we see, surplus production and widespread hunger coexist at the national level. At present, India alone accounts for one fourth of all world hunger. It is particularly ironic that there are 200 million food-insecure people in a country that currently has buffer stocks of foodgrains in excess of 60 million metric tonnes.

Table 2. Per capita net availability of foodgrains in India (g day^{-1})

Year	Cereals	Pulses	Total food grains
1951	334.2	60.7	394.9
1961	399.7	69.0	468.7
1971	417.6	51.2	468.8
1981	417.3	37.5	454.8
1991	468.5	41.6	510.1
2001	385.1	29.1	414.1

Source: FAI (2003)

Inadequate or lack of purchasing power among the poor is the main cause for food insecurity in rural India. As reported by Rajendra Prasad (2003), the per capita consumption of most food items in rural India is far below the recommended dietary allowances (**Table 3**). Though the per capita intake of cereals in all regions, and sugar and milk in North and Western regions is closer to or above the standard requirements, the consumption of all other food items throughout the country is woefully lower than their respective dietary requirements as per the ICMR (Indian Council of Medical Research) norms. A general low intake of pulses, vegetables, fruits, fats and oils, eggs, meat and fish is responsible for widespread occurrence of protein energy malnutrition (PEM) and chronic energy deficiency (CED). It was reported that 23 to 70% of rural population in different parts of the country was suffering from protein energy malnutrition, while the chronic energy deficiency affected 17 to 54 per cent of people (**Table 4**). Prevalence of poverty, and low and fluctuating income levels also limit the access to diversified diet and thus adversely affect balanced diet. The vegetable products account for a lion share in the intake of all dietary constituents. A comparison of share of vegetable products and animal products in meeting total dietary energy, protein and fat in India, USA and the World as a whole makes this point clear (**Table 5**). In India, vegetable products provide 93% dietary energy, 84% protein and 73% fat, while the products of animal origin supply remaining small proportions i.e. 7%, 16% and 27% of energy, protein and Fat, respectively. Thus the share of animal products in dietary supply is lower in India as compared to the world average. On the contrary, in a developed country like USA, the animal products account for 30%, 64% and 51% share in meeting dietary energy, protein and fat supply, respectively. Child malnutrition rates in India are still very high. According to the UNDP, 53 percent of children under five in India were under-weight during the period 1990-97, the highest rate of any of the 174 developing countries listed.

Table 3. Per capita food consumption in rural India (g day^{-1})

Region	Food items									
	Cereals	Sugar	Pulses	Vege-tables	Fruits	F&Oils	Milk	Eggs	Meat	Fish
Northern	424.9	39.7	29.8	62.4	20.7	14.6	308.3	1.0	2.7	0.3
Eastern-Central	483.8	13.4	20.5	57.8	18.5	9.6	52.0	2.8	3.1	9.6
Western	416.0	32.3	21.5	61.2	17.7	13.5	179.8	1.2	2.5	1.5
Southern	402.1	18.9	21.7	57.9	33.3	9.4	76.9	5.6	6.3	14.8
ICMR Norm	**420**	**30**	**40**	**125**	**50**	**22**	**150**	**45**	**25**	**25**

Source: Adapted from Rajedra Prasad (2003)

Table 4. Extent of PEM and CED in rural IndiaThreats to Future Food Security in India

Region	% of population with	
	PEM	CED
Northern	34.9 – 36.9	23.0 – 44.0
Eastern and Central	23.5 – 58.2	17.1 – 57.3
Western	30.2 – 39.8	36.2 – 53.1
South	31.4 – 70.3	33.2 – 53.8

PEM = Protein energy malnutrition; CED = Chronic energy deficiency
Source: Adapted from Rajedra Prasad (2003)

Table 5. Average share (%) of vegetable and animal products in meeting total dietary energy, protein and fat supply in India, USA and the World (1990-92)

Country	Dietary energy		Protein		Fat	
	VP	AP	VP	AP	VP	AP
India	93	7	84	16	73	27
USA	70	30	36	64	49	51
World	84	16	64	36	53	47

Note: VP = Vegetable Products; AP = Animal Products.
Source: Calculated from FAO (1996) Sixth World Food Survey, Food and Agriculture Organization, Rome.

Growing population: In India, unabated growth in population has been and will continue to be the single most factor with the potential to negate all the progress made in agricultural production. India's population grew at an annual growth rate of around 2% in 1970s, 80s and 90s to reach 1027 million in 2001 and is estimated to increase further to 1262 and 1542 million by the year 2011 and 2021, respectively (Sekhon, 1997). Growing population means mounting more pressure on natural resources to meet increased food demand. According to a conservative estimate (Kumar 1998), the foodgrain demand in India for the years 2010 and 2020 is projected to be 246 and 294Mt, respectively (**Table 6**). This means that our foodgrain production has to increase from 212 Mt (highest production ever achieved in 2001-02) to 246 Mt in 2010 and then to 294 Mt in 2020. It is by all means a daunting task and our ability to accomplish this task determines the future food security in the country.

Table 6 . The current production and future demands of foodgrains in India

Food item	Current (2001-02) production (Mt)	Estimated demand (M t) 2010	2020
Rice	93.1	103.6	122.1
Wheat	71.8	85.8	102.8
Total cereals	198.8	224.4	265.8
Pulses	13.2	21.4	27.8
Total foodgrains	212.0	245.8	293.6

Source: FAI (2003) and Kumar (1998)

Declining land to man ratio and size of farm holdings: With continued rise in population, the arable land to man ratio has decreased from 0.5 ha (1951) to 0.14 ha at present and is expected to decline further to 0.08 ha by 2020 AD. The average number of land holdings has also increased simultaneously from 77 million (1976-77) to over 115 million at present due to population growth and law of inheritance of land property. The average size of operational farm holding is only 1.57 ha. Further, about 78% of the 115 million farm holders in the country come under small and marginal category with the size of farm being less than 2 ha. The small size and scattered nature of the holdings will adversely affect the farm efficiency and result in high cost of production, low productivity and thus, reduced agricultural sustainability and food security.

Soil degradation: It has been estimated that of the total 328.73 M ha geographical area, nearly 188 M ha of land in the country is potentially exposed to various degradation forces (Sehgal and Abrol, 1994) **(Table 7).** The land area subjected to degradation by way of soil displacement through erosion by water and wind is estimated at 148.9 and 13.5 M ha, respectively (nearly half the total area). About 13.8 M ha is under chemical deterioration due to loss of nutrients and organic matter, salinization and sodification. Water logging also represents a serious soil physical deterioration and has rendered 11.6 M ha of land degraded. Problem of developing saline and alkali soils is a common feature of canal-irrigated areas with poorly developed drainage facility. In this situation, indiscriminate use of water results in upward movement of soluble salts from lower layers to upper cultivable layer. In addition to these, indiscriminate use of pesticides and heavy metal containing urban wastes is also gradually polluting our soil resources in various parts of the country. Widespread deterioration of soil resource quality/health is a serious threat to agricultural production and food security.

Table 7. Extent of soil degradation in India

Degradation type	Area (M ha)	% of total area
A. Water erosion	148.9	45.3
B. Wind erosion	13.5	4.1
C. Chemical deterioration (loss of nutrients & Salinization)	13.8	4.2
D. Physical deterioration (water-logging)	11.6	3.5
Total	**187.7**	**57.1**

Source: Sehgal and Abrol, 1994

Decreasing total factor productivity : The total factor productivity (TFP) is used as an important measure to evaluate the performance of a production system and sustainability of its growth pattern. As stated earlier, adoption of green revolution technology comprising three critical inputs *Viz*., HYVs of crops, chemical fertilizers and irrigation water led to a phenomenal growth in agricultural production during 1970s and 1980s. But, of late there are signs of fatigue in agricultural growth process. In spite of continued growth in the above inputs, there has been no matching growth in agricultural production during 1990s, indicating a decrease in TFP. The declining trends of annual growth rate of productivity in respect of all major crops (**Table 8**) are also suggestive of decreasing TFP in Indian agriculture. In fact, all the crops except wheat registered a negative annual growth rate in their productivity during the recent past (2000-01 to 2002-03). If this alarming trend is allowed to continue and no corrective measures taken urgently, it will spell doom for the country's future food security prospects.

Table 8. Productivity growth rate of important crops in India

Crop	Annual growth rate in productivity (%)		
	1980-81 to 1989-90	1990-91 to 1999-2000	2000-01 to 2002-03
Rice	3.19	1.27	- 0.72
Wheat	3.10	2.11	0.73
Pulses	1.61	0.96	- 1.84
Total foodgrains	2.74	1.52	- 0.69
Oilseeds	2.43	1.25	- 3.83
Non-foodgrains	2.31	1.04	- 1.02
All principal crops	2.56	1.31	- 0.87

Source: Chhonkar and Dwivedi (2004)

Approaches to Sustainable Food Security

Food security of a nation depends on self-production of food grains in sufficient quantities and ability to distribute grains on a large scale, commensurate with population size. An efficient food security system should withstand challenges posed by calamitous weather and other natural disasters unfavourable for agricultural production over successive seasons. Effective food security system requires food grains production at a somewhat higher level than that which meets the immediate needs, safe storage of extra food grains to overcome any seasonal or prolonged deficiencies in production levels. Besides adequate food availability at national level, ensuring the access to balanced diet at household is of paramount importance in elimination of malnutrition and ensuring nutritional security in the country. Since poor people lack access to alternative sources of livelihood, there is tendency for them to exert more pressure on the little resources that are available to them. The intensified pressure on natural resources is a vicious cycle in which resource degradation lead to reduced household assets and reduced household assets in turn affect resource degradation. Thus, considering the present situation marked by deteriorating natural resources, decreasing factor productivity and stagnant technologies, rising population densities, low public investments and inadequate policy initiatives, India needs to address the following key issues in order to meet the challenges of future food security.

1. Increasing agricultural production
2. Agricultural diversification
3. Policy initiatives for nutrition security
4. Management of soil quality

Increasing agricultural production through productivity enhancement and bridging yield gaps

The massive gains in India's foodgrain production during the post-green revolution period were because of intensive agriculture driven primarily by the productivity improvement oriented HYV-fertilizer-irrigation technology. This is clear from the fact that the area under foodgrains (around 120 M ha) and net cultivated area (around 140 M ha) remained more or less unchanged during 1980s and 90s. The productivity enhancement technologies have had a very positive impact on land use in terms of sparing of land requirement for increased foodgrain production. Had the Indian grain productivity levels of 1950 still prevailed in 2001 we would have needed nearly 180 million ha of additional land of the same quality, instead of 120 mIlion ha that was used, to equal the foodgrain production of 212 M t achieved in 2001-02 (**Figure 1**). Obviously, such a surplus of land was not available. Since there are no future opportunities to bring in additional area under plough, the future increases in agricultural production to meet the projected demands must come from the area already under cultivation i.e. by way of productivity enhancement and bridging yield gaps.

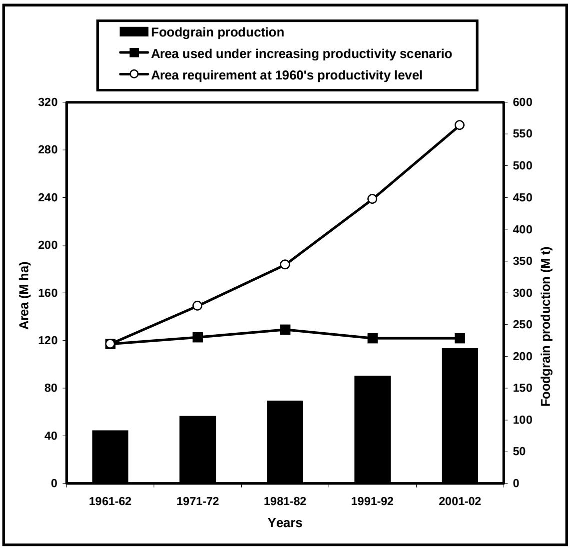


Figure 1. Area spared under foodgrain crops by the use of productivity enhancing HYV-Fertilizer-Irrigation technolgy in India

The average yield levels of paddy and wheat (the most important crops that triggered green revolution) are still woefully low as compared to the average yield in many other developed and developing countries (**Table 9**). The vast difference in yield levels of paddy and wheat between India and other countries suggests that there is room for future productivity improvement. In fact, in India there exists a wide gap between potential yields and the yields that are actually obtained in respect of several crops, bridging of which again offers real opportunities for future growth in grain production For example, Aggarwal et al. (2000) have analyzed potential yields of rice, wheat, and rice-wheat systems in various districts/states of the Indo-Gangetic Plain using validated crop growth simulation models, spatial weather data, land- use patterns, agronomic-management details, and GIS. The simulated potential grain yield in rice-wheat system varied between 13.4 and 18.3 t ha^{-1} (**Table 10**), higher in the northern compared to the eastern region of IGP. Temperature and solar radiation during crop season had high impact, suggesting the need for matching the genetic potential, phenology, and ecological features. Such models can be used to calculate yield gaps in different regions, and to identify pathways for bridging those gaps. Breaking the yield barriers, and development and large-scale adoption of integrated crop and soil management package should receive greater attention in future in order to meet the foodgrain production targets in India.

Table 9: A comparison of average productivity of paddy and wheat in selected countries of the World (2001)

Paddy		Wheat	
Country	**Yield level ($t\ ha^{-1}$)**	**Country**	**Yield level ($t\ ha^{-1}$)**
Egypt	8.77	UK	7.08
USA	7.21	France	6.63
Japan	6.66	Egypt	6.34
China	6.36	China	3.83
Indonesia	4.25	Italy	2.82
Vietnam	4.26	USA	2.71
World Average	3.91	World Average	2.73
India	**2.96**	**India**	**2.74**

Source: FAI (2003)

Table 10: Yield potential of rice-wheat systems in the Indo-Gangetic plains

State	Average potential yield, $t\ ha^{-1}$		
	Rice-wheat	**Rice**	**Wheat**
Punjab	18.29	10.60	7.69
Haryana	17.87	10.53	7.34
UP	17.48	10.34	7.14
Bihar	16.43	9.73	6.70
W.Bengal	13.37	8.07	5.30
I-G Plains	**16.70**	**9.88**	**6.82**

Note: Current (2001-02) national average yields of rice and wheat are **2.09 and 2.74 $t\ ha^{-1}$**, respectively *Source: Aggarwal et al. (2000)*

Agricultural diversification

The issue of food security is closely linked with poverty and purchasing power of the people. Agricultural diversification as an instrument of poverty alleviation is an important approach to ensure food security. Agricultural diversification can be attempted at both crops and enterprise levels i.e. Crop diversification and enterprise diversification. Crop diversification involves inclusion of leguminous pulse and oilseed crops and trees to evolve more remunerative and resource conserving cropping systems. On the other hand the enterprise diversification refers to having a variety of interrelated on- and off-farm enterprises (across crops, livestock, aquaculture, horticulture, agro-forestry, mushrooms cultivation, food processing and value addition) best suited to the specific resource base, socio-economic setup and market opportunities. In general terms, the goal of agricultural diversification is to increase and stabilize farm production and farm income. Having diverse enterprises creates opportunities for recycling, so that pollution is minimized because a waste in one enterprise becomes an input for another. The risk minimization, employment generation and sustained/ increased household income are the benefits associated with multienterprise farming systems. At global level the agricultural diversification is generally considered as an important strategy because of the following reasons:

- Responsive to market changes and to socio-economic and agro-ecological settings;
- Increases employment/income-generation opportunities and judicious use of land, water, labour, biodiversity and other resources;
- Reduction of the incidence and damage caused by pests and diseases and risk diffusion leading to higher and more stable production and income; and
- Promotes resource conservation through the adoption of integrated farming systems, (incorporating integrated pest management and integrated plant nutrient management), thereby exploiting synergism and lessening the requirements for increasingly-scarce water, land, and other resources.

Agricultural diversification holds special significance for Indian agriculture because of prevalence (78%) of small and marginal farms (i.e. size of land holding being <2 ha/farm). The very size of small farms, coupled with a growing problem of land fragmentation, presents considerable problems for their development. Low crop and animal productivity, inefficient use and often deterioration of resource base, cost/price squeeze, high risk and, low and uncertain farm income leading to perpetual poverty, and under- and malnutrition are some of the idiosyncratic consequences of small farms. In such situation, diversified farming has been shown to be a boon to small and marginal farmers. As highlighted by Sharma et al., (2002), diversification in Indian context offers several opportunities to: increase farm income, withstand price fluctuations, ensure constant flow of in come, generate year round employment, mitigate adverse impact of aberrant weather, effective recycling of farm wastes, diversify food basket, alleviate hunger and malnutrition, and meet future food demand.

To realize the fore-listed possibilities, appropriate and situation specific farm diversification models shall need to be developed and diffused. Efforts are underway in different locations to develop farm diversification models involving judicious enterprise mix that may provide attractive income besides meeting household demands from a given piece of farmland. One such model put-forth by Behera and Mahapatra (1999) suggests an optimum integration of farm enterprises for a small land holding of 1.25 ha for Bhubaneshwar conditions (**Table 11**). In this particular model land was allocated for different enterprises in proportion to their significance in household needs and demand in local market. It was shown that with the adoption of this diversification model a net income of Rs. 58,360/- per year was accrued from 1.25 ha farm land. This kind of models are worth emulating in parts of the country as well in our search for comprehensive food and nutritional security.

Table 11: A farm enterprise diversification model for 1.25 ha farmland at Bhubaneshwar and its economics.

Components	Employment generation (man days)	Total expenditure (Rs.)	Net return (Rs.)	Return/Rupee invested (Rs.)
Field crops	98.2	3315	5638	2.70
Multistoried cropping	87.0	3831	9089	3.37
Pomology	18.4	900	1466	2.63
Olericulture	96.4	3812	8302	3.18
Floriculture	4.0	125	100	1.80
Pisciculture	31.0	3722	16603	5.46
Poultry	23.0	9240	981	1.10
Duckery	23.0	5387	713	1.13
Mushroom cultivation	180.0	18184	12856	1.70
Apiary	1.0	170	1180	7.94
Biogas	11.0	600	1431	3.38
Total	573.0	49,286	58,360	2.18

Source: Behera and Mahapatra (1999)

Policy initiatives for nutrition security

Over the years in past, the government policy was primarily focused to attain self-sufficiency in foodgrain production as seen in terms of the per capita availability of foodgrains at national level. However, with the recognition of the importance of nutrition security in the broader context of food security, the Tenth Plan calls for a paradigm shift in planning and implementation from the concept of macro-level food security at the National level (i.e., the per capita availability of food) to nutrition security at the level of each individual household (more particularly individual child, woman and man). As envisioned by M.S. Swaminathan, the nutrition security encompasses "physical, economic, social and environmental access to balanced diet and clean drinking water". The major cause of food insecurity in our country is the lack of the minimum purchasing power essential for economic access to balanced diet. Swaminathan (2005) has suggested a 7-point Action Plan for accelerated advance in achieving the goal of nutrition security at the level of every child, woman and man. The components of the 7-point Action Plan are as follows:

a. Restructure the delivery of nutrition support programmes on a life cycle basis, starting with pregnant women and extending upto old and infirm persons; fill the gaps in the ongoing support programmes, particularly with reference to adolescent girls, pregnant and nursing women and infants in the 0-2 age group. Also, extend nutrition support to persons affected by HIV/ AIDS, Tuberculosis, etc. since a drug based approach alone will not be effective in the case of the poor.

b. Introduce a well planned programme for elimination of hidden hunger caused by the deficiencies of micronutrients in the diet, like Iron, Zinc, Iodine and Vitamin - A.

c. Promote in areas characterized by chronic under- and malnutrition, the establishment of Community Food Banks by local self-help groups, for the purpose of enlarging the food basket with locally grown grains like ragi, various millets, pulses and tubers.

d. Ensure the availability of clean drinking water, environmental hygiene, primary health care and primary education.

e. Undertake a nutrition literacy programme and provide every household an "Entitlements Card", indicating their entitlements to nutrition safetynet programmes.

f. Enlarge and engender the on-going "Food for Work" and Employment Guarantee Programmes by including in the case of women, activities like provision of day care services for children, operating the school meal programmes and undertaking immunization programmes, within the scope of "work".

g. Enhance the productivity of smallholdings, as well as dairy and livestock enterprises. A "Livestock Food Corporation" may be established to stimulate and support the growth of SHGs (Self Help Groups) devoted to the production of fodder and feed and for establishing Fodder and Feed Banks.

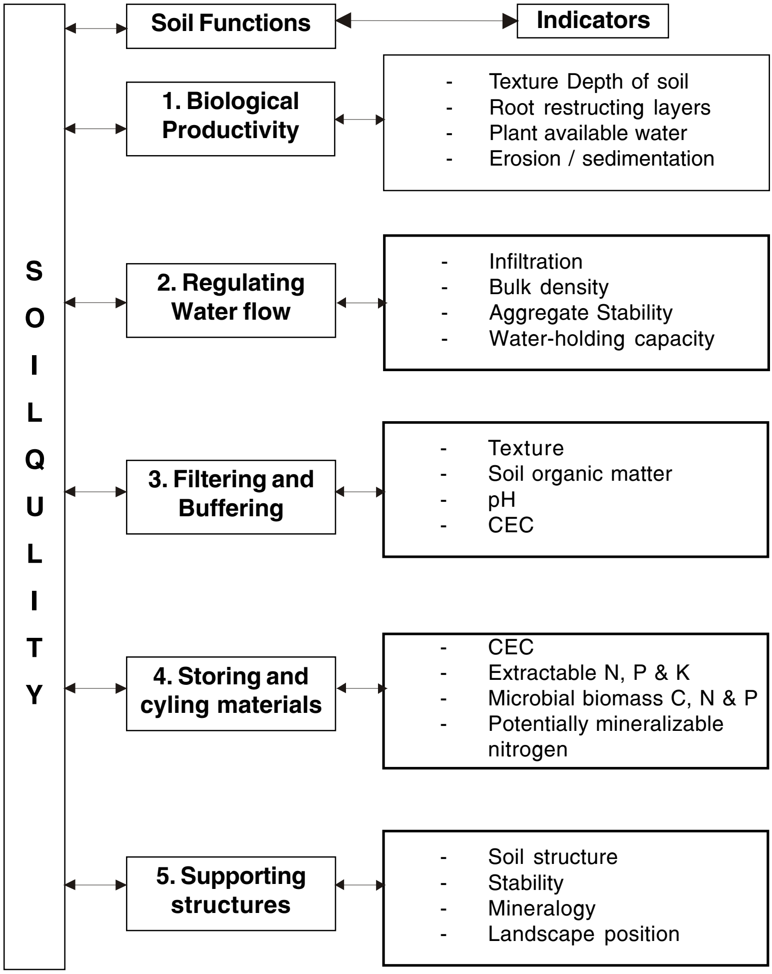
Ultimately, success in achieving a sustainable end to hunger will depend upon our ability to generate skilled off-farm livelihood/ job opportunities for rural women and men who have no assets like land or livestock or fish pond. A paradigm shift for unskilled to skilled work is essential to add economic value to the time and labour of assetless.

Management of soil quality (health)

Soil being the 'Soul Of Infinite Life', the continued maintenance of good soil quality is critical for agricultural production and food security in a predominantly agrarian country like India. Soil quality integrates the biological, chemical, and physical components and processes of the soil interconnected with its surroundings in the landscape. Soil quality is the capacity of soil to perform a range of productive, environmental and habitat functions, and is defined in various ways depending upon the objectives of its specific use. Doran and Parkin (1994) defined soil quality as "capacity of soil to function within ecosystem boundaries to sustain biological productivity, maintain environment quality, and promote plant and animal health". The quality of soil encompasses two distinct but interconnected parts:

- ♣ **Inherent quality**: It results from innate properties (qualities) of soils; as determined by the factors of soil formation—climate, topography, biota, parent material, and time. The inherent quality of soils is often used to compare the abilities of one soil against another, and to evaluate the worth or suitability of soils for specific uses.
- ♣ **Dynamic quality**: It results from the changing nature (health or condition) of soil properties that are influenced by human use and management decisions. Collectively, these effects of management will either result in a net positive or negative impact on the health of the soil. This dynamic aspect of soil quality is the focal point of the concern for assessing and maintaining healthy soil resources.

For the purpose of assessment and management of soil quality, it is necessary to identify soil quality indicators as surrogates of the soil functions (Doran and Parkin, 1994). Several minimum data sets of indicators have been proposed by the researchers. An example minimum data set is presented in Figure 2 along with an illustration of how indicators are related to soil function. In most cases one or two indicators can sufficiently represent each function, however, indicators may be related to more than one soil function



(Figure 2).

Figure 2. Illustration of the conceptual linkages between soil functions and soil quality indicators. (Modified from Karlen et al. (2001)

We have no national inventories of these dynamic properties and their threshold (critical) values for important soil types for assessment of soil quality. Concerted research attention is, therefore, required in direction and should specifically focus on:

- Inventory the soil resources and characterize them for behaviour prediction under various land uses and management regimens.
- Develop indicators of soil quality that can be used to determine present soil health, assess degree of soil deterioration, and predict threshold soil condition (a boundary between healthy soil and degraded/problem soil). The soil quality indicators must be in the form of measurable soil parameters because of the truism that "what gets measured can get managed".
- Since SOM is basic to optimum physical, chemical and biological functioning of soils, the ways and means of its build-up and maintenance in soils need to be explored.
- Assess the vast reservoir of existing protective and productive technologies that are available but unused, and refine them into an appropriate location specific best-bet and least-cost TECHNOLOGY MIX for improvement of soil quality.
- Long-term efforts to develop and use the soil management systems that cooperate more and interfere less with the natural functioning of soils.

Soil quality maintenance

From the agricultural productivity enhancement point of view, soil quality management requires identification and understanding of soil related production constraints and evolving suitable remedial measures to overcome them as summarized in Table 12.

Table 12. Major soil-related problems, causes, impact and suggested remedial measures

Problem	Causes	Impact	Suggested remedial measures
Soil erosion	Upland cultivation on sloppy lands, light soils, removal of vegetation during rainy and windy seasons, deforestation	Soil and nutrient loss, siltation of reservoirs and river courses	Watershed approach, afforestation, policy measures to arrest soil erosion, making water Development Boards functional
Soil salinization	Arid and semi-arid areas, coastal zones, areas of limited water availability, water with high salt content	Decreased productivity	Judicious irrigation, gypsum application, proper cropping practices
Soil acidification	Torrential rains, deforestation. Improper fertilisation	Decreased productivity	Liming, afforestation, balanced fertilisation, proper cropping practices
Decline in grassland productivity	Overgrazing desertification, urbanisation	Nutrient imbalances, low productivity of animal based systems	Arrest of over-grazing beyond carrying capacity, policy measures to restraining desertification and urbanization
Gaseous emissions from soils	Emission of gases such as methane, nitrous oxide, oxides of sulphur from agro-ecosystems due to human interference	Climate changes and threat to ecological safety	Appropriate tillage, irrigation, manurial and fertilisation practices

Agro-chemicals pollution	Indiscriminate and excessive use of pesticides and fertilisers and use of unsafe pesticides	Pollution of soils, air, ground water, river water resulting in health hazards	INM, IPM, Integrated weed management including use of biofertilisers, organic manures, vermicompost, biofertilisers etc., agrochemical registrations and restrictions on use
Deterioration of soil fertility	Improper soil health care	Nutrient deficiencies in crops leading to yield losses and endemic malnutrition in humans and animals	Proper soil health care including monitoring changes in soil properties, IPM, Organic farming, proper crop mix and crop rotations

Source : Subba Rao (1999)

Building Soil Organic Matter – a key soil quality determinant : The soil organic matter is the key component that regulates the available nutrient status and reflects the overall state of soil fertility and health. This dependence stems from the fact that: (i) organic matter is a basic resource of several elements essential for plant growth, and (ii) it buffers the effect of pH dependent changes in nutrient availability. Normally, 95% of the N and S is tied-up in soil organic matter. The proportion of P that resides in soil organic matter varies between 20 and 80% in different soils. Thus, a fall in organic matter level multiplies nutrient deficiencies, and adversely affects the soil health and production sustainability.

Indian soils, in general, are poor in organic matter status (i.e. OC is less than 0.5% in most soils). This may be ascribed to one or more of the following: 1. Continued cropping with inadequate and imbalanced use of inputs of organic and inorganic sources of nutrients, 2.Complete removal from fields of above ground portion of crops for various reasons, 3.Erosion induced loss of topsoil rich in organic matter and 4.Natural loss of soil organic matter through degradation/ decomposition mediated by soil microbes and high temperatures particularly in arid and semi-arid regions.

Building organic matter status of soils and maintaining it at or near maximum possible levels dictated by the prevailing climatic condition of the region. In this context, it is important to look for low cost means of building soil organic matter. Katyal and Reddy (1997) suggested the following strategies to generate organic matter in non-competitive ways:

- In-situ production and incorporation into soil of short duration legume crop without interfering with cultivation of the main crop. Long-term analysis of rainfall patterns indicates positive availability of 20-25% of the total rainfall during the pre- or post-monsoon periods. This off-season rainfall, which otherwise goes waste, can be gainfully utilized for resurrecting a fast-growing high biomass producing, drought-tolerant legume. The biomass can be incorporated in the soil either at flowering or after harvesting of grain. A classic example of this is from CRIDA, Hyderabad, where the successful production of horse gram with off-season rains was demonstrated. This practice was reported to add about 1.0-1.5 t dry biomass ha^{-1} (with N equivalence ranging between 20 and 30 kg ha^{-1}) into soil.
- Another approach for generating organic matter could be to raise fast-growing leguminous trees or shrubs on wasteland part of a holding or in the form of rows in an alley cropping system. In alley cropping, the height of the tree should be regularly pruned to about 30 cm from the ground to avoid shading of the arable crops.
- A third strategy to generate organic matter in a non-competitive way is to plant fast-growing N-fixing trees or bushes on either side of bunds. In India, because of dominance (>75%) of small and marginal holdings (<2 ha), boundary bunds occupy between 5 and 10% of the area. Bunded area which otherwise remains unutilized can be covered with green leaf generating species. For example, Gliricidia, a drought-tolerant non-browsable legume can be planted on either side of the bunds to generate additional green leaf material for incorporation into soil.

Soil Fertility and Fertilizer Use: Soils of India are generally poor in fertility as these are low in organic matter and have consistently been depleted of their finite nutrient reserves due to soil degradation (losses of nutrients by soil erosion and runoff) and continuous cultivation for many centuries. Production under intensive cropping system has resulted in large-scale removal of nutrients from the soil resulting in a negative balance of these nutrients. Although India with an annual fertilizer consumption of 17.4 Mt (2001-02) ranks third among the countries, the per hectare nutrient ($N+P_2O_5+K_2O$) consumption continues to be very low at 91 kg ha^{-1}. This becomes clear when we compare the per hectare nutrient ($N+P_2O_5+K_2O$) consumption of India (91 kg ha^{-1}) with that of even other Asian countries such as Japan (282), China (225), Korea Rep. (379), Bangladesh (160) and Pakistan (132). Estimates suggest that at national level there exists a net nutrient gap of about 8-10 M tonnes annually between nutrient removal by crops and additions through fertilizers. This wide gap in nutrient additions and removals can be minimized to some extent through i) tapping nutrients from hitherto underutilized organic and inorganic nutrient resources and ii) increasing use efficiency of applied fertilizers.

Balanced Fertilizer Use

The underlying philosophy of balanced fertilization envisages the application of plant nutrients in adequate amounts to match their removals by crops and in appropriate proportion to reap the benefits from positive interactions among nutrients and with other production factors. The need for considering balanced fertilization in soil fertility management for sustainability in agriculture is borne out by the results of several long-term fertilizer experiments carried out in India and elsewhere. The long-term fertilizer experiments being conducted at different locations of the country have clearly demonstrated the following (Swarup *et al.,* 1998):

- A declining trend in productivity even with application of NPK fertilizers due to emergence of deficiencies of secondary and micronutrients and depletion of soil organic matter stocks.
- Accentuation of decline in yield, often the yield levels falling below the control plots, with continuous N-alone application in red, lateritic, foot-hill and mountainous soils characterized by low to medium status of other nutrients. Accelerated appearances of P, S and Zn deficiencies associated with more fertilizer-N induced dry matter production are the prime reasons for such a malady.
- Deterioration in factor productivity of the cropping systems is associated with the emerging deficiencies of S, Zn etc.

- Decline in soil organic matter (SOM) associated with continuous application of nitrogenous fertilizers is arrested with balanced application of NPK in association with annual application of 10-15 t FYM/ha/annum, with effects being more pronounced on laterite and black cotton soils.

The continued efforts to increase food production through intensification would inadvertently result in heavy removal of not only major nutrients (N, P and K) but also secondary (S, Ca and Mg) and micronutrients (Zn, Fe, Mn, Cu, B, Mo etc.). This creates imbalance in plant nutrient supply owing to the emergence of micro and secondary nutrient deficiencies. It has been demonstrated in the past that application of micro-nutrients together with NPK could make substantial contribution in increasing crop yields (Table 13). Effectiveness of any balanced fertilization can be judged from the extent to which it is able to harness the benefits that accrue from positive interactions between nutrients and other production inputs. Some examples on benefits of positive interactions between nutrients and other inputs are presented in Table 14. The appropriate combination of nutrients for balanced fertilization will depend on the nature of soil and its nutrient status, and cropping systems followed in a given location. Some component nutrients of balanced fertilizer strategy suitable for different situations are illustrated in Table 15.

Table 13. Average yield increases due to micro-nutrient application over optimum NPK levels

Crop	Increase in crop yield (kg ha^{-1}) due to					
	Zn	Fe	Mn	Cu	B	Mo
Wheat	380	780	560	380	520	440
Rice	510	1880	360	340	340	-

Source: Takkar and Nayyar (1984)

Table 14 . Contribution of positive interactions between the inputs to the total increase in crop yields

Interacting inputs	Crop	Response attributed to interaction (% of total response)
N x P	Wheat	30
N x P	Sorghum	50
N x K	Pineapple	46
N x K	Rice	38
N x Water	Rice	34
P x Plant stand	Pigeonpea	26
K x Boron	Blackgram	41

Source: Tandon and Narayan (1990)

Table 15. Components of balanced fertilization under different situations

Situation	Component of balanced fertilization (nutrients whose application needed)
Newly reclaimed alkali soils	N & Zn
Many areas in alluvial soils; wheat belt	N ,P, K, Zn, & S **or** N, P, Zn, & S **or** N, P & Zn **or** N, P,K & Zn
Many areas under oilseeds	N, P, K, & S **or** N, P, & S **or** N, P,Zn & S **or** N, P, S & B
Legumes in acid soils	N, P, K, Ca &Mo
High yielding tea plantation	N, P, K, Mg, S & Zn

Source: Tandon and Narayan (1990)

Organic Inputs in Soil Fertility Management

The organic inputs to soil (animal manure and composts, crop residues, green manures, urban wastes etc.) are known to have favourable effects on soil physical, chemical and biological processes and its overall health. Organic materials generally improve the soil organic matter (SOM), a basic indicator of soil health and resilience, in addition to supply of substantial quantities of plant nutrients to enrich soil fertility. Though abundant quantities of organics are generated annually, the entire quantity is not available for returning to soils because of several competing alternate uses in rural India. Animal dung is either not properly collected or frequently used as fire cakes in rural hearths. Crop residues are either used as cattle feed, domestic fuel, thatching material or burnt on the field itself. Situation with respect to urban waste (night-soil, municipal waste, sewage-sludge etc) utilization is also no better. Recognizing that the use of organic resources for non-agricultural purposes is unavoidable and that only 80% of human excreta, 30% of livestock dung and 33% of crop residues are trappable for returning to soil, Tandon (1997) estimated organic resources availability to be 246 and 307 Mt in 2010 and 2025 AD, respectively (Table 16). If used properly, these quantities of organic resources can supply plant nutrients ($N+P_2O_5+K_2O$) to the tune of 6.24 and 7.75 million tonnes in 2010 and 2025 AD, respectively and certainly help minimize the negative nutrient balances.

Table 16. Some projections on the tappable* organic resources and their nutrient supply ($N+P_2O_5+K_2O$) for agriculture in India during 2010 and 2025AD.

Resource	2010 AD Tappable quantity (m t)	2010 AD Nutrient Supply (m t)	2025 AD Tappable quantity (m t)	2025 AD Nutrient Supply (m t)
Human excreta	15	1.80	17	2.10
Livestock dung	119	2.10	128	2.26
Crop residues	112	2.34	162	3.39
Total	246	6.24	307	**7.75**

* Tappable = 80% of excreta, 30% of dung and 33% of crop residues.

Source: Tandon (1997)

Integrated Plant Nutrient Supply (IPNS) System

Integrated plant nutrient supply refers to the maintenance or adjustment of soil fertility and of plant nutrient supply at an optimum level for sustaining the desired productivity through optimization of the benefits from all possible sources of plant nutrients in an integrated manner (Roy, 1995). Conceptually, the IPNS as depicted in Fig. 3 strives to achieve: (a) regulated nutrients supply for optimum crop growth and productivity, (b) maintenance or some times an improvement in soil fertility, and (c) minimum adverse impact on agro-ecosystem quality by means of striking a balance among various nutrient sources Viz., soil fertilizers, organic manures and bio-inoculants. The IPNS approach, as one of the prescriptions for sustainable agricultural production, is a most efficient way of managing soil fertility because it

- Enhances the availability of applied as well as native soil nutrients during the growing season of the crops.
- Synchronizes the nutrient demand of the crops with nutrient supply from native soil and applied sources.
- Provides complete (balanced) nutrition to crops and minimizes the antagonistic effects resulting from hidden deficiencies and nutrient imbalance.
- Improves and sustains the physical, chemical and biological functioning of soil, and
- Minimizes the deterioration of soil, water and ecosystem quality by promoting carbon sequestration, reducing nutrient losses/leakage to ground and surface water bodies and to atmosphere.

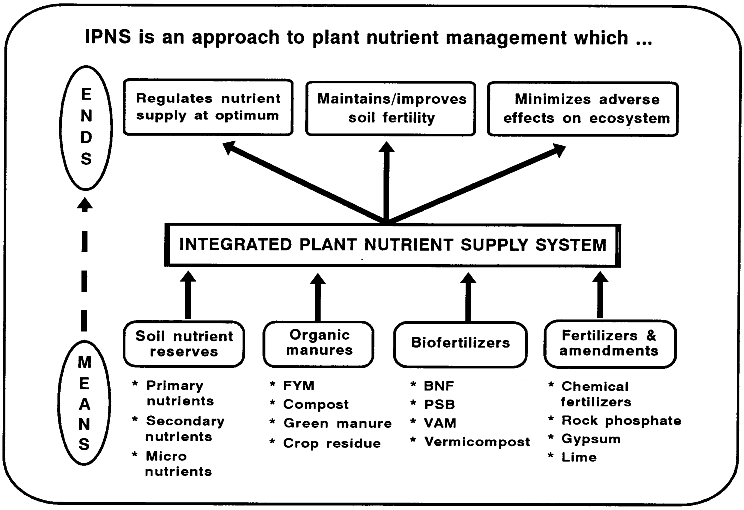


Fig. 3 The Concept of Integrated Plant Nutrient Supply

In practice it is, however, important to recognize that it is neither practically possible nor economically feasible to combine all nutrient sources into a single package that is adaptable across all agro-ecoregions. As a corollary, the appropriate combination of mineral fertilizers, organic manures, crop residues, compost or N-fixing legumes varies according to location specific system of land use, and socio-economic and ecological conditions. The most important determinants of an IPNS in a given agro-ecosystem include:

- Nutrient demand/requirement of cropping system as a whole
- Soil fertility status and special management needs to overcome soil sickness, if any
- Local availability of nutrient resources (Organic, inorganic and biological nature)
- Economic conditions of farmers and profitability of proposed IPNS option
- Social acceptability
- Ecological considerations

Whether judged by sustained yield gains or improvement in soil quality, the integrated nutrient management system scores over the individual applications of either manures or fertilizers. This fact has been amply demonstrated by quite a large number of reports covering different soil types and cropping systems across agroecological regions. Few examples of classical nature are presented below.

Hegde *et al.,* (1988) reported that the mean yield of finger millet over a period of nine years was similar with optimum NPK application or with 50% NPK through fertilizers combined with 10 t farm-yard manure (FYM) ha^{-1} (Table 17). A further yield gain of 630 kg ha^{-1} was obtained when recommended dose of NPK was capped with 10 t FYM ha^{-1}. With this treatment, it became possible to harvest >3t grain ha^{-1} during eight out of nine years. Field studies with soybean-wheat system on a Vertisol at IISS, Bhopal (Damodar Reddy et al., 1999) have clearly demonstrated that the crop yield response obtained with integrated supply of P through FYM and fertilizer-P was of the higher magnitude than that with either FYM or fertilizer-P separately. Integrated use of FYM and fertilizer-P not only increased productivity and P use efficiency but also enhanced the sustainability of the soybean-wheat system. In a recent review of the Indian work, Subba Rao *et al.,* (2002) have brought out most effective IPNS modules suitable for different cropping systems and soil types at different locations of the country. Some of these are presented in Table 18. The long-term fertilizer experiments in India have presented a large body of evidence on the beneficial of integrated nutrient management for not only increasing and sustaining the crop productivity but also for improving soil organic carbon at many locations (Table 19) (Swarup, 2001). Recycling of crop residues as a component of IPNS was shown to be effective for soil fertility improvement. From a recent study, Bellakki and Badanur (2000) reported that sorghum stubble co-incorporated with subabul loppings (50:50) at the rate of 5 t ha^{-1} or sorghum stubble @ 5 t ha^{-1} + 20 kg N ha^{-1} not only helped increasecrop yields but also improved soil nutrient status as well as organic carbon content in soil (Table 20).

Table 17. Effect of application of NPK and FYM on the productivity and stability of rainfed finger millet over a period of nine years

Annual treatment		Mean yield (kg ha^{-1})	No. of years with yield (t ha^{-1})		
FYM (t ha^{-1})	$N-P_2O_5-K_2O$		<2	2-3	>3
0	0-0-0	1510	9	0	0
10	0-0-0	2550	1	6	2
0	50-50-25	2940	0	5	4
10	25-25-12.5	2900	0	6	3
10	50-50-25	3570	0	1	8

Source : Hegde et al. (1988)

Table 18. Most effective IPNS modules suitable for different cropping systems in India.

Location	Cropping system	Soil	IPNS module
Modipuram	Sorghum-Gram	Sandy clay	6 t FYM ha^{-1} + 50% fertilizers
Junagadh	Chickpea	Medium black	20 kg N + 40 kg P_2O_5 ha^{-1} + *Rhizobium* inoculation
Indore	Soybean-Wheat	Vertisols	Substitute 50% N through FYM
Hyderabad	Rice-Gram+G.nut	Sandy loam	1 00% NPK + 2 kg^{-} l ^{1}each of Rhizobium and Phosphobacteria
Maruteru	Blackgram	Vertisols	VAM + 50 kg P_2O_5 ha^{-1}
Coimbatore	Blackgram	Black soil	75% P_2O_5 as RP + 2 t ha^{-1} vermicompost + 2 kg ha^{-1} Phosphobacteria
Coimbatore	Pigeonpea, Sunflower, Cowpea, Onion, Soybean, Cabbage	Sandy clay	75% recommended N + biofertilizers
Paiyur	Sorghum-horsegram	Loamy sand	Recommended NPK + 1 0 t FYM^{-1} har 75% RDF + biofertilizers.
Varanasi	Rice-Lentil	Sandy clay loam	50% N as FYM + 50% N as Urea to rice (residual benefit for lentil)
Sehore	Pigeonpea-Blackgram	Vertisol	FYM and Sugar pressmud @ 5 t ha^{-1} + Rhizobium
Udhamsingh nagar	Soybean	Clay loam	25 kg N + 5 t FYM or 1 t Neem cake ha^{-1}.
Bapatla	Soybean	Sandy loam	15 t ha^{-1} Biogas slurry + 50 kg N as Urea

Source: Subba Rao et al. (2002)

Table 19. Long-term effect of integrated use of fertilizers and FYM on SOC (g kg^{-1}) at some locations of India.

Location	Control	NPK	NPK + FYM	Period
Bangalore	4.8	5.9	8.4	10
Bhubaneshwar	3.7	5.7	8.1	21
Delhi	4.4	5.5	6.7	25
Hyderabad	4.6	5.3	8.0	23
Jabalpur	5.3	6.0	9.8	25
Palampur	7.3	10.0	12.0	22
Pantnagar	5.0	8.3	15.0	24

Source : Swarup (2001)

Table 20. Effect of organics and inorganics on rabi sorghum and chickpea yields and soil properties

Treatment	*Sorghum yield kg ha^{-1} (3 yrs, ave.)*	*Chickpea yield kg ha^{-1} (Residual effect)*	*Soil Properties*			
			OC (g kg^{-1})	*Available Nutrient (kg/ha)*		
			OC	*N*	*P*	*K*
Sorghum stubbles @ 5 t ha^{-1}	841	672	5.4	200	1 0	533
Sorghum stubbles + Subabul loppings (50:50) @ 5 t ha^{-1}	1 098	788	6.0	21	1 1	566
Sorghum stabbles @ 5 t ha^{-1} + 20 kg N ha^{-1}	1 060	670	5.3	208	1 0	570
Recom. dose of fertilizer, (50-25-0)	1 1 (	637	4.8	1 9	1 1	428
Control	825	452	4.1	1 5	7.1	456

Source: Bellakki and Badanur (2000)

Some suggestions to make IPNS effective : Since IPNS has a commitment to: a) sustain soil and crop productivity, b) improve health of soil resource base of the farmers, and c) maintaining or enhancing environmental quality, following few suggestions may be useful in making it effective tool in soil fertility management.

- Ameliorate soil sickness in its varied forms before venturing on evolving a realistic IPNS technology by which all the locally available nutrient resources could be utilized more efficiently.
- Use most appropriate soil, water and crop management practices, which are congenial for most efficient nutrient utilization.
- Maximize crop productivity with minimum use of chemical fertilizer, with highest achievable use efficiency and lowest avoidable losses of the latter. Harness the synergistic interactions between water x nutrients, FYM x nutrients, crop cultivars x nutrients and other beneficial interactions of technology with nutrients.
- Exploit the potential of FYM, on-and off-farm generated organic materials, biofertilizers and legumes as nutrient supplements and as improvers of soil organic matter and overall soil health and quality.
- Earthworm induced transformation and mobilization of the nutrients and mycorrhizal fungi-induced transport and mobilization of the immobile nutrients are the natural processes enhancing the efficiency of the native soil nutrients. These need to be considered in evolving appropriate IPNS modules for different agro-eco systems.
- Time the application of the fertilizer nutrients to synchronize with the physiological stage at which demand for them is maximum. Also tune the application of FYM in such a way that the maximum mineralization of the organic nutrients also occurs at the peak of their demand set by the plants.

In summary, our approach to soil quality maintenance/ improvement for sustainable agriculture should essentially be an integrated one with due focus on: (i) removal of various kinds of limitations inherent to soil, (ii) building carbon stocks in soils, (iii) harnessing benefits of positive interactions between nutrients and other inputs such as soil moisture, and (iv) economizing the fertilizer use through balanced fertilization and integrated plant nutrient supply from organic and inorganic nutrient sources.

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EMERGING TRENDS IN AGRICULTURAL EXTENSION

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In order to survive in this era of economic liberalization and globalization, attaining excellence in agricultural extension is inevitable. This century has thrown open new challenges for extension due to a paradigm shift in sustainable agriculture and agi-business. In the current changing scenario extension needs to be more relevant and effective keeping in view the goal of sustainable development and livelihoods. Some of the future area of agricultural growth are nutritional security, agricultural productivity, sustainability and environment concerns, implications of WTO, public and private roles in agricultural development and human resource development. It is important to improve the economic efficiency of young and adult farmers. Extension needs to be demand driven, participatory and problem solving in the process of agricultural development. A relationship needs to be forged between agricultural extension and vocational agricultural education for sustenance of both.

With an increase in per capita income there are going to be increasing demands for high value agricultural products such as vegetables, flowers and animal products, domestically and abroad. This requires a high value of competence in order to compete and farmers need to become more specialized. Income aspirations of farmers are also bound to be increase and hence more enterprises in agriculture are expected to earn good income from agri-business.

As rightly said by Van Den Ban (2004) agricultural extension has to change because:

1. There is an increase in the demand for agricultural products with a high value with the growing per capita income in many countries in access to world markets.
2. Knowledge about production technologies for these products and markets become crucial for the ability of farmers to complete.

3. This results in an increased productivity in agriculture, and in many countries,in a decrease in price of farm products. Farmers who increase theirproductivity less than their competitors will either decrease in income or will have to find a non-farm source of income.

4. Productivity in agriculture does not only depend on the decision of individual farmers, but also on the support they get of input supply, marketing and credit companies and cooperatives.

5. Farm income does also depend on government policies and hence, on the power of farmers' organizations to influence these policies.

6. The role of agricultural extension is not only to transfer technologies developed at research institutes but also

   - technologies developed by commercial companies
   - technologies and farming systems developed through experimentation by farmers.
   - finding non farm sources of income
   - increasing the managerial abilities of farmers.

7. Only experience can teach us which extension approach and system will be most successful in a given situation.

Commercialization in agriculture, equity in agricultural development (small and marginal farmers and landless labour and women), environment concerns, disaster management etc. have added new dimensions to extension systems at all levels. Now, extension is viewed in the contest of livelihood for the rural poor. Marketing extension, participatory technology development and extension and cyber extension are some of the new dimensions of extension.

Public Sector Extension Services have come under increasing pressure to reform in the phase of some times dramatic changes. Listed below are some of the changes that have affected public sector extension services: (Collin 2004)

- The State financial crises that lead to a sharp decrease in overall public investments, leading to pressure to downsize and consider more cost efficient extension methods away from the labour intensive, training and visit (T&V) management type approach.

- The increasing criticism of poor performance of public services Extension such as a) their lack of accountability to clients; b) the lack of relevance and quality of their programmes and due to poorly trained extension agents; c) Their limited coverage, in-terms of area and type of clients as they insufficiently addresses the needs of the poor, women farmers and farmers in this advantaged area; and d) the lack of sustainability.
- The emergence of other agencies and service providers that can disseminate agricultural knowledge and information; in particular producers organization,NGOs and private sector.
- The political forces linked to democratization, liberalization and decentralization which in conjunction with financial constraints and emerging new actors, leads to redefining the role of public services and re-thinking extension methods away from top down, supply driven approaches.
- The revolution in information and communication technologies which provides new vehicle for supplying information.
- The changes in agriculture and, therefore, in the information needs of the farmers.

Extension has to embrace a broadened mandate such as information on marketing.There is also growing public concern about environmental conservation and poverty reduction which adds to the extension mandate.

The public sector services can respond to these pressure by : (Collion 2004)

- Partnership with other agencies and service providers ;
- Changing public sector service extension methods-departure from the traditional T&V extension methods (technology transfer, supply driven, top/down) towards extension methods that are bottom up, participatory and demand driven.
- Decentralization : Another major aspects of extension reform is decentralization of the services and linkages established with local governments.
- Role in policy making - though public sector agencies are less involved in the actual delivery of extension, they have a major role to play in providing a national vision and strategy as high lighted.

Main features of the policy framework for agricultural extension (MOA, GOI, 2000)

The Policy Framework for Agricultural Extension (2001) proposes path-breaking changes to agricultural extension in India so that it is better able to respond to the diverse agro-climatic regions and the varied categories of farmers and farming systems approach to extension, increased use of media and information technology, improving research-extension linkages and a multi agency extension system with a far greater role for private extension services.

At the policy level- a move towards a farming systems approach and partnership with private and other public agencies in extension provision

- Institutional restructuring
- Financial reforms
- Strengthening research-extension linkages
- Capacity building and skill upgrading
- Mainstreaming women in agriculture
- Use of media and information technology
- Financial sustainability
- Changing role of government

Government of India's support to State Extension in X Plan

To operationalize the reforms as conceived in the Policy Framework for Agricultural Extension during the 2002-2007 phase a restructured centrally sponsored scheme to support extension progarmmes of the states has been proposed. The salient features of this are:

- Each state prepare a state extension work plan (SEWP), comprising a mix of on going extension programmes from the IX plan and a set of new initiatives.
- SEWP is an annual proposal of extension strategies, activities and investments prepared by the state centering around reforms envisaged in the PFAE.
- The expenditure for implementing the programme in SEWP would be shared between the centre and the state in the ratio of 90:10.

- No funds would be provided for the vehicle, major civil works and staff salary.

Funding for the core establishment and infrastructure (for ATMA like model) has to be borne by the States.

- SEWPs to have three important aspects
- Public sector reforms
- Promotion of private sector initiatives
- Promotion of media and IT applications
- Public extension system would be re-organized in a new structure (ATMA model) which facilitates a participatory mode of extension delivery, which is farmers driven and fanners accountable.
- 25% of the total SEWP allocation must reflect direct support to women farmers.

Farmers' organizations

With globalization there is a major change in the trade in agricultural products. Selling to multinational companies needs larger quantities of products of a standardized quality. This can be done by contract fanning and by farmers organizations. According to Koopmans (2004) "with the increasing power of multinational companies in the markets, it becomes more important that farmers do not deal with them as individuals, but through their own organizations." The success of these organizations depends on motivated and educated farmers with leadership qualities.

Furthermore Lans *et al*. (2004) also emphasized the role of farmers organization in educating fellow farmers. The competence of the members can be built up through education and exchange of experience in the matters like production technologies, farm management and marketing. These organizations may run agricultural schools where youngsters are prepared to become competent farmers and offer courses which support life long learning. These schools and courses do not only teach production technologies, but increasingly also entrepreneurship. Along with this informal training is also important in order to better adjust their farming systems to developments trends in the markets. Similarly, discussion groups can play an important role in farm management extension, so as to help in better problem solving and decision-making (Faure and Kleen, 2004).

The mushrooming of self-help groups across the country are evidence of the effectiveness of this self-help movement for empowerment of farmers, especially rural women. Extension has to play a catalytic role in mobilization and organization of various groups like special target groups, users groups, fanners interest groups, growers associations, young farmers/ youth clubs and special interest groups etc depending upon the local need and nature of enterprise.

Vocational Agricultural Education

The Krishi Vigyan Kendras, numbering at present 461, and planned for every district in the country, can play a crucial role in imparting need based and relevant vocational education to our farmers. Experience suggest that the quality of these short courses need to be upgraded in order to build the capacity of farmers to compete in the market.

ICT in Agricultural Extension

As highlighted by the World Food Summit (Rome, 1996) information is one of the priorities for achieving food security . FAO has established World Agricultural Information System (WAI CENT) for use in farm priority areas- human recourses, information content system and community development. One of the conceptual models is the Rural Information Network (Farm Network). The Department of Agriculture and Co-operation, MOA, has launhed a project called DACNET for strengthening of information technology infrastructures. Under the NATP, Farmers Information and Advisory Centres (FAIC) have been set up for establishing linkages.

Major challenge for agricultural extension is to develop strong e-linkages through Krishi Vigyan Kendras. E-extension through KVK's has been initiated but we still have a long way to go.

ICT to be used in the broadest possible sense, consisting of a range of tools that build human networks, increase public awareness and provide access to information and knowledge for the use of the people. ICT's need to integrate the 'concept of multi-source, multi-disciplinary, multi-media and multi-users'.

Decision-making support system for farmers :

In today's era of competition the farmers have to be well informed in order to make fanning more profitable Extension services should use all available information sources about new technologies. These technologies are not only developed in government research institutions, but increasingly also in commercial companies selling inputs to farmers on marketing their products and by innovative farmers. (Sulaiman and Hall, 2004).

Information and communication technologies offer new and wider opportunities to provide farmers and extension professionals with information for good decisions. Market information for high value products can also be sought through ICT's.

A paradigm shift in different components of extension has to take place :

- 'Transfer of technology' to 'Capacity enhancement'
- From 'general' to 'precise' recommendations
- Distribution of information' to 'facilitation of access for information'
- "Dissemination model' to 'fanner-driven needs model' (Vijayraghvan 2004)

Key reform measures (Hassanullah, 2004)

- Working with all categories of farmers.
- Decentralisation
- Demand-driven extension
- Working with all kind of groups - all types of available groups of farmers

  operating in an area.
- Extension-research linkages to be strengthened
- Multiple extension methods

Reform initiatives must fit with national goals and strategies, the reform package must evolve to match the socio-technical context of the existing extension and support systems, the reform measures need to be developed collaboratively by appropriate representatives of government, extension professionals and clientele, the policy advocacy role for the extension system be strong enough to ensure government commitment and continued support for a long enough time to institutionalize the changes. The success of these reforms depends on the economic benefits that accrue to fanners and motivated, and devoted staff.

Private Extension Services:

Even though there is increasing interest in privatizing the extension services, "the Government has a major role in establishing policies and programmes to facilitate the operation of private extension services, along with continued sustenance in some cases, and extension systems need to be designed with the understanding that they will be cost effective only 'if the public role is defined so as to complement what the private sector can and will fund and deliver." (Beynon, 1998. Anderson and Feder, 2003) Private Extension generally addresses commercial farmers. Conflicts may arise in contracting schemes which need public regulation and monitoring.

Learning for sustainable agriculture involves a transformation in fundamental objectives, strategies, skill and professionalism of farming. The key element in their learning path are: (Roling and Pretty 1997).

i) Extension has to be responsive to the changing circumstances and farmers' needs through encouraging farmers to invest in observation, record keeping and monitoring,

ii) Extension has to go beyond dissemination of broad based recommendations and concentrate on a complete range of management practices, skills and knowledge related to adoption of sustainable farming methods,

iii) Extension has to involve farmers in the whole process of extension. This involves use of participating approaches in overall planning and implementation of programmes.

iv) Extension has to demonstrate the feasibility of sustainable practices.

v) The use of location specific farmers' knowledge and promotion of indigenous knowledge and practices will be an important component of extension services to promote sustainable farming methods.

Broad agenda for Extension: With changing farmers' needs regarding agricultural information as well as increased concerns for poverty reduction and environmental conservation, the focus is changing from narrow agricultural mandate to a broad rural development one, recognizing that agriculture alone may not be the best or only way to improve rural people's livelihood. There is a call for broader services, aimed at more marketing and group formation efforts.

§ Capacity building-especially of extension staff to master new extension methodologies.

§ New information and communication technologies-These have the power to revolutionize extension systems and the way public extension service work.

§ Sustainability-Extension service can partners with rural producer organizations to disseminate information.

According to Sulaiman and Hall (2004) Worldwide, it is now widely recognized that agricultural extension needs to reform in ways that allow it to fulfill a diverse set of objectives. The emerging paradigm of extension-plus ranges from better linking of fanners to input and output markets, to reducing the vulnerability and enhancing voice of the rural poor, development of micro-enterprises, poverty reduction and environmental conservation and strengthening and support of fanners organizations. Extension is being forced to embrace a broadened mandate as fanners find themselves in an even more complex production and market environment, with an expanding need for information and services. There is a need for:

♣ Development of forward and backward linkages.

♣ Need to coordinate the efforts of multiple agencies involved in technology development and dissemination.

♣ Contract farming-a strategy of integrating major actors.

♣ Integration of efforts of government, fund facilitators, R&D, input providers, NGO's and farmers.

♣ People's participation

♣ Diversified input system-public, private and local entrepreneurs

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PERFORMANCE – ORIENTED EVALUATION SYSTEM FOR PUBLIC SECTOR RESEARCH ORGANIZATIONS IN AGRICULTURE

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INTRODUCTION

Indian agriculture has undergone a major transformation in the last four decades. Through extensive application of science and technology, the country has made great strides in agricultural production and productivity. The massive network of agricultural research organizations, particularly in the public sector, has made it possible for the National Agricultural Research System (NARS) to enable the country move forward from food deficit to surplus status. In the light of rapidly changing national and global agricultural scenario, coupled with increasingly scarce research resources, the public sector research organizations are now frequently being asked to show results that are acceptable to the end users, improve their performance (in terms of output and impact) and enhance their accountability to varied groups of stakeholders and beneficiaries. Besides, the trend towards privatization of research and re-examination of the role of public research organizations has necessitated the policy-makers and research planners to focus on the impact of public sector research as well as on their accountability to the society.

The public funded research organizations are now confronted with the urgent need to demonstrate performance and accountability to ensure the support and funding from planners and policy-makers on a sustainable basis.This calls for a more realistic performance-oriented evaluation system, particularly at the organizational level. Such system, if internalized, can assist the research managers to assess the level of performance of their organizations, in terms of output and outcome; identify the management constraints, both internal and external; and evolve appropriate strategies to improve their performance.

Conceptual Framework

There has been growing internal as well as external demands for improved performance and accountability of public funded agricultural research organizations in the country. They need to be productive by showing research results that are relevant to the needs of their clients and various stakeholders. In essence, productivity and relevance are the two major dimensions of performance. The performance is closely linked to accountability. While the measurement of organizational performance is a precondition for accountability, the accountability mechanisms are instrumental to improve their performance.

Concepts

Performance assessment and accountability enhancement of agricultural research organizations are vital issues to be considered in the good governance of NARS. Though simple in intent, they are complex in nature and have different aspects.

Accountability :

It refers to the research organization's ability to justify to its varied stakeholders (farmers, government, policy-planners, funding agencies, etc.) and beneficiaries (consumers, NGOs, etc.) the relevance and quality of its research programmes, and the use of resources to achieve its goals and objectives.

Accountability has both internal and external aspects. Internally, all aspects of research management process (planning, priority setting, monitoring, and evaluation) can be improved when the goals and objectives of the research organization are clear and well integrated with the national goals set for the agricultural sector. Externally, funding support can be maintained when it provides timely, accurate and objective reporting on its output and outcome.

Performance :

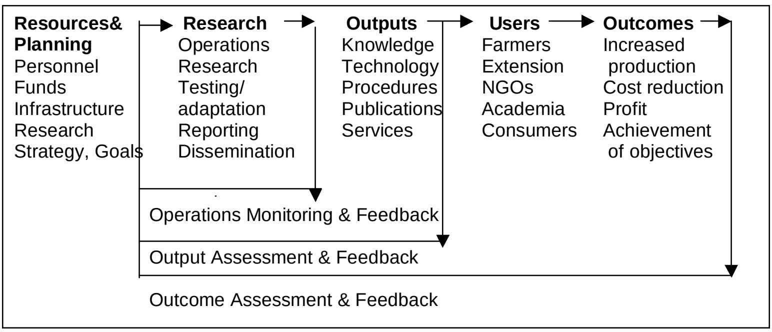
It is the ability of a research organization to use its resources efficiently and consistent with its objectives, for the production of outputs that are relevant for its users.

The ability to define, measure and assess (evaluate) performance is an essential condition for its improvement. Accountable management implies that public research organizations are responsible for specified levels of performance.

Approach

Performance evaluation function is generally weak in many public sector research organizations in the NARS. It is mostly carried out to meet the external requirements and not targeted at the crucial internal management issues. It often remains as an isolated activity (mid-term review, quinquennial review, etc.) to satisfy external demands, instead of integrating them as a part of the internal management process in the organization. Inadequacy of systematic information flow supporting the management decisions makes it difficult to identify structural, organizational and management problems, or to bring about improvements in outputs and outcomes. In this context, it becomes necessary to critically look at the characteristics of agricultural research organizations in order to build performance orientation into the public sector.

Characteristics of Agricultural Research Organizations



Source: Warran Peterson, Discussion Paper, ISNAR, July 1998.

If viewed as a production system, agricultural research organizations have certain basic features. With differing structures and organizational processes, they use resources as inputs (personnel, funds and infrastructure) in research operations (research, testing, reporting, and disseminating results) that generate various types of outputs (knowledge, technology, procedures, and publications). Users attempt to transform the outputs into positive outcomes (increased production, cost reduction and profits). In this sequence of events, performance assessment and feedback mechanisms are required at different levels to ensure that public research organizations use their resources efficiently and produce relevant and useful outputs:

Assessment Procedures

Performance of public sector research organizations are influenced by certain special characteristics, as under:

- As partner in the overall development efforts, reflect the national goals and objectives.
- Have multiple social and economic objectives.
- Operate in a dynamic policy and funding environment.

- Due to the existence of civil service rules, have very little flexibility either to suitably reward better performance or to punish non-performance.
- Difficulty in attributing positive outcomes to organizational efforts due to the activities of multiple institutional actors.
- Have more diverse accountability requirements.

Because of these complexities, it becomes imperative to consider organizational processes (efficiency) along with output/ outcome (effectiveness) factors while evaluating their performance. In other words, information on output/outcome need to be evaluated in conjunction with the management factors that produce them. Both types of assessment are an integral part of performance-oriented management. On this premise, the performance-oriented evaluation procedure encompasses three basic components, as under:

- Research outputs (productivity)
- Research outcomes (impact)
- Management processes/domains/functions (performance)

The suggested procedure attempts to integrate research output and outcome evaluation with the assessment of key management processes that affect the performance. The performance - oriented evaluation system contemplates to essentially focus on the following critical areas of assessment.

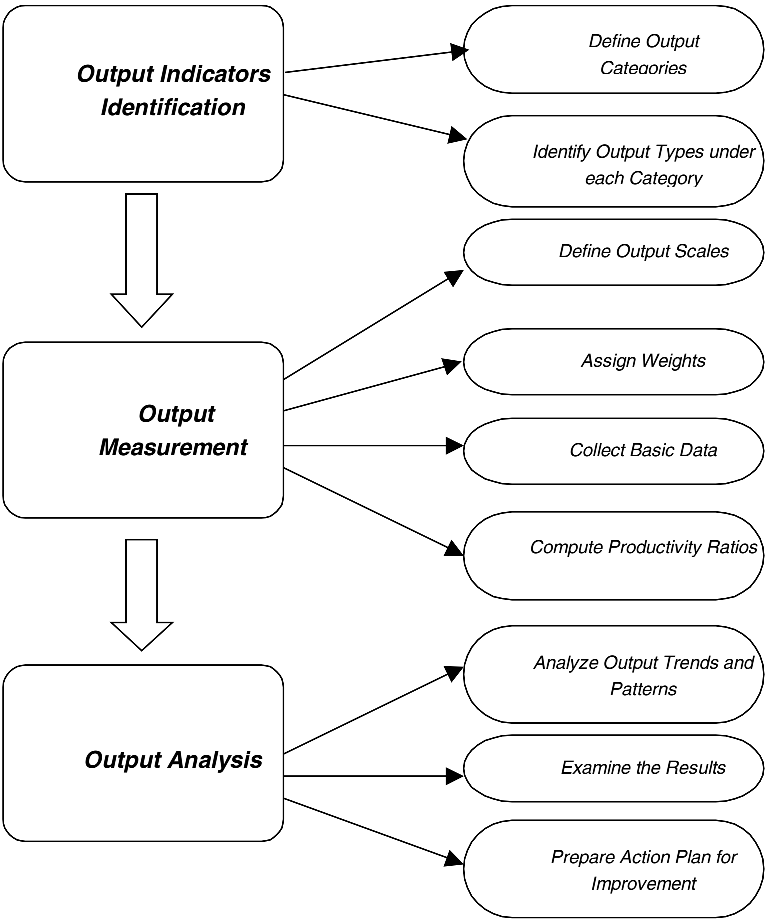
- Identification of suitable indicators pertaining to research output, outcome and management processes.
- Measurement of the selected indicators by assigning appropriate weights as per their relative importance, for every year over a selected period, and expressing them in quantitative terms.
- Critical analysis of the level of performance, and integrating the results into internal decision-making to evolve relevant strategies for improved performance.

Output Assessment

Through a step-wise procedure, research output (productivity) can be assessed by a *productivity index or ratio* composed of a weighted sum of the key goals. The output assessment essentially focus on the following three components:

- Output indicators identification (categories and types under each category).

- Output measurement (in terms of productivity index/ratio).
- Output analysis (trend analysis and cumulative performance).



Output indicators identification

In any agricultural research organization, one of the most important and commonly used performance assessment parameters relates to various categories and types of research outputs. They include the following:

Output Category	*Output Type*
Improved Crop Varieties/Animal Breeds/Tree Species *In any agricultural research organization, one of the most important outputs is the number of crop varieties and hybrids/animal breeds/tree species released.* *(It also includes their success rate, in terms of actual adoption by the clients)*	• *Improved crop varieties* • *Improved animal breeds* • *Improved tree species*
Improved Management Practices *Sustainable crop production is also based on timely adoption of appropriate plant/animal management practices.* *(It also includes their success rate, in terms of actual adoption by the clients)*	***Plant Sciences:*** • *Agronomic practices (tillage, seed rate, spacing, etc.)* • *Soil and water management,* • *Integrated management of pests, weeds, water and nutrients* • *Integrated farming systems, including eco-sustainable practices* • *Horticultural practices (tissue culture, propagation, etc.)* • *Farm management* • *Farm mechanization* • *Post-harvest technology* • *Biotechnology* • *Green house technology* • *Others* ***Animal Sciences:*** • *Animal nutrition* • *Vaccination* • *Shed maintenance* • *Rapid diagnosis and treatment of injuries and diseases* • *Biotechnology* • *Others*

Publications and Reports *One of the most commonly used performance measurement indicators of research organizations is the number of publications and reports published in a year.*	• *Papers in referred national / international journals* • *Papers presented in conference / symposia / workshop* • *Conference / symposium / workshop proceedings* • *Policy papers* • *Concept / occasional papers* • *Discussion papers* • *Books / reviews / chapters* • *Abstracts* • *Research highlights / bulletins / brochures* • *Bibliography / monographs* • *Technical reports* • *Training manuals* • *Training materials for students / trainees* • *Posters / newsletters / leaflets* • *Farmers / extension material* • *Audio-visual materials (radio / TV / videotapes)* • *Electronic database* • *GIS Mapping* • *Case studies* • *Others*
Training Events *Various types of training programmes organized for different client groups are also a valuable indicator in order to measure the performance of agricultural research organizations.*	• *Training of national and international researchers* • *Training of farmers and farmers' organizations* • *Training of women farmers* • *Training of extension officers* • *Training of students* • *Training of private / public input agencies* • *Training of NGOs* • *Others*

Dissemination Events *Dissemination of research results through a variety of programmes for different categories of stakeholders and beneficiaries.*	• *On-farm research trials* • *Field visits / field days* • *Demonstrations* • *Farmer programmes in mass media (radio, TV, newspapers, magazines, etc.)* • *Farmer fairs* • *Exhibitions* • *Campaigns* • *Gram Sabhas* • *Press release* • *Through contact farmers / NGOs* • *Agriculture Technical Information Centre (ATIC) DAAT (District Agriculture Advisory Technology Transfer) Centres / ZARS (Zonal Agricultural Research Station)* • *Collaborative links with other institutions* • *Others*
Public Services *Public services provide to a variety of end users is also an additional indicator for performance assessment of research organization*	• *Seed production activities* • *Advisory services (field visits and office calls)* • *Pest and disease surveillance / crop protection management / eradication* • *Biological control labs* • *Soil and water testing* • *Pesticide testing* • *Fertilizer testing* • *Seed testing* • *Gene / germplasm banks* • *Germplasm enhancement* • *Screening technique* • *Testing for quarantine* • *Land use mapping and planning* • *Biotech services* • *Taxonomic services* • *Farm / veterinary clinics* • *Others*

Professional Recognition *Awards received in recognition of the research work undertaken by the faculties, resources generated, scientists invited to be the members of the professional societies/Committees and the financial resources generated from the consultancy service are considered as indicators to assess the professional recognition of the organization.*	• *Awards* • *Resource generation* • *Membership in Professional Societies / Committees* • *Consultancy service*
Product Development *Includes patents/copy right for the innovations made by the scientists, software developed, agricultural machinery developed for improving the work efficiency of the end users and processed food items, both plant or animal origin.*	• *Patents* • *Implements* • *Software* • *Processed food items (plants / animals)*

Output measurement

Once suitable indicators (output categories and types) are identified, measurement matrices for each year during the assessment period (say, five years) are to be constructed. This can include simple quality elements (number *vs.* adoption rate) and weighting factors, i.e. assigning relative weights to different types of output to correct imbalances. Multiplying the number and / or adoption rate with the weights assigned, scores for each output type can be obtained. The scores of all the output types in that particular category are to be summed up to arrive at the total index score of that category. Dividing the total index score by the input (researcher time/man-months considered as a proxy to achieve scale neutral measurement) would result in a '*productivity ratio*' for that particular category. All the outputs can be finally assessed in terms of productivity (output/input) that result in productivity ratios.

Outcome Assessment

It is necessary to properly evaluate the impact of research. It can only be accomplished by tracking specific outputs to establish a causal relationship between the research output and benefits to producers. Since periodic tracking of specific research outputs to their targets is necessary, outcome assessment is more difficult requiring more resources and expertise. Moreover, multiple agencies are involved in realizing the impact of technologies developed by the research organizations. Careful planning is, therefore, needed to combine simplicity in design, reasonable levels of resource requirement and appropriate assessment targets. Because of the inherent difficulties associated with the outcome / impact assessment, most organizations tend to keep this type of assessment outside the purview of performance assessment exercise.

Outcome indicators identification:

Not withstanding the difficulties associated with impact assessment, which constitutes a vital component of performance assessment, it is worthwhile to consider a few of the selected indicators so that the evaluation is complete in all aspects. As per the level of difficulty associated with outcome assessment, some indicators can be considered as simple and some others as very complex.

Simple:

- ❖ Area expansion (crops) / increase in number (animals)
- ❖ Increase in production
- ❖ Reduction in production cost
- ❖ Profitability to the producer
- ❖ Achievement of objectives- Adoption rate (reach)
- ❖ Sustainability of adoption

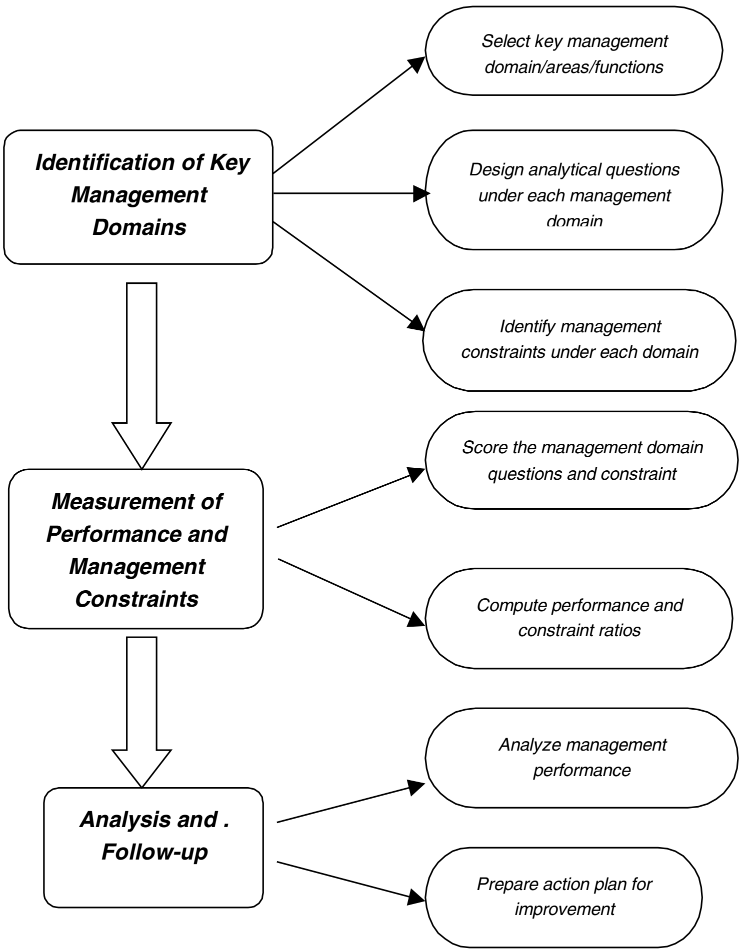
Complex:

- ❖ Internal rate of return (IRR)
- ❖ Benefit- cost analysis (BCA)
- ❖ Total factor productivity (TFP)
- ❖ Environmental impact assessment (EIA)

While it is relatively easy to measure the simple indicators, reliable database and expertise are essential to measure the complex indicators. As per the availability of database and expertise, relevant indicators may be considered for impact assessment. In this context, it is desirable to develop the required database as well as the expertise to ensure more realistic assessment of the impact of technologies developed by the research organization. Careful planning is, therefore, required to combine simplicity in design, reasonable levels of resource requirement and appropriate assessment targets.

Management Process Assessment

Effective management has a greater influence on the performance of research organizations. Assuming a direct relationship between management and performance, it is considered as yet another major component of performance assessment methodology. Various steps involved under this component are presented below.



Management process indicators identification :

Critical management processes or elements that drive the performance of research organizations need to be identified first. They include:

- ***Assessment of context and organizational responsiveness:*** *It is vital for the research organization to properly understand the opportunities and threats prevailing in its environment (in terms of farmer's conditions and aspirations, national policies and goals, markets, prices, funding levels, partners, and competitors) in order to plan relevant research and produce outputs that are useful for its varied groups of stakeholders and beneficiaries.*
- ***Planning strategy and goals for the organization:*** *In order to effectively respond to the rapidly changing environment, it becomes pertinent for the organization to periodically review and adjust its directions and goals. Strategic planning can be a better option available for repositioning itself in its environment.*
- ***Selecting research objectives and outputs:*** *At the operational level, the development goals and client needs are to be reflected in the organization's research objectives and priorities for making them more relevant.*
- ***Research project management:*** *The organizational objectives and strategies are to be translated into relevant projects that need to be well planned and managed in terms of inputs, activities and expected outputs.*
- ***Maintaining the quality of operational research:*** *To ensure effective research operations and quality of output, improved research management practices need to be followed by creating conducive working environment in the organization.*
- ***Human resource management:*** *It is important that adequate numbers of qualified staff, in different category, are in position to ensure expected level of organizational performance. Proper human resource management practices, in terms of planning, recruitment, development, and evaluation, are to be implemented for realizing improved performance.*

- ***Coordination and integration of internal functions, units and activities:*** *For the smooth and efficient running of research operations, activities of various functional units within the organization are to be well integrated through a proper coordination mechanism. Suitable organizational structure that is facilitative for good governance, effective co-operation and internal communication need to be ensured.*
- ***Transfer of technology:*** *For effective dissemination of research results, in the form of new knowledge and technology, to the end users, it becomes necessary to establish strong linkages and working relationships with various agencies such as farmer organizations, extension, development agencies including NGOs, universities, private sector, and other agencies (both national and international). This will not only help to put into practice the developed technologies but will also provide the necessary feedback to the organization for developing relevant research agenda.*
- ***Protecting organizational assets:*** *In the best interest of the organization, due attention needs to be paid to protect its assets such as staff, funds, infrastructure facilities, and intellectual property.*
- ***Ensuring the flow and use of information for monitoring, evaluation and reporting:*** *Proper monitoring, evaluation and reporting of research through systematically designed and managed information system will immensely benefit the organization by providing useful information for sound decision-making as well as for ensuring accountability.*
- ***Governance****: Provision of inspirational leadership through participatory decision-making as a team, empowering people with operational freedom and rights due for them, existence of personnel policies conducive for improved performance, proper motivation to get the best out of the individual, and devolution of power resulting in decentralized decision-making will lead to good governance of the research organization.*

Management process measurement:

As per the specific characteristics of the organization concerned, a set of analytical questions needs to be first raised for each of the critical management functions/domains. The degree to which these questions are answered is then scored, on a point scale, for individual domains. By summing up all the scores under each domain, the total score can be obtained. Dividing the total score by the possible/potential score would result in a *'performance ratio'* for that particular management domain. Measurement matrix with performance ratios for all the domains can then be constructed for that particular year.

Due to varying nature of decision-making as well as the prevalence of bureaucratic norms and procedures, constraints to effective management often exist in the public sector research organizations of NARS. For each management domain, specific management constraints (both internal and external) need to be identified and scored, on a point scale, as per their relative importance. Summing up all the scores in that particular management domain can then arrive at the total score. Dividing the total score by the possible/potential score would yield a *'constraint ratio'* for that particular management domain. Similar to the performance ratios, measurement matrix for the constraint ratios can also be constructed for that particular year.

Analysis of Performance Assessment Results

Trend Analysis

Year-wise comparison of productivity/performance/constraint ratios can be made during a selected period, the length of which will vary with the availability of quality information and the nature of commodity (annual / perennial) handled by the research organization, to examine the changes in performance over time. It is also possible to work out a benchmark threshold value (average ratios over a selected period), which can serve as useful indicator for identifying the years of over, normal and under-performance of the research organization.

Relative Contribution

In accordance with the mandate of the research organization, contribution of the individual category to the cumulative performance can be assessed (separately for output, outcome and management process) for each year by assigning weights as per their relative importance. The trend in overall performance, in terms of productivity / performance / constraint ratios, can then be arrive at during the period of assessment.

Development of Strategy

By critically examining the reasons for under-performance, as reflected in lower productivity/performance ratios coupled with higher constraint ratios in comparison with the benchmark/threshold values, appropriate action plans need to be developed to overcome the problems towards improving the performance level.

As a strategy, the performance assessment results need to be integrated into the internal decision-making process, so that the potential of the methodology as an effective tool for improved performance can be fully realized.

Future Scope and Strategy

At the present juncture, nobody can venture to doubt the utility and value of performance-oriented evaluation system. However, the following conditions are to be satisfied in order for the public funded research organizations to fully realize its potential.

- Performance-oriented culture to be inculcated among the agricultural research organizations.
- An internal organization management perspective, rather than an external donor perspective, to be developed.
- Awareness on performance assessment approaches suitable for public sector research organizations to be created through sensitization programmes.
- Interest of management (or external pressure!) to initiate performance-oriented evaluation system, and effective participation, commitment and guidance of managers to its development and use to be ensured.
- Ready availability of information and provision of adequate resources (staff, funds and time) to be assured.
- Integration of the evaluation system into management processes and decision-making to be considered as the hallmark for improved performance.

CONCLUSION

Agricultural research organizations in the public sector are currently facing the onerous task of meeting the greater demands of varied stakeholders and beneficiaries with the limited resources at their disposal. Not only the quantity and quality of various forms of outputs / outcomes, but also the efficiency with which they are generated reflects their performance. The performance-oriented evaluation system described here attempts to integrate output and outcome evaluation with the assessment of key management processes that affect the performance.

The evaluation system primarily aims at efficient and effective management towards improved performance within the research organization. It basically assumes that internal assessment is more useful than external evaluation for the effective management of research organizations and the improvement of their performance. Internal research managers have far more knowledge of their own organizations than do outsiders; and the information from internal assessment are more likely to be used if they are directly involved in the design and management of the performance-oriented evaluation system.

Although the described evaluation system is essentially meant for self-assessment of research organizations, it can serve as a critical input (in quantitative terms) to external evaluation bodies like QRT in the NARS. Most importantly, the full potential of this comprehensive evaluation system can be realized only when a performance-oriented culture is inculcated and the results emanating from the assessment are integrated into the decision-making process in the research organization. Any effort to enhance the efficiency and effectiveness of public research organizations in the NARS necessitates the institutionalization of a performance - oriented evaluation system in order to make them accountable to increasingly varied groups of stakeholders and beneficiaries.

GLOBALISATION, NEW TECHNOLOGIES AND RICE LIVELIHOOD : WHAT ABOUT RURAL WOMEN?[1]

Ms Revathi Balakrishnan, Ph.D.[2]

INTRODUCTION

The theme of the International Year of Rice, "Rice is Life", sums up the reality of rural Asia. India is no exception. Across India, farming systems and agricultural production systems are most often centred on rice crop cultivation or rural enterprises associated with rice crops and rice by-products. Hence, in most Indian rural communities, rice based or rice integrated livelihood systems define economic opportunities and the rhythm of life. From the dual perspectives of global trade and household economy, the rice crop holds a significant position in India. Developing countries account for 95 percent of the total global production of rice; China and India alone contribute 50 percent of this production (FAO, 2003). In India, about 43 percent of the food grain production in 2001 came from rice. Seventeen states accounted for 97.7 percent of the total rice area in the country in the triennium ending 1999-2000. About 40 percent of the crop is consumed on farm; the remainder is marketed (Vepa, 2004). Fluctuations in rice prices and natural phenomena threaten rice farmers' livelihood and food security. Within households seasonal activities of production, demand for productive resources including labour and social events are marked by the production cycles of the rice crop. In the cultural perspective, Tamil Nadu celebrates the January rice harvest festival.

Crop production intensity and diversity in production constraints are illustrated by various rice production practices adopted within the country. In some systems three crops of rice are common while in other areas only a single crop in a year is planted depending on the abundance or scarcity of agriculture inputs, primarily water. The rice centred farming systems and rice integrated farming systems

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[1] The paper is not cleared by FAO and is an unedited version. Thus the ideas and arguments presented do not represent the official position of FAO/UN. The author is solely responsible for its contents. The paper or sections of the paper can be used only with prior permission of the author.

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should be recognised for the diversity of livelihood strategies and the complex production calendar affected by seasonal demands and resource constraints. When the expected water fails the farmers, such as in droughts or when floods drown the paddy fields, rice farmers experience economic vulnerability and the threat to food security. The livelihood strategies of rural populations are characterised by integrated systems of resource management such as rice-fish, rice-livestock, rice-agro forestry, rice-vegetable, rice-homestead and rice-homestead-wage labour. Such integrated resource management strategies are responses to local agro-ecological resource situations and production constraints. It could be easily affirmed that the rice livelihood system integrates crop production, livestock, rural industry and rural employment in India. In such multifaceted rice livelihood systems, gender roles vary ranging from transplanting to processing, and provisioning through supplementary income generation activities. Invariably, women make critical contributions to the rice livelihood system marked by multi-tasking work-loads. The changing global and natural resource conditions place demands on farm households' work demands and resource allocations. The labour patterns in the households are determined by gender defined roles, responsibilities and knowledge base. These gender dimensions have yet to be well documented to guide polices for the advancement of rural women in rice based economies such as India and within India the states that produce rice crops.

Women in the rice livelihood system: Redefining research significance

In rice bowl countries such as India, gender roles in rice livelihood systems are characterised by diversity- beginning with agricultural practices such as seed selection, planting and weeding, and extending to processing for household consumption and marketing. The multitasking of rural women in the rice livelihood system was a primary focus of study in the late 1970s and early 1980s. Since that time, the study of rural women's situation in rice livelihood systems has declined. It is important to refocus attention on rural women in rice livelihood systems as the economic and the technological milieu of India changes with considerable impact on rice livelihood systems. In today's India, rice has become an important export commodity as well as the basic food. In rural India, however, rice producing households may not enjoy the amenities that new technologies can provide or the advantages of the global economy. Within rural households there persists gender asymmetry that adds to the inequality in access to resources including technology, information and training.

The decline in the study of women in rice farming systems occurred as new areas of focus emerged within the agriculture sector and in gender/women in development programmes. In particular, within the agriculture sector the focus shifted from mono-crop, such as rice, to crop diversification and sustainable natural resource management. Green Revolution interventions were criticised and the search for alternatives was promoted. Research efforts were redirected to develop alternative crop management practices including integrated pest management and crop diversification such as horticulture. New modes of technology transfer and training of farmers emerged in the form of Farmer Field Schools (FFS) and farmer to farmer information exchanges. With the technology development paradigm shifting toward crop management and natural resource sustainability, the social research focus on women in rice systems was relegated to a lower status. Perhaps the assumption was that women would adapt to the changing times and their division of labour at the household level would not be impacted. This assumption is untenable when the facts of labour force participation in rice farming systems are reviewed.

In the global development arena, the debate over *gender mainstreaming paradigms* versus *women in development approaches* contributed to a decreased emphasis on the study of rural women by research institutions. Additionally, the overt acknowledgement and increasing advocacy of social evils in the Asian region, (and India is no exception), paved the way to emergence of academic and development interests on issues related to domestic violence and trafficking of women. In India, the social concerns of persisting gender based discrimination became a central focus of advocacy and academics. It is seldom overtly acknowledged that the economic ill of rural poverty is a contributing factor to such social disharmony. It is also true that such social issues have a rural dimension where discrimination and poverty are widely prevalent and poorly studied; the analytical focus moved away from research related to rural women's access to land, capital, technology and agricultural services. In India, women centred development projects for income generation through credit and self-help groups became a centre piece of strategies for women's advancement. Yet, the agriculture research service could have taken on the role of monitoring these interventions through objective assessment of the household level resource gains and impediments for economic, welfare and equality gains with gender, class and ethnicity dimensions.

Paradoxically, while the interest and importance of studying rural women in rice livelihood systems was on the decline, in many countries of the region the phenomenon termed as feminisation of agriculture was on the rise. Feminisation of agriculture, simply stated, is a rural situation where due to various social and economic reasons, men are absent from the farms and fields and women have become the farmers and agricultural labourers. Along with feminisation, marginalisation of women's role in agriculture also should be recognised. A demographic change in agriculture labour such as feminisation of agriculture in the milieu of changing technologies and economic transformations creates new divisions of labour at the household level. Social researchers in agriculture research systems have not studied this phenomenon in the rural centres of India that are dependent on rice based production systems.

Indian census data show that over the past ten years the percentage of women engaged in agriculture has risen. As per the 1991 census, 48.40 percent of the total rural workers were cultivators and 31.65 percent were engaged as agricultural labour. The 2001 census reports 40.14 percent were cultivators and 33.20 were engaged as agricultural labour. An overall situation is 40 percent of all cultivators, and 47 percent of all agricultural labour are women. In the state of Tamil Nadu, more than 50 percent of agriculture labour is women, and the percentage of cultivators is also high, though relatively less than agriculture labourers. Women are moving from being cultivators to the roles of agricultural wage labourers. The roles of women in agriculture are being incrementally marginalised (Vepa, 2004) .

Within Indian states it appears that agriculture in more backward districts attracts a larger percentage of women than men, while more prosperous districts have fewer women than men. In the case of Tamil Nadu's prosperous irrigated district of Tanjavur, the percentage of women in agriculture labour is only 44 percent, while backward districts like Ramanathapuram have as high as 58 percent of agricultural labour as women. In districts such as Namakkal, Pudukkotai, Tiruvannamali and Perambalur, a large percentage ranging from 55 to 60 percent of agricultural labour is women. The reason for higher employment of women as labour appears to be the lower wages paid to women. Thus, women seem to be pushed to the poorest areas of the state where wages are low compared to prosperous districts, and there again they get lower wages than men (Vepa, 2004). The price advantage for the rice commodity seems to arise from the labour wage advantages of employing women at lower wages.

Women and smallholder farmers play an important role in rice production and in post-harvest activities, yet they often do not receive proportionate social and economic benefits when improvements in rice cultivation are initiated at the field level. In order to enhance the productivity of rice-based production systems, especially for smallholder farmers, it is essential to make a careful assessment of gender and labour roles (FAO, 2003). Social variables such as caste, class and traditions determine the gender roles in the rice livelihood systems of India.

In a study completed by Paris et al (2000) in India, upper caste households in the rainfed lowland rice environment of Eastern Uttar Pradesh used a relatively high percentage of hired female labour (87.4 %) compared to middle and lower caste households (83.6 % and 65.3 % respectively). Lower caste households, on the other hand, used the highest percentage of female family labour in rice production (54.2 %), compared to upper caste households that used the lowest level of female family labour (0. 2 %). But in every category of household, the female labour far exceeded that of male labour (upper caste 87.5 %; middle caste 83.7 % and lower caste 82.6 %).

In Jeypore, India, the primary centre of the origin of cultivated rice, Oryza sativa, women have the major responsibility for selection and storage of seed for the next season (Sharma, Tripathy and Gurung, 1997). On the other hand in the Malayali culture (Vedavalli, 1997) and in the Kurichiyas community, Kerala (Vedavalli and Sharma, 1997) the decision to grow certain paddy varieties, based on various factors such as nutritive value, tastiness and size of the grain, are reached by both men and women farmers. Religious concepts of purity and pollution prevent women from participating in selecting and storing paddy seeds in the Kurichiyas community. Only occasionally, older women may become involved in seed selection. In Arunachal Pradesh, India, older women identify varieties of paddy suited to differing soil conditions and also select "pure seed". Men do not have this skill and neither do younger men and women, especially if they have had some education (Krishna, 1998).

Though women play key roles in rice livelihood systems, the prevailing situation presents aspects of vulnerability for women in agriculture due to sex differentials in wages and uncertain access to the agriculture wage labour market as well as no access to drudgery reducing technologies and technical information in rice production. There also could be migration related impacts of the economic

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[3] Labour input is measured in person days per hectare.

vulnerability of wage contracts, and the social marginalisation of women agriculture labourers who lack assets. An important asset issue is the land rights for women. Under India's secular law, women have equal rights to land, however the customary law and local traditions undermine women's land rights. Women agriculture labourers also face the issue of technology training and access to technical information beyond the farmer-cultivator households in Tamil Nadu as well as across India.

Generally, rural and scientific communities are reluctant to accept and accommodate the changing gender realities with their implications for the advancement of rural women. Such persisting traditional perceptions that refuse to recognise changing gender realities contribute to additional constraints on women's access to technology, productive assets and resources in rice livelihood systems. Yet there is no significant effort evident to capture the changing realities of gender specific household division of labour or to address persisting gender specific constraints that might alter the situation of rural women in rice livelihood systems. The research agenda for the rural economic dynamics in changing India should expand the scope of studies to authenticate the changing realities of rural households with a gender perspective.

The United Nations Millennium Development Goals promote eradication of poverty and hunger through gender equality, empowerment of women and environmental sustainability (UN). These goals are relevant to organisational objectives promoted by FAO such as poverty reduction for food security, gender equality in rural agriculture and rural development and sustainability (FAO, 2000). India is home to the largest population living in poverty that also has rural dimension; small rice farmers are highly represented in the poverty population. India records greater gender equality gains in the urban sector compared to rural areas. In many countries of the region, as in India, rural women still lack access to basic services such as health, education and information. Such resource barriers undermine the advancement of rural women. Hence the timely focus of the Indian National Commission for Women: to reach rural women under the Common Minimum Programme. Indian agricultural institutions should address visible and explicit policy agenda and programme strategies for the advancement of rural women in the country that dominates the global rice trade. The rally for rural women's advancement should be supported by reliable field research to provide facts for advocacy and policy formulation.

Technological changes relevant to rice based livelihood systems

Many confer on women the credit for domestication of the rice crop that thus ushered in cultivated rice technology to the world food systems. But it is a demonstrated fact that access to technology and the impact of technology on rural women presents a mixed picture – gains and constraints. Rural women as workers in the subsistence rice based systems depend on their physical labour, time at their disposal and rudimentary technologies that are passed

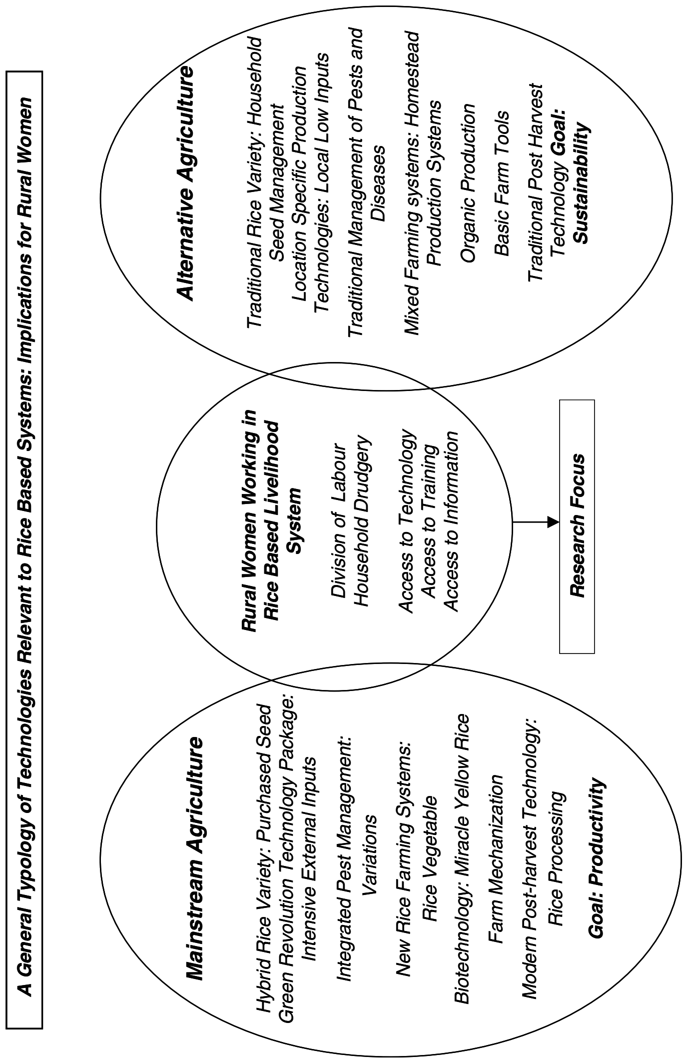


Figure 1

from generation to generation of women. It is of interest to review the changing modes of technologies that have impacted rice systems in the Asian region with implications for women's work and access to technologies. The regional synthesis has implications for India. The typology of technologies used here is a general description providing an overview, rather than systematic research on technologies and impacts (Figure1).

The technologies are grouped into two broad categories, mainstream agriculture and alternative agriculture. Mainstream agriculture is defined here as those technologies promoted by the agriculture research, education and extension organisations to improve productivity and that depend on high external inputs. Alternative agriculture is defined as technologies promoted by those opposed to technologies that they believe are destructive to local production systems, local communities and environment and that promote low external inputs (Savant, no date). The ideological foundations among these groups vary between productivity and sustainability. The proponents of mainstream agriculture promote productivity. The promoters of alternative agriculture emphasise sustainability. It is obligatory for those working to improve rural women's situation to assess current and potential impacts of competing technology paradigms for rural women in the rice livelihood systems.

A few essential facets of gender realities and women's situation should be considered in assisting rural women to take advantage of changing technologies in the agriculture sector. As mainstream agriculture technologies and crop management systems become increasingly sophisticated and complex, they require a basic level of formal education for absorption and adoption. As the feminisation of agriculture becomes increasingly common in Asia, it will be women farmers who will adopt these technologies. Most often the rural Indian women who are becoming farmers are deprived of formal education, particularly those working in small subsistence rice farming systems.

It also could be true for certain aspects of alternative agriculture technologies that labour centred production approaches would increase the work load of women. All technologies are not labour saving; some increase rural women's workload such as the case of biological pest control that requires labour in addition to the traditional method of pounding the paddy. There also is an inherent danger of farm women not moving away from the traditional methods of production that are passed on from generation to generation. For example, changing realities of the agro-ecological resource base will create new production constraints and increase demand on family labour.

The costs and benefits of such competing technology paradigms must be evaluated critically from the perspective of women farmers, yet very few systematic analyses address the impact of these technologies on rural women's work load, the drudgery of work, women's ability and capacity to adopt the technologies effectively or gender-equal access to these technologies. Technology assessments that have been driven by the ideological energy of the competing paradigm promoters focus on productivity or sustainability outcomes. Among proponents of both groups, the prevailing perception in technology assessment is that women's time lacks opportunity cost, meaning that women's time has no market exchange value in these subsistence production systems. Rural women generally use limited technology, not mechanised farming practices. Such differences in technology based task options that are available to women may help explain their wage differences. Hence, the need to develop an information base on rural women and technology to address the paucity of research based data and to provide a realistic assessment of differential impacts of promoted technology packages. The dearth of documentation on technology for rural women continues to undermine the effectiveness of policy advocacy and programme planning for gender responsive livelihood strategies in rice production systems.

Furthermore, innovations to use information and communication technologies (ICTs) to improve rural women's access to technical information are very few and still in the pilot phase. Among the barriers to apply ICTs for improving rural women's access to technical knowledge are the poor rural infrastructure and the lack of relevant content. India holds the potential to be a leader in breaking the information barriers to rural communities, including women in rice systems, by applying information technology expertise in the country.

The Asian region has set the trend for innovative technology transfer modality, such as Farmer Field School (FFS) for Integrated Pest Management in rice systems. Though women are equal partners in rice system management, the modality of FFS did not encourage the participation of women. Simply, rural women's role in rice livelihood systems varied from that of men and required different knowledge; this difference was not recognised in the FFS curriculum. Additionally, given women's multitasking work-load and their responsibilities in both on-farm and off-farm household production, the single technical focus or mono-crop oriented training may not be of interest to them. Thus, the current modality of Farmer Life Schools (FLS) for covering wide ranging topics may have greater potential attraction to women in rice based systems. The FLS helps farmers to develop their critical thinking (Vuthang, 2003). Yet the social restrictions and demands on women's time should be recognised and addressed in the technology package development and transfer approaches. It is important to research the ICT-based technology transfer approaches to reach rural communities with specific attention to content areas that assist rural women to use farm and home production technologies effectively.

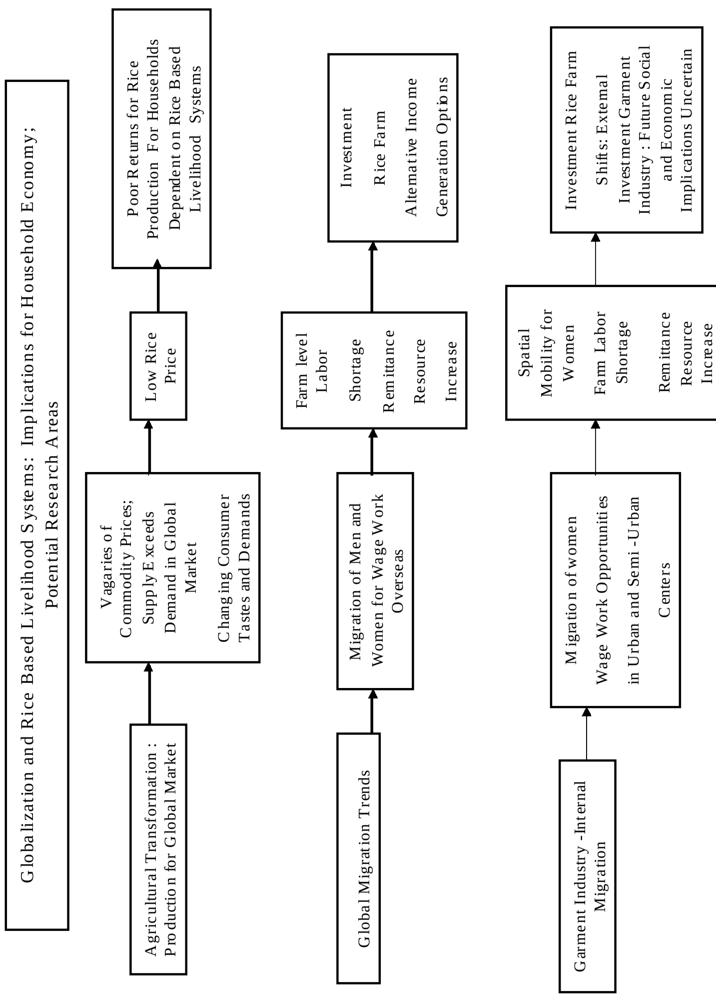
Globalisation impact on women in rice based livelihood systems: A regional scenario

Globalisation in its current complexity is marked by intricate economic linkages, intensified liberalisation of trade and the accelerated pace of economic integration. Globalisation can be viewed as a multifaceted phenomenon inclusive of economic integration, social transformation, population mobility and information exchange. In recent times the social, economic and information environments for agriculture production and rural development have constantly been affected by multifaceted processes referred to as "globalisation". All these aspects can impact the livelihood strategies adopted by women in agriculture and rural communities and their access to economic alternatives that may improve their living levels. In many instances the implications of these aspects to rural household resource allocation and the livelihood strategies adopted by rural women, though obvious, have yet to be approached analytically and quantified objectively. Although the rationale behind opening domestic markets was to create an efficient resource allocation and to enhance growth, the impacts in terms of gender differentiated benefits and losses at the individual level and the household level remains poorly understood.

Since globalisation involves many diverse aspects, a few components with identifiable links to the rice livelihood system and thus to rural women's livelihood strategies are selected here for discussion. The three scenarios presented (Figure 2) illustrate the impact of globalisation on women in rice based livelihood systems by drawing upon the realities of Asian rice economies. The general inferences from existing regional information have implications for India as well. To date, the analysis of linkages from global economic integration and consequent impacts on rural women in the rice based livelihood system is not extensive. Hence, the discussion depends on informed suggestions rather than systematic research on resource flow and rural livelihood assessments. An area of future research could focus on rural household dynamics to identify the external and internal forces that influence resource flow and thus the implications for poverty alleviation. Such research can be developed with the informed suggestive causal linkages identified in Figure 2.

Agricultural transformation and global market

Agriculture transformation is marked by placing less importance on production for self-sufficiency and investing instead in production for the global market. In many countries, including India, the green revolution achieved the objective of food grain sufficiency; but today the trend is toward agricultural transformation to serve a global market with a focus on economies of production for certain crops as well as diversification. The trend is driven by commercial purposes first to



Source: R. Balakrishnan

Figure.2.

meet the demands of the national urban markets followed by international agro-product markets. The agriculture sector increasingly depends on the global market for inputs such as fertilisers and pesticides to achieve high productivity, as well as for global consumer markets for selling the agriculture commodities. The global economic and technological linkages have become progressively more complex and present high risks to small farmers and marginal producers in the rural economies.

Developing countries are the main players in the world rice trade, with 83 percent of total exports and 85 percent of total imports. In the context of trade, in many exporting countries government intervention is aimed at supporting domestic producers. Trade measures are widely used to protect domestic rice markets. International prices for rice have been under strong downward pressure since 1997-1998, reflecting sustained growth in production combined with weak overall demand (FAO, 2003). This is reflected in the reality that most small Asian rice farmers are not in a position to build wealth from global trade, but adopt strategies to maintain their livelihood dependent on rice. In India, rice production is the way of life known for generations and as such farmers would continue rice cultivation, particularly since the production depends on unpaid family labour provided by women and children. *This aspect of emerging global markets and rural poverty and female unpaid labour in rice livelihood systems should be an interesting area of research.*

Population mobility : Global migration trends

Globalisation may accelerate population movement within the country and across country boundaries due to some economic benefits of globalisation that nonetheless pose risks and costs to individuals and rural communities. Due to the migration of younger people from rural to urban areas, ageing is often manifested earlier in rural areas than in urban areas. This process impacts the composition of the agricultural labour force by age and sex with implications for the division of labour in agricultural systems. In Asia the ageing of the population, combined with migration of youth, results in the greying of the farming population and feminisation of agriculture. In some Asian countries where the rural population depends on the rice based livelihood system, rural men and women migrate to other countries to serve in the labour markets. This phenomenon of female migration is common in Indonesia, Philippines and Sri Lanka. In such situations the impact on the local production system and household economy, most often centred on the rice farming system, can be anticipated. First, the remittance income from the migrant household member can contribute to maintaining a rice-based production system with hired labour and external inputs. Second, alternative investment diversification such as in transport industry (cycle rickshaw or auto rickshaw or small transport vehicles) will create livelihood alternatives in rural communities. It would be important to explore whether changes in the resource base for the rice farming rural households are dependent on migrants' contributions to the production process or to development of alternative livelihood strategies.

Garment industry and internal migration

There has been a high level of foreign interest and investment in the garment industry of Asian countries that are traditionally dependent on rice based livelihood in rural areas. Examples are Bangladesh, Cambodia, China, India, Sri Lanka and Vietnam. The interest stems from the economic advantage of low labour costs. The low labour costs have created employment opportunities for young rural women. Subsequently, the process has created a new generation of mobile female population moving away from the rural areas to semi-urban areas with aspirations of secure wage labour. These women's remittance incomes could provide additional resources to rural households while depriving the family of labour for rice based production systems. Looking ahead, as these countries would lose favoured trading partner status they could face rural social and economic disruptions. The generation of women would lose economic opportunities in the garment sector due to relocation of the industries to other countries on the rationale of comparative cost advantages. These women thus may need to return to their rural base with uncertain economic and social prospects. *The study of social and economic dynamics of female labour returning to rural areas is important to guide economic planning in rural areas.*

CONCLUSION

The rice livelihood systems observed in India demonstrate wide variation in resource management strategies and small rice farms that are mixed farming systems. In such multifaceted rice livelihood systems gender roles vary ranging from transplanting to processing and provisioning through supplementary income generation activities, but invariably women make critical contributions to the rice livelihood systems marked by their multi-tasking work-load. The cropping practices determined by agro-ecological factors, market demand and socio-cultural factors influence the demand and supply of female labour as family labour as well as cultivators and waged agricultural labour. Access to technology and the impact of technology on rural women present a mixed picture. It is obligatory for those working to improve rural women's situation to assess the current and potential impacts of competing technology paradigms for rural women in the rice livelihood systems. In recent times the social, economic and information environments of agricultural production and rural development have continually been affected by multifaceted processes referred to as "globalisation". All these aspects can impact the livelihood strategies adopted by women in agriculture and rural communities and their access to economic alternatives to improve their living levels. Yet to date, the analysis of global economic integration and consequent impacts on rice based livelihood systems and on rural women is not extensive. Asian rural women's multitasking activities in rice livelihood systems, though a primary research focus in late 1970s and early 1980s, have since then experienced declining attention. It is important to refocus attention on rural women in rice livelihood systems as changes in the Indian economic and the technological milieu bring considerable impact on rice livelihood systems. The agriculture research services should undertake quantitative analysis and qualitative case studies to document the situation of women in rice based livelihood systems. The research interests relevant to rural women's situation in changing India set in the milieu of globalization and emerging technologies should be identified and pursued.

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AGRICULTURAL EDUCATION : HISTORICAL PERSPECTIVE

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INTRODUCTION

Language profile of the people of a country in a given era is a true manifestation of the level of development of its education. Indians, since ancient times, speak in as many as 380 languages; today 18 are officially recognized. Sanskrit, the mother of almost all Indian languages, is one of the oldest and eminent languages of the World. Apparently, education was well embedded into Indian culture and way of life since time immemorial. Gurukal system of education, which emphasized a kind of day-in and day-out interaction between teachers and taught as the method of teaching and learning existed much before the 5000 year-old Harrappan and Mohenjodaro civilizations.

Agriculture continues to be the primary source of employment and economic activity for the continuance and sustenance of man and his animal support system. Our Vedic scriptures and pristine texts are replete with mention of a systematic and scientific methods of agriculture. This points to existence of a well-developed agricultural knowledge system based on experience and education. So much importance was accorded to spread of scientific agriculture, that as early as 660 BC, agriculture was included in the curricula of Nalanda and Takshila Universities as one of the 18 arts. In fact, it was Kautlya (~ 0 BC) who was engaged seriously to replace primitive agriculture with more scientific farming. Menon (1987) believes that it was during the British period (1770-1947) when birth of systematic enquiry for the development of agriculture took place.

Early History of Agricultural Education in India

In 1839, the East India Company brought in 12 American cotton growers to teach their Indian counterparts how that crop should be raised. In order to infuse good cultivation practices, the then Madras Government imported steam ploughs and a battery of implements in order to demonstrate how the soil should be cultivated. The great Famine of 1876-78 led the British Government to appoint a Famine Commission in 1880. Specifically, the recommendations contained in the Report of Dr. J.A. Voelcker, Consulting Chemist to the Royal Agricultural Society premiered the thesis that without promotion of scientific enquiry and development of appropriate human resource to pursue that endeavor, permanent stability to agriculture would not be possible. Launch of Famine Relief measures in 1881, setting up of a battery of agricultural farms and an Agricultural School at Saidapet in 1876, near the present-day Chennai city, marked the beginning of planned agricultural enquiry and education in India.

Agricultural education system in India distinctly evolved during pre independence era on British system of education and post-independence era on US Land Grant Colleges pattern. Some important landmarks of establishment of institutions and starting of programmes are mentioned in the Table 1. The available records show that the first school for organized teaching of agriculture was established at Cawnpore (now Kanpur) around 1880, which was followed by setting up of the first Veterinary College in undivided India at Lahore (now in Pakistan) in 1882. It was in 1889, when real beginning of research started with the setting up of an Imperial Bacteriological College at Poona (present day Pune). A three-year Veterinary Science course was started in 1884 at Parel, Bombay (now Mumbai). In fact, Veterinary Colleges were the first to be established. Besides those mentioned above, more Veterinary Colleges were set up at Calcutta (1893) and Madras (1903). Also as an outcome of severe famine, Lord Curzon, the then Viceroy of India (1898-1905), realized that the Government of India must pay priority and urgent attention to the development of agriculture. Thus in the beginning of 20th century, an Agricultural Research Institute each at Pusa in the Darbhanga district of Bihar (subsequently named Imperial and now Indian Agricultural Research Institute) and Coimbatore in present-day Tamil Nadu were established in 1905. Coinciding with these, Agricultural Colleges were also established at Kanpur, Lyalpur (now in Pakistan) and Nagpur in 1906, Pune in 1907 and Sabour (Bihar) in 1908. Like IARI, Agricultural College at Coimbatore has the proud privilege of 100 years of establishment and contribution to the development of Indian Agriculture.

Agricultural Education in Schools

Agricultural education in schools started with Punjab during 1923 when elementary agriculture was introduced as an optional subject in the curriculum of vernacular middle schools. Pedagogy included both classroom theory and field practicals. Either an agricultural farm or a garden were used for practical training. United and Bombay Provinces later adopted Punjab Model of school education. In 1937, Mahatama Gandhi advocated concept of ‘basic education’. His innovative concept dwelt around the concept – an educational system that combined work and dignity of labour. Students were involved in practical training through practice sessions in various village crafts, primarily agriculture. By 1944, there were 269 'basic schools' in the country. Along side development of agricultural education, fishery was also introduced as a vocational subject in school curriculum typically in the State of Kerala. It was the Department of Fisheries that since the beginning of 20^{th} Century operated 54 schools having vocational fisheries as one of the subjects in the curriculum. Also, as part of the formal school curriculum, agriculture was included as a technical subject in Gujarat, Maharashtra, Rajasthan, and UP.

Table 1. Historical landmarks of agriculture allied sciences education in India up to the set up of first SAU at Pant Nagar

1882	Lahore Veterinary College
1884	Degree awarded as Graduate of Veterinary College
1886	Bombay Veterinary College
1877	Agriculture college, Saidapet Tamil Nadu
1889	Imperial Veterinary Research Institute, Poona
1923	Two year diploma (associateship) equivalent to PG at Imperial agricultural research institute (IARI)
1924	Associateship of Indian Dairy Institute equivalent to PG, started
1930s	Masters and doctoral degree programmes in agriculture
1936	B.V.Sc. started at Madras Veterinary College
1905	Imperial Agricultural Research Institute, Pusa, shifted to New Delhi in 1936
1905-1908	Six Agricultural Colleges-Layalpur (now Pakistan), Kanpur, Nagpur, Coimbatore, Poona and sabour.
1923	Imperial Institute of Animal Husbandry & Dairying, Bangalore
1929	Imperial Council of Agricultural Research (now Indian Council of Agricultural Research)
1958	Grant of Deemed to be University status to IARI
1960	UP Agricultural University, Pantnagar-the first state agricultural university

In the independent India, only in the States of Madhya Pradesh and Uttar Pradesh, agricultural education is offered at 10+2 level (secondary education). Otherwise, it focuses primarily on graduate and postgraduate degree programmes (higher education).

Higher Agricultural Education

Following the launch of degree level programmes by the agricultural research institutes beginning 1905, a two-year postgraduate diploma also known as IARI Associatship was initiated at the then Imperial Research Institute at Pusa in 1923.On the recommendations of the Royal Commission on Agriculture (1928), Imperial (now Indian) Council of Agricultural Research was set up in 1929 to provide further encouragement and support to the already existing agricultural research institutes. In the early 1930s, postgraduate programmes leading to M.Sc. and Ph.D. degrees in agriculture were started. The Madras Veterinary College with affiliation from the University of Madras in 1936 launched a 4-year B.V.Sc. course. Further impetuous to veterinary education was given with the establishment of five more veterinary colleges between 1946 and 1948 at Mathura (1946), Rajendra Nagar (1946), Jabalpur (1948), Jorhat (1948) and Hisar (1948). Earlier than the establishment of these veterinary colleges, a degree courses in agricultural engineering began in early 1940s at the Allahabad Agricultural Institute (currently this institute enjoys a deemed to be university ststus).

By 1947, the year of independence, there were 17 agricultural colleges affiliated to general universities. Research and extension functions at that time remained the responsibility of the State Departments of Agriculture. In order to remove this distortion and to provide a holistic scientific base to Indian agriculture, Government in 1948 appointed the University Education Commission under the chairmanship of Dr. Radha Krishnan. One of the important terms of reference for this Commission was to review the state of higher agricultural education and to suggest measures that could lead the country to self-sufficiency in food grains and other food items. The Commission in its Report recommended that agricultural education be recognized as a major national priority so that country is able to feed itself. The commission recommended establishment of rural universities.

In order to further pursue the recommendations of the Education Commission, Government of India set up an Indo American Joint Team in 1955. After making a thorough study of the agricultural research and education system in the USA and India, the joint team recommended strengthening and reorientation of agricultural education including veterinary education. The recommendation of the team regarding improvement of Agricultural Education on the pattern of Land Grant Colleges of USA had far reaching impact, which resulted into the establishment of State Agricultural Universities. Government of India and Indo-US Technical Cooperation Mission in 1955 authorized five US land grant universities to strengthen agricultural institution in India. The five US universities were: Tennessee, Ohio, Kansas, Illinois, Pennsylvamia and Missouri.. In 1958 the second joint Indo-American Team on Agricultural education, research and extension was appointed to frame specific action plan for the Third Five Year Plan. The Team emphasized that there should be complete integration of research, teaching and extension at the college level. The Joint Team rechristened the Rural Universities. Their suggestion gave birth to State Agricultural Universities. Modeled on the pattern of the Land Grant Colleges of the USA, each State of the Indian Union was envisaged to set up one SAU each. With that arrangement, States provided large tracts of land, which was seen to subsequently become asset of the university both for the purpose research and demonstration and a source of internal resource generation. First SAU namely Gobind Ballabh Pant University of Agriculture and Technology was set up at Pant Nagar. Today, there are 210 constituent colleges of 38 SAUs, five DUs (four of the DUs are National Level Institutions of the ICAR), one CAU, and four CUs having distinct agricultural faculties (Table 2). In addition, some 100 private colleges affiliated to several General and some Agricultural Universities also provide agricultural education. The Indian Institute of Technology – a Deemed to be University – imparts education in the field of Agricultural Engineering.

Of the 38 State Agricultural Universities, one exclusively devotes to Horticulture and Forestry Education; another five concern with education in Veterinary, Fishery, Dairying and Animal Sciences. Education in agriculture and allied subjects has been patterned on the Land Grant College Model of the United States. With that influence, except private colleges, Agricultural Education establishments in India have embraced education, research and extension as integral to their functioning.

Table 2. Agricultural Education System in India

University	Number of Universities	Number of Colleges
State Agricultural Universities	38	210*
Central Agricultural University	01	06
Deemed-to-be Universities	05	10
Central Universities	04	04
Indian Institute of Technology	01	01
State General Universities	16	~ 100
Total	65	331

Includes nine affiliated colleges

Several states have more than one state agricultural university (five each in Maharashtra and UP, four in Gujarat, three each in Karnataka, West Bengal, two each in Rajasthan, Tamil Nadu, Himachal Pradesh, and Jammu & Kashmir. In addition to these universities there are large number of agricultural colleges affiliated to general universities and state agricultural universities. In

Maharashtra alone there are about 50 colleges affiliated to the state agricultural universities. The original recommendation of R.W. Commings committee for establishing one agricultural university has not been adhered to by several states and multiple and even sectoral universities have been established without considering manpower needs and financial, human resources and infrastructure availability. The Indian Council of Agricultural Research through Education Division coordinates, supports guides and facilitates higher agricultural education in the country. However ICAR due to lack of statutory powers is unable to play a decisive role in expansion and proliferature of institutions. Yet ICAR has succeeded in initiating and implementing several reforms in all state agricultural universities addressing quality and relevance of agricultural education.

Higher agricultural education is a state subject. As a consequence of that ICAR - the national apex body to support and promote research and education in the country – it is not able to institutionalize system-wide reforms. Since halting adhoc expansion of agricultural universities and colleges and sustaining quality of agricultural education imparted by them are the first ranking reforms, it is time to consider grant of legal authority to Accreditation Board of ICAR to adhere to prescribed academic norms and standards. The Accreditation Board was constituted within the framework of ICAR Society laws and by-laws and SAUs have accepted accreditation by it. So that more universities are opened after need analysis and recommendations on improving quality of agricultural education are complied with, grant of statutory status to Accreditation Board of ICAR by an Act of Parliament is need of the hour.

EXPERIENCE OF TEACHING SUSTAINABLE DEVELOPMENT TO BUSINESS AND ENGINEERING STUDENTS IN MEXICO

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INTRODUCTION

Leadership for sustainable development (LSD) course in ITESM-CEM is one of the consistent educational courses for postgraduates in different disciplines of Engineering, Administration and Science. Leadership and Sustainable Development is a common course to create a way for postgraduate students to contribute to have thought, care, insight, commitment and energy to perform assigned task (Barron & Goldman 1994, Allington, 2002). Great pools of prospective principals of interdisciplinary will continue in this program to enhance professional and Leadership development in the environmental, social and economic dimensions.

ITESM-CEM recognizes importance of teaching interdisciplinary themes of sustainable development course to post graduate students of Engineering and Science discipline and the students to develop Leadership and sustainable development through quality work. Consistent mission of this course program is to train students on knowledge base and practice to teach Leadership and Sustainable development. The teachers at ITESM-CEM know-how to construct and develop motivation for post graduate students to learn the Leadership and sustainable development through contextual, coherent professional experience with enthusiasm and academic excellence.

The aim of the present comprehensive study was to analyze the teaching materials of Leadership for Sustainable development to postgraduate students at ITESM-CEM, Course evaluation by students self assessment, teaching the interdisciplinary themes perspectives and academic challenges, Advantages and disadvantages and future improvement in design of course material for different discipline in postgraduate study.

Perspective

Leadership for Sustainable development contributes the spirit of partnership. In ITESM-CEM we believe the spirit of partnership as an essential to institutional health and performance. If the Leadership for Sustainable development is our purpose we consider that inter-institutional, interdisciplinary collaboration will be our style for teaching the course for postgraduate students. Besides academic institution we also believe firmly in building partnership with private and public sector. Our efforts on trade, technology, environment, international protocol, climate change and leadership through skills obtained students with higher level of proficiency in Sustainable development and Leadership.

Challenge

Through teaching of an interdisciplinary knowledge base educational communication we bring global messages into our class room audience to launch the experience locally through our advanced course material in Leadership development program to post graduate students with great interest, enthusiasm and greater level of institutional performance for quality in education.

Objective of the study

The over all purpose of the study is to analyze the critical interest and acceptability of Leadership for sustainable development course material for different discipline of Engineering and Science post graduates. The study investigates the following key premises: Course content, Students interaction, Professional development and Environment, Opinion of students on the Course material based according to their discipline and Course materials for Professional and Personal development.

Course Content

The course is mainly designed following Monterrey Tech innovative teaching techniques, project oriented learning and problem based learning, encouraging students self learning and collaborative work.

The course contents have been agreed upon student's area of specialty and the three dimensions of Sustainable Development. A common introduction is given about Sustainable Development and the main documents that precede the concept of sustainability and the SD sustainable agreements are read, reviewed and discussed, such as the 1980 World Conservation strategy, the 1992 Rio de Janeiro, Agenda 21 and the Johannesburg 2002 resolutions.

Following the introduction, there is an overview and analysis of Mexico and the world from the perspective of each sustainable development dimension. The main objective is to make the students aware of the social, environmental and economical problems and show them that there is still a solution to most of them. Some very successful activities are the ecological footprint calculations, carrying capacity, population growth models and case studies such as Curitiba in Brazil. Rural and urban sustainability exercises have been designed so as to let the students experience applications in nearby communities.

The next step in the course is to approach the specific topics of tools for Sustainable Development according to the type of Masters Course. For engineers a more technical content is offered whereas, for administration students sustainable business is the main theme of LSD.

For the engineering students, in the environmental dimension, cleaner production, life cycle analysis and ecodesign are studied. In the economic dimension cost-benefit analysis and economic input-output assessment are introduced from the point of view of the Mexican technical environmental standards and pollution prevention strategies. Case studies from the Mexican Cleaner Production Center and Mexican ecodesigned products are analyzed. The ecodesign strategies for material selection, and reduction, product structure and manufacturing process eco-efficiency, distribution system optimization, reduction of environmental impact during the use stage, reliable and durable design, and end of life sustainable options. In the social dimension, risk assessment and corporate social responsibility are studied. The conceptual map of the course is presented in Figure 1. The engineering course project topics are mainly related to cleaner production, life cycle analysis or ecodesign applications in a Mexican company.

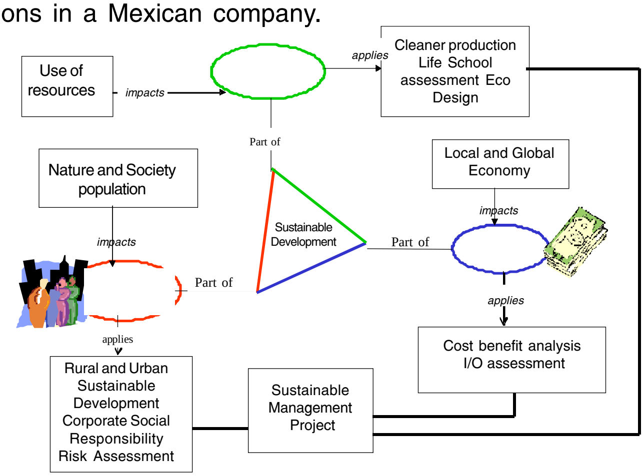

Fig.1. Leadership for sustainable development (M.Sc Students) ITESM- CEM

The administration students study mainly topics that are relevant to businesses seeking for sustainability. The Mexican environmental and social regulatory framework is presented and analyzed. The concept of a "sustainable enterprise" is introduced with different case studies from companies and the analysis of: *Sustainable Development: the next generation of business opportunity* (Hedstrom, d. Little), *A road map for natural capitalism (Hawken) and Walking the talk* from the World Business Council of Sustainable Development. (Holiday). Other topics studied are: environmental management systems (the ISO 14001 certification and the National Environmental Auditing Program from the Environmental Protection Attorney), green marketing, corporate social responsibility and life cycle assessment for benchmarking and ecolabelling. The conceptual map of the course is presented in Figure 2. The administration course project topics are mainly related to green marketing, life cycle costing and environmental management systems.

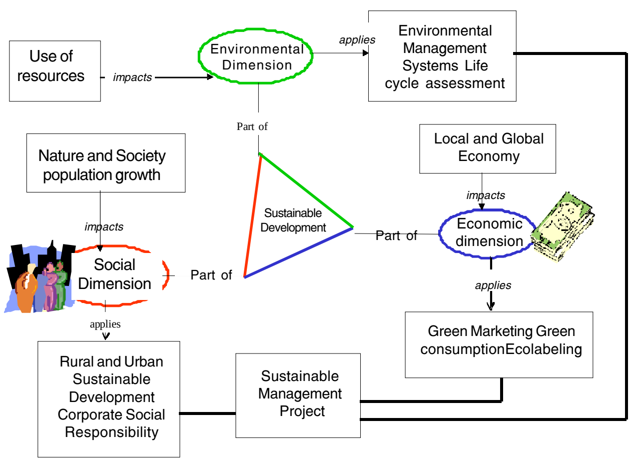

Figure 2. Leadership for sustainable development administration students at itesm-cem

The course material designed for Leadership and sustainable development is innovative to create a virtual space for collective knowledge on innovation and complex adaptive environment for post graduate students at ITESM-CEM. We are confident that our investment in staff development will lead this course for greater level of institutional performance and academic excellence.

Methodology & evaluation procedure

As a part of our research on teaching sustainable development and Leadership to master students we made a survey in 2004.

Students were given with questions to obtain open ended response. Types of responses were not specified in advance, we freely proposed following selected critical categories questions such as;

1. Why do they want to study LSD
2. Interest, leadership and commitment
3. Do they interact with environment as a specific interest
4. Are they making special effort to relate experience in environmental themes with their professional development
5. What is the most important themes from the syllabus that could be related to their professional career development
6. Do they think that LSD can help I their personal and professional development
7. What is the most interested themes in the LSD syllabus
8. What is their opinion of the themes of the syllabus

The questions helped to make an excellent survey to obtain the final result. In the survey we have given importance to evaluate the themes and sub themes of the proposed syllabus of LSD.

ITESM-CEM has always been committed to provide faculty and students with access to resource of reading, collection of research papers and we aware of wonderful collection of resources for the students in ITESM-CEM. Institutional commitment, infrastructure and technical support was not included as part of our survey because Students aware of the existing excellent infrastructure of the Institution.

RESULTS AND DISCUSSION

Since 2003, Leadership and Sustainable Development (LSD), has been given as a compulsory course to groups of the master degree courses in the ITESM-CEM system for post graduates of different Engineering & Science career and administration. We believe that all post-graduate students regardless of their career should take a beginning class in LSD. The themes can help in developing Sustainability Leadership and preparation for future.

Comparing proficiency levels across the subjects within the syllabus

Students come to ITESM-CEM campus with proficiency in most of the themes of the syllabus and staff and faculty provide assistance to resource of learning materials. Students have adequate access to our network as well. However, we have identified that the students from Finance, Business Administration and Computational sciences are lacking knowledge in basic environmental sciences for leadership. Students from Industrial engineering, Chemical engineering, Sanitary and Environmental engineering, Biotechnology, Architecture and Mechanical engineering had less informative on leadership development.

We consider developing interdisciplinary professional development and leadership by teaching the following themes to all the Science and engineering students such as;

1. Introduction to sustainable development (SD)
2. Natural resources, indicators of SD
3. Environmental management systems
4. Life cycle analysis
5. Society, population and corporate social responsibility
6. Risk analysis, green consumption and marketing
7. Environmental costing
8. Environmental Management simulation

Assessment from the survey

When we asked respondents why they have chosen LSD and the result (Fig.3) tended to mirror 84% of engineering students and 66% of administration students described as noteworthy mainly due to plan of study whereas, 16% of Engineering students, 26% of Administration students and 99% of students from Masters in Sustainable development (SDSC) responded due to their exemplary personal interest.

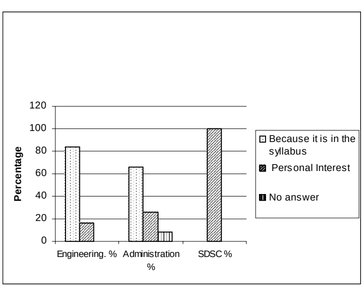

Figure 3. Students Assessment on Sustainable Development and Leadership Course (Why have you taken LSD?)

How is your own relationship with the environment?

Our tentative recommendation was that all the students to have basic knowledge in environment in LSD course. When we asked their relationship with environment to the respondents, almost 90% of the students are certain the importance of relationship with environment whereas, 7% have no idea of relationship with the environment at work or in daily life.

Table 1. Post-Graduate Students proficiency in syllabus themes of LSD

Syllabus Theme in SDL Course	Engineering (%)	Administration (%)	MSD (%)
Environmental Impact	26	0	0
Environmental Management	0	8	0
Green Market	0	8	0
Life Cycle of Products	26	10	0
Sustainable Development	0	8	0
Social Responsability	11	8	0
Energy	11	5	0
Pollution Control and Prevention	0	0	75
Environmental Global treaty	0	0	50

MSD = Masters in Sustainable Development

SDL = Sustainable development & Leadership

Table 1 shows the results of the survey of students career related to the themes of the syllabus of LSD. The data are presented in table 1 clearly indicate that administration student's proficiency in several environmental themes is relatively less consistent than engineering students.

Table 2. Themes of major interest showed by the post graduate students from different discipline in Engineering and Administration

Theme of LSD syllabus	Engineering %	Administration %	MSD %
Legislation and Norms	58	8	0
Environmental Impact	26	0	25
Water treatment	21	0	25
Life Cycle of Products	10	13	0
Environmental Leadership	0	2	100
Social Responsability	10	28	50
Soils	10	5	25

MSD= Masters in Sustainable Development

SDL=Sustainable development & Leadership

Table 2 indicates the results of the students interest in different themes of the LSD course. The respondents from administration did not show any interest in environmental leadership. 28% of Administration students showed interest in social responsibility whereas, 50% of post graduate students from sustainable development showed contextual interest in social responsibility besides environmental leadership. From our survey it is evident that postgraduate students should have LSD as an obligatory subject

CONCLUSION

The course material designed for Leadership and sustainable development is innovative to create a virtual space for collective knowledge on innovation and complex adaptive environment for post graduate students at ITESM-CEM. We are confident that our investment in staff development will lead this course for greater level of institutional performance and academic excellence.

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PLANTBREEDING:TRANSLATION, TRANSGRESSION OR TRANSFORMATION?

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Agriculture dates back to more than tens of thousand years and Plant breeding has evolved as a natural process. For example, farmers were selecting plants for their favoured traits from crops generation after generation in their own native environments. Thus mass selection, an important concept in plant breeding was in vogue in ancient days. Even now, traits preferred for taste and cooking quality are selected by tribal farmers in traditional landraces grown in tribal habitats and natural ecologies under their traditional practices of cultivation. As a result, such tribal habitats continue to be home to rich biodiversity though their custodians continue to be poor economically.

In India, Plant Breeding is known for its role in the development of high yielding varieties (HYVs) that steered a hunger-stricken India from poverty to plenty. The 'Green Revolution' brought in by HYVs of food crops, mainly wheat and rice, recorded high productivity increase. Over the 0time, however, its impact has receded creating special concern to scientists and administrators alike. But parallel improvements in molecular biology, in the recent past, have built a new vision. This vision despite involving significant costs has come for preferential promotion to reset the path of time-tested plant breeding.

But there are at least three seemingly divergent ground situations. The first is the spread of HYVs. They were sustaining India's food needs admirably so far. Requiring high chemical and agronomic inputs, they could spread more among endowed and large farmers leaving behind the poor and marginal farmers. To that extent, the spread was lopsided. Further the economic viability of HYVs held farmers to adopt the same crop rotation like rice-wheat year after year. Application of chemical fertilizers, and in addition a wide spectrum of pesticides, herbicides and fungicides to protect from increasing intensity and range of pests and diseases debilitated soil structure and hastened soil degradation. HYVs were given irrigation adequately and more, that led to mining of water and pushed water table deep down. Thus resulted stagnating and unsustained productivity, being described as the "fatigue" of green revolution.

The second concerns the farmers left out of the HYV technology and benefit. A large proportion of such farmers live in remote areas with a fertile ecology and environment. Tribal farmers are important among them. They grow traditional farm varieties and landraces that represent valuable agrobiodiversity. Tribal farming community has extreme regard for tradition. They possess valuable indigenous technical knowledge (ITK). They were conserving biodiversity as a routine tradition. Their ancestral cultivation methods were tuned to systematic weather that was in order years ago. Over time, changes in weather, causing temperature and rainfall fluctuations became hostile to good crop yield. This led to weaning of cultivation of landraces that led to genetic erosion. Poor yields of food crops accelerated poverty. Thus 'conservers' of crop diversity continued to suffer poverty in silence.

The third stemmed from the hypothesis that HYV farmers who helped to stem hunger in the green revolution era need to be helped with varieties countering pests and diseases improving the realized productivity substantially. The new group of 'molecular breeders' felt that developments in molecular biology would meet the demand. They desired to cross the barriers of sexual hybridization and attempt transfer of desired genes even from across species, basically for stress resistance. Importantly they were clear that development of novel varieties needs to occur fast and quick and the time normally needed by classical breeding process has to be reduced substantially.

But then what is the reality in each situation?

Increased efforts to produce a new spectrum of HYVs did not produce the impact of 'green revolution' period in the first situation. Efforts to introduce HYVs among poor farmers in remote habitats and tribal areas were not greatly successful in the second instance since traditional community does not prefer HYVs deficient in their preferred traits. Despite the great importance and large support given to molecular breeding in the third situation, products preferred by farming community remain either to be developed or those developed are yet to produce visible positive impact.

Yet the complex realities of the three situations generated adverse impact and testing time for the time-tested plant breeding. They provided evidence for radical change.

Plant Breeding is thus at cross roads. Many avenues in many directions are open. Molecular avenues beckon with indicative success. Globalisation of agriculture and the need to stand up to global competition are stepping up. Pressure on classical 'Plant Breeding' to perform more and beyond is increasing. Do we see any solution loud and clear? An analysis is attempted in this chapter.

Translation

'Translation' is an important phenomenon in cell function in which mRNA sequence is translated into the amino acid sequence of a polypeptide. In a literal sense, translation can be said to be a process of adapting theoretical logic to a line of action.

The classical 'Experiments in plant hybridization' of Mendel published in 1866 provided an unprecedented breakthrough in the now-familiar subject of quantitative genetics. They led to formulation of the celebrated Mendel's laws of heredity. Those laws helped to relate a phenotype (characterized by a QT) with the underlying genotype (characterized by a single gene with two alleles) and in turn, provided a fundamental logic to the science of plant breeding.

In the early days of plant breeding, a single (diallelic) gene was generally used to approximate genetic control of QTs including yield. It was generally conceived that a dominant homozygote would have high yield and recessive homozygote low yield. In other words, yield phenotypes (~ the QT, yield) were directly correlated to genotypes. The assumed perfect correlation between the phenotype and genotype implied that a plant selected for high yield would be a dominant homozygote. In breeders' population therefore, selection was made for high yield. If, in the process, heterozygotes were selected due to dominance, successive generations obtained by selfing would increase the frequency of selectable homozygotes. This genetic logic was translated as the concept of single plant selection in practice.

In course of time with the emergence of the subject of quantitative genetics, the assumption of single gene control was used only to draw firm fundamentals as a first approximation. In turn they helped to extend the theory from a simple to a complex situation. But compared to 3 possible genotypes in the case of a single diallelic gene, there would be 10 genotypes including the coupling and repulsion heterozygotes in the case of two diallelic genes. In addition there would be added complexities due to linkage and linkage disequilibrium when dealing with even simple selection. At this point, quantitative schools of thought diverged. The British school led by Mather, Jinks and others worked on theoretical extension of various results from single gene. Their work (Mather and Jinks, 1982) was directed more at a clear understanding of the theoretical framework in two- and multi-genic situations than on practical decisions for plant breeding. Though based on examples from animal breeding, Falconer (1981) dealt with principles of Quantitative Genetics of application value to breeding. The American and Australian schools led by Comstock, Robinson, Griffing and others directed their theoretical research to exploring newer methods of plant breeding. Development of mating systems, the consequent changes in the genetic structure of breeding population and various options in breeding for improvement and the like received special attention over time.

But Fisher's school of thought of working with variation instead of means proved to be uniquely powerful. Starting with a simple model relating phenotype (P) and genotype (G), namely, P = G + E in which E refers to environmental component, the relation $\mathbf{s}^2_p = \mathbf{s}^2_G + \mathbf{s}^2_E$ where $\mathbf{s}^2_{()}$ refer to the variances was derived under an assumption of independence of G and E. An analysis of variance of field data on a QT would help to estimate $\mathbf{s}^2_E$; $\mathbf{s}^2_G$ could then be estimated from the value of $\mathbf{s}^2_p$ using the above equation.

Further partitioning of the genetic value, G into its components like A, additive value and D, the dominance deviation, laid the foundation for predictive plant breeding. The variances of G, A and D gave rise to concepts of heritability and genetic advance and the base for the theory of selection. All the theoretical developments have well been documented in excellent detail in many books (see, for e.g. Kempthorne, 1957; Arunachalam and Owen, 1971; Falconer and Mackay, 1996; Mather and Jinks, 1971).

Further advancements of the subject modified the basic equation, P = G + E by adding components of genotype X environment interaction (popularly known as G X E interaction). However the assumption of independence of components in addition to a linear model (that is only an easy option not confirmed by any *a priori* logic) continue to be restraints. On a keen introspection, we need to agree that the fundamental equation and its extension do suffer by such indefensible assumptions.

Those situations came to the fore when geneticists and breeders had specific problems of plant/animal breeding to tackle. This led to more theoretical developments. For instance, random mating and selfing populations were examined for changes in gene and genotypic frequencies in successive generations. The theory of inbreeding was set in firm perspective and correlation between relatives was worked out. In particular, the covariance between half-sibs was derived as Cov (HS) = ¼ $\mathbf{s}^2_A$ and the covariance between full sibs as Cov (FS) = ½ $\mathbf{s}^2_A$ + ¼ $\mathbf{s}^2_D$ where $\mathbf{s}^2_A$ refers to additive genetic variance and $\mathbf{s}^2_D$ to dominance variance. They also highlighted mating between relatives in efficient estimation of additive and dominance variances and hence narrow sense heritability leading the way to analogous designs of mating such as North Carolina designs (NCDs, Comstock and Robinson, 1948, 1952). Yet inference and test statistics were rooted on restrictive single gene theory or its notional extension (for example, the average degree of dominance estimated using NCDs).

In due course of time, improved experimental plant breeding led to exploring the underlying genetic logic based on generalised assumptions instead of specific genetic control for traits. A specific case is the general treatment of diallel crosses by Griffing (1956a,b) compared to the treatment by Mather and Jinks (1982) based essentially on a single gene control (Arunachalam, 1984). Breeders started using Griffing's methods of analysis that gave a new fillip to the concepts of general (gca) and specific combining ability (sca) given by Sprague and Tatum (1952). Theoretical relationship between covariance of relatives and variance of gca and sca, particularly, Cov (HS) = Var (gca); and Cov (FS) - 2 Cov (HS) = Var (sca) easily admitted extension to many genes and thus were relevant to the practical breeding methods (Kempthorne, 1957; Arunachalam, 1995; Falconer and Mackay, 1996). Analysis of variance of combining ability helped to test the gca effects of parents and sca effects of related and unrelated crosses. Breeders were able to order parents on their gca effects and make desired crosses. Similar analysis of sca effects gave them clues either to select crosses that would have high chances to be bred as hybrids or to select those that could provide productive segregants to be further bred as productive pure lines. However, inconsonant results across traits and lack of simple methods to collate them still remained as major bugs. In this context, the problem of aggregating information across traits was given due consideration and efficient methods developed (Arunachalam and Bandyopdhyay, 1984; Arunachalam, 1993).

We thus see that the subjects of plant breeding and quantitative genetics were developed in synergy to relate practical breeding carried out in field with the theoretical basis behind. In this way, the logic behind obtained results was better understood. Under the built-in restrictions, it was possible to judge, with a probability, the efficiency of the breeding method. For example, high gca variance implies predominant additive effects and the possibility of some crosses doing better than their better parent on the strength of parental gca effects alone. Such crosses would provide prospective initiating points for deriving productive pure lines.

Space restricts exposition of such predictive logic behind every intervention of plant breeding. But the few examples given above do suggest that genetic theory is important to interpret a plant breeding action. They further illustrate that translation of an inherent genetic logic into plant breeding action was a milestone in purposive plant breeding.

Transgression

In Genetics, transgression refers to transgressing or outperforming a standard. Usually it refers to plants in segregating generations that transcend the performance of the parents. Performance is usually measured in terms of QTs of interest like yield, flowering time, maturity and the like. In the literal sense, it can be roughly referred to as significant improvement over an existing process or plan of action.

Transgression was a signal phenomenon that produced rich dividends in Plant Breeding. Development of hybrids is a classical example. Initial theory hinged on the fact that heterozygote could be superior to either homozygote due to a phenomenon known as overdominance. Such a superiority known also as heterosis provided a valid reason for preferential breeding of heterozygotes. The overdominance hypothesis emanating from the single gene theory was extended to more than one gene too. After a time, it was realized that overdominance *per se* was not a necessary condition when various types of genic interactions also govern the trait. It was shown that additive X additive interactions alone could provide heterosis under some conditions (Arunachalam, 1977). In general, significant sca variance governed by epistatic interaction would be a fair indicator for breeding of hybrids.

Falconer (1960; and in later editions of his book, Falconer and McKay, 1996) propounded that heterosis (betterment over the mid-parental value) was a function of dominance deviation and the square of deviation of gene frequencies of parents. This theory was based on random mating of two populations from which the parents were drawn. In practical breeding, hybrids are not always developed by such a process. But this hypothesis led to selecting for genetic divergence of parents to increase the chances of heterosis. Advances in hybrid breeding further suggested that moderate, and not extreme, levels of divergence are optimal for realizing heterosis (Cress, 1966; Arunachalam and Bandyopadhyay, 1984; Arunachalam *et al*., 1984).

Thus entered the problem of measuring genetic divergence in plant breeding. Several measures were in practice but we found that multivariate distance (*Mahalanobis' distance*) statistic extensively used in various types of problems (Rao, 1952) was quite efficient in measuring genetic divergence too (Murty *et al*. 1965; Chandrasekhariah *et al*., 1969; Arunachalam, 1981; Arunachalam *et al*. 1998). The distance statistic, popularly known as D^2, was commonly used later to classify and group varieties probable to be selected as parents in hybridization.

In theory, phenotypic expression of a QT is not only a function of the genes governing it but also those that influence it from background. For instance, several physiological traits like seedling vigour, leaf area and biomass in the pre-flowering stage influence traits at flowering, like days to flower and primary branches and post-flowering stages like grain number and grain weight. There could also be several other lurking genes constituting the genetic background that govern traits that are of no direct concern to breeders and others that are not even expressed. Such genes influencing QT expression constitute genetic background (GB) and it is as important as the expressed trait.

Langham (1963) proposed a hypothesis of high acumen to plant breeding. He defined a high (H) genotype as one that has a high frequency of genes enhancing expression but under a retarding GB. If, on the other hand, an augmenting GB were invoked, H would already serve the purpose of an improved variety. Similarly, a low (L) genotype was conceived as one that has a high frequency of genes impeding expression but under an augmenting GB. If a retarding GB were associated, L would have been out of existence under pressure of low genes in a retarding GB. Mating of the type H X L would then generate in the F_2 generation a spectrum of recombinants. It is then possible to recover a trangressive segregant governed by H genes under H background. Though the formulation could seem to be imperfectly simple, its credence remains above question.

This logic is inherent in a number of success stories in plant breeding. For example, in almost all the hybrid varieties in crops like sorghum, pearl millet, maize and others, one parent has always been low and the other high in the sense explained above (for example, all the male sterile parents used in hybrids are L in yield). In addition, genetically distant parents that produce heterosis over better parent reflect the High-Low concept effectively (See Arunachalam, 1980). In breeding for disease resistance, lines carrying resistance are usually low in productivity while those that are productive carry low resistance. Methods employed to derive productive and resistant lines, like repeated backcrossing or convergent crossing, are essentially High X Low crosses. In advocating the H - L concept, methods have also been devised to characterize an entity as H or L, for instance, based on the gca effects across a number of traits (Arunachalam and Bandyopadhyay, 1976). Breeders have been using these methods in various crops successfully.

It is known that QTs sustaining constant expression over time, say for earliness and low yield, would have the controlling genes and their GB in a flux known as coadapted gene complex. A population may have plants carrying various types of coadapted gene complexes like for example, relatively late but fairly productive. This implies that coadapted gene complexes formed a tightly linked combination in the particular environment. A breeding programme that needs to combine earliness with high yield would propose *inter se* crosses within population. Such crosses would promote recombination gradually and as linkage is broken, successive intermating would increase recombination to the desired end. The rate of success would improve only if a large number of crosses are made in each cycle. In the process, 'high' recombinants would get a fair chance of mating with 'low' ones producing successively improving population. Depending on the crop and the initial genetic status, a few cycles of intermating is expected to result in a productive population. This process is given various terminologies like biparental mating in an F_2 population and intermating in other cases.

The few instances explained in detail above demonstrate how simple single gene theory could transgress its restrictive frame and catalyze logical paradigms of practical breeding for QT improvement.

Transformation

Gene transformation is the process of introducing genes into plants by methods which bypass the sexual seed production process. Essentially, in this process genes (the parts of a cell that provide blueprints for inherited traits) are "cut" from the cells of one organism and "pasted" and integrated into the cells of another organism including plants. Once the cells are transformed, they are grown into new plants capable of "expressing" a desired characteristic. The panacea of this process is the possibility of transfer of a desired gene from any species to any other cutting across sexual barriers of hybridization. In a literal sense, transformation refers to the heritable modification of the properties of a plant.

In this sense, normal biotechnological processes including plant breeding are also examples of transformation. In a different context however, it is projected that regular plant breeding needs to be augmented by molecular technology assisted options. Molecular polymorphism as the path to generate a variety of molecular markers (MMs) some of which can be closely associated with QTs, has opened a new dimension of breeding. MMs showing inheritance pattern as single diallelic genes have generated a new class of 'perceptible genes'. They are credited with environment independence unlike 'Mendelian' genes. It is claimed that MM-assisted plant breeding would be more precise as genetic performance can be assessed direct without being clouded by environment as inherent in phenotype-based assessment in classical ('Mendelian') breeding. Those aspects will not be expatiated further here except to underline the crucial fundamental differences. The visual presentation below (Fig 1) depicts those differences vividly.

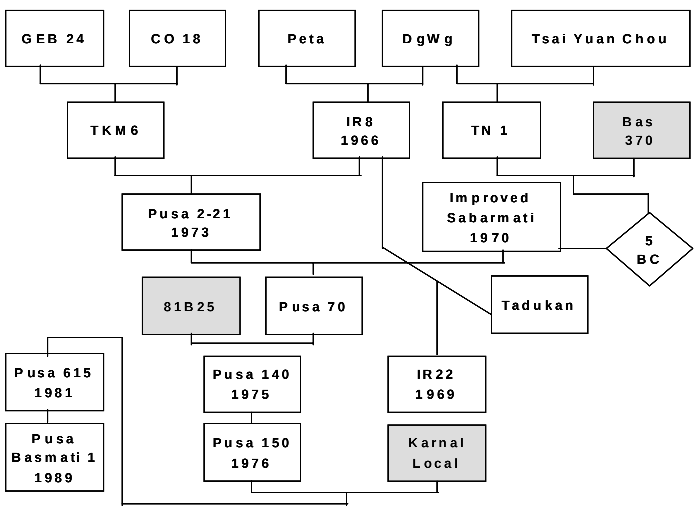

Fig 1. Molecular marker and Mendelian gene

The following points need to be recognized :

Though MM and Mendelian gene have genotypes, MM does not have a phenotype and hence no QT can be associated with it. Even if a very close association is conceived between MM and the Mendelian gene, the moment the QT value (of the phenotype) is associated with MM genotype, environmental component associated with QT automatically gains entry nullifying the claim that MMs are independent of environment. Application of known quantitative genetics theory then equates MM with the QT nullifying the advantage claimed.

- Only conventional plant breeding, particularly the mode of F2 segregation, is used to study the inheritance pattern of MM and the desired trait; but realized QT improvement has to be evaluated through the progeny performance in F3 and F4. Therefore other than the theoretical possibility (see below) of marking the presence of a QT through an MM, there seems to be nothing independent of classical breeding process and hence saving in the generation time needed for QT improvement does not automatically follow the process behind identification of an MM.

- In the published literature, papers enumerating a number of markers for various QTs in various organisms including crops are frequent. But papers establishing the sustainability of such markers to identify plants, say from a germplasm, that carry the marked trait are rare.

- MMs can at the most be analogous to single diallelic genes. Different MMs may mark different genes. But MMs are independent and there is no way by which they exist linked. Estimation of linkage, even if attempted, would be based on QT values of various phenotypic classes that would negate environment independence. A detailed published analysis of the deficiencies in MM based breeding (Arunachalam and Chandrasekharan, 1993) provides details.

- Further most of the MM-assisted breeding studies use recombinant inbred lines, backcross or F_2 selection lines as material to work with, admittedly at a high cost. But modern high yielding varieties with established performance have very complex pedigree involving years of complex breeding (see, for example, the pedigree of the Indian scented rice variety, Pusa Basmati 1 that fetched a creditable export market, Fig 2). Majority of MM-assisted breeding has targeted stress resistance and most of them used a few crops like soybean and maize across the globe.

Referring to transformation of fruit trees, Petri and Burgos (2005) observed that transformation and regeneration of commercial cultivars were not routine and generally limited to a few genotypes or seedlings. They further highlighted the need for development of methods that avoid the use of antibiotic-dependent selection or allow elimination of marker genes from the transformed plant as research priorities. The applicability of the import of those observations merit general consideration in plant breeding too.

But there are some innovative leads to pursue in the area of transformation breeding. Two examples will amplify the point.

Zidenga (2004) has reported "switchable" expression systems as a powerful biotechnological tool to regulate gene expression. A

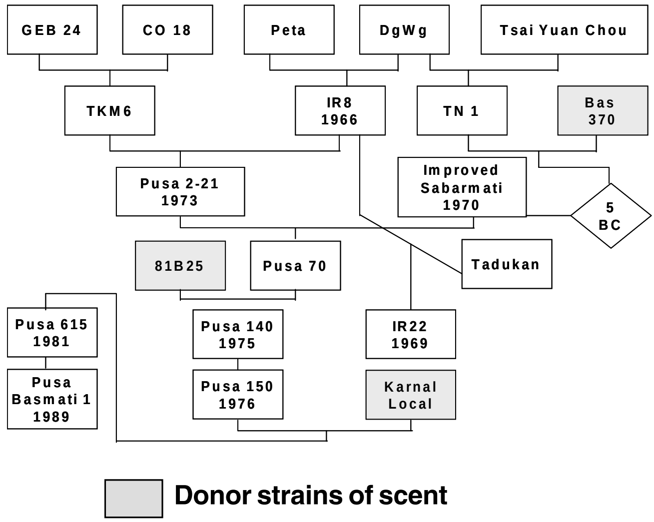

Fig 2. Pedigree chart of the rice variety, Pusa Basmati 1

case in point is the green revolution wheat varieties. They were dwarf because they responded abnormally to the plant growth hormone, gibberellin (GA). A group of DELLA proteins found in plants including *Arabidopsis* was shown to mediate GA-responses in all plants that contained them. *GAI* (*Arabidopsis* Gibberellin Insensitive) gene was shown to encode a member of the DELLA protein family. The *gai* gene encoding a mutant protein, gai, lacked DELLA domain and produced dwarf rice due to low GA response. But such transgenic expression could negatively affect yield. Further research showed that ethanol, an environment-friendly "green inducer", could act as a switch to induce dose-responsive repression of growth. It is then possible to programme whether a plant needs to dwarf or not, or even when to dwarf and by how much. Such a system should become versatile to tailor the growth properties of different crops and increase harvest index.

Correlated response of yield-related traits concomitant to incorporating dwarfing genes in wheat and rice varieties were highlighted earlier. Likewise it is recently reported that the floral homeotic gene, APETALA2 (AP2) determines seed size, seed weight and the accumulation of seed oil and seed protein in *Arabidopsis thaliana*. Several ap2 mutants could be recovered showing many of those traits (Jofuku *et al*., 2005). The question whether it would not then be possible to incorporate AP2 to improve the QTs like seed size, seed weight etc. remains appetizing.

Such leads using physiological, genetical and biochemical approaches would make sense only if committed efforts are made to translate transformation path into reality.

During 1960s plant breeding was specifically targeted for improving yields of food crops to solve the enormous deficit of foodgrains and consequent hunger in India. High yielding varieties developed in wheat and rice based on Mendelian breeding stood the test of time, mitigated the deficit and made India more than self-sufficient. Yet poverty still remains in remote areas and with people owning small areas of unproductive land. Not only people in such areas need exposure to science of agriculture and breeding but also they need training through demonstration of scientific agriculture. More than lateral transfer of high yielding varieties that may not also suit the areas and their consumption needs, the native local strains need to be conserved and bred for productivity increases. Several among the poor farmers are highly tradition-bound with high indigenous traditional knowledge. Their site-specific agro-biodiversity needs to be converted as their valuable assets using their intense desire to learn and adopt, despite their negligible knowledge on modern cultivation. The strong preferences for native varieties and the fact that perceived benefits would only persuade participation should be respected. In this light, there is hardly any scope for high end breeding options. This would need working with farmers hand in hand in their own lands, demonstrate not only high yields but also their economic value and benefit through necessary marketing avenues. In short, the need is for ensuring livelihood in its entirety using cultivable land as the base. This new approach to breeding that is fast growing is known by the popular name, participatory plant breeding.

Therefore recalling the fundamental equation, P = G + E we can observe the following:

1. Classical breeding progresses on P and E, inferring G through analysis of variation.

2. Molecular breeding aims to work directly with G alone that seems to be too ambitious a goal.

3. Participatory breeding deals essentially with the component, P of small, poor but biodiversity-rich farmers, visualizes their varieties, ecology and environment as a unified whole and aims to work for an integrated participatory technology.

We thus come back to the question we started with — Plant Breeding: Translation, Transgression or Transformation? We projected translation as a force and advanced transgression as a need in dynamic breeding, and rated transformation as a cutting edge, modern and innovative tool. All said, the current scenario demands a special pathway for poverty alleviation– doable options of the farmer, for the farmer and by the farmer. At the same time, we know conservation of biodiversity is urgent; cultivation, commercialization and conservation need to be mutually reinforcing. Preferably then the target varieties and the target traits for upgradation would be those desired by the farmer. Such varieties when developed would be "owned" by farmers. Their benefit and continuum would be automatically sustained. The challenge does not therefore remain in engineered HYVs and their horizontal transfer demanding heavy inputs, physical, chemical and economical, into farmers' rich habitat and ecology. The challenge should then be how we could design the phenomenal yield potential (we talk about in other contexts) into those farmer landraces and varieties. Abundance of such 'designer varieties' permeating fertile ecologies of the poor farming community would challenge poverty effectively. Our technology developments must fit to this frame. Breeding varieties in numbers, transforming varieties as a major option disregarding or ignoring alternatives and expecting the new products and technology to make forward inroads among the poor would be a tantalizing overexpressed anticipation at a great cost. Nevertheless discovering and exploring new avenues for plant improvement are forward developments; but providing scope for them to extenuate old and proven avenues would be a dangerously retrograde finale.

Therefore a thoughtful and well-balanced integration of the processes of translation and transgression with needed transformation would only be the path for successful plant breeding.

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PARA-NODULATION OF NON-NITROGEN FIXING PLANTS

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INTRODUCTION

Searches to discover new species of plants that form nitrogen fixing root nodules have a long history. These have been successful in identifying many new genera of legumes or families of actinorhizal plants that bear nodules induced by rhizobia or *Frankia*, respectively. One of the most fascinating of such discoveries was the identification of *Rhizobium*-induced nodules on the roots of *Parasponia*, a member of the Ulmaceae (Akkermans *et al.,* 1978). However, a significant number of observations of nitrogen fixing nodules on the roots of genera that are not legumes, members of the genus *Parasponia* or species of the eight families of actinorhizal plants that form symbioses with the actinomycete *Frankia*, have not been confirmed. For example, Steyaert (1932) noted the occurrence of root nodules on *Coffea klainii* and *C. robusta* growing in the Congo basin, from which bacteria were isolated with a morphology remarkable similar to *Rhizobium*. Nodules were observed on roots of *Tribulus terrestris* in 1913 by Issatschenko and subsequently there have been reports of nodulation on other members of the Zygophyllaceae (Sabet,1946). The nitrogen-fixing status of these structures, reputed to be the result of infection by rhizobia, was not obtained and later research casts doubt on the veracity of the findings (Allen and Allen, 1950; Bond, 1983). Similarly, reports of nodulation of *Arctostaphylo*s and of *Rubus* by *Frankia* have been discounted subsequently (Bond and Wheeler, 1980; Becking, 1977; Stowers, 1985). The structures reported as being caused by diazotrophic micro-organisms are often rather small and may be starch storage structures or caused by mycorrhizal fungi, by species of *Penicillium* (Capellano et. al., 1987) or by pathogenic bacteria such as *Agrobacterium tumefaciens.*

Nevertheless, discoveries such that of diazotrophic, rhizobium-induced nodules on *Parasponia,* a member of the Ulmaceae (Akkermans *et al.,* 1978) and of *Frankia*-induced actinorhizal nodules on *Datisca*, the only herbaceous genus of actinorhizal plants

(Chaudhary, 1979), have been partly responsible for encouraging continued searches for new nodulating genera in the field and also for stimulating attempts to induce nitrogen-fixing nodules on the roots of non-nitrogen fixing species, especially crop species. These approaches have been encouraged in the past by consideration of morphological and floristics data which indicated that many of the families of plants forming root nodule symbioses were distantly related taxonomically, suggesting that these symbioses evolved independently many times. Consequently, the view was held that Rhizobium and *Frankia* can adapt to a wide range of genetic backgrounds of the host plant and that the physiology and genetics of non-nodulating plants might be modified to form symbioses with diazotrophic organisms. However, the hypothetical foundations for such an approach were undermined by phylogenetic analysis of chloroplast gene sequence data, which showed that species of all ten families with diazotrophic nodules occur in a single, nitrogen-fixing clade (Soltis *et al.,* 1995). It seems, therefore, that only one lineage of closely related taxa evolved the genetics necessary for root-nodule symbiosis. Nine other families lacking this association were also placed in this clade, however, and there are many nonnodulating genera within families with nitrogen-fixing species. Further molecular data indicates the occurrence of multiple origins of symbiosis within this group (Swensen and Mullin, 1997) . Soltis et al. (1995) suggest that "efforts to unravel the process and evolution of nitrogen-fixing symbioses, and the transfer of this capacity to nonnodulating species, should first focus on taxa from the nitrogen fixing clade that possess and lack symbiotic nitrogen-fixing ability."

Paranodules induced with Rhizobium.

Several studies with the above objectives in mind have demonstrated that it is possible to induce the formation of nodule-like structures, para-nodules, on a variety of both monocotyledonous and dicotyledonous plants in culture by relatively simple manipulation of growth conditions (Christiansen-Weniger, 1998; Koval'skaya *et al.,* 2001; Cocking, 2003). The critical variable in such studies has been the levels of growth hormones, particularly auxins, in the culture media. Intracellular infection of such structures by symbiotic and associative nitrogen fixing bacteria such as *Rhizobium* (Spencer *et al.,* 1994), *Azorhizobium* (Christiansen-Wegener (1996); *Azospirillum* (Yu *et al.,* 1993) have been observed. While significant levels of nitrogen fixation have been detected in intracellular infections with associative bacteria (Christiansen-Weniger, 1998), nitrogen fixation with *Azorhizobium* was insignificant except under conditions of reduced oxgen pressure (Christiansen-Wegener, 1996) and insignificant or absent from associations with *Rhizobium* (Ridge *et al.,* 1993; Francisco and Akao, 1993; Spencer *et al.,* 1994). Such studies continue to have a role to play in identifying critical steps in the formation of symbiotic associations that may be modified or missing in non-nodulating plants.

Paranodules with *Frankia*

The actinomycetous, symbiotic nitrogen fixer *Frankia* has rarely been considered for inclusion in such experiments despite the obvious attractions of this organism, such as its ability to nodulate genera in eight different plant families, high rates of nitrogen fixation in culture and the differentiation of specialised structures, the vesicles, that provide a protective environment for the synthesis and functioning of nitrogenase (Schwintzer and Tjepkema, 1990). Pseudonodulation of actinorhizal species by cytokinins has been described (Bermudez de Castro *et al.,* 1977) but intracellular infection by *Frankia* of these tissues and of callus derived from roots or nodules of *Alnus* (Becking, 1977) and *Ceanothus* (Ellmore *et al.,* 1983) was not observed.

The absence of published information concerning the induction and the functioning of paranodules on actinorhizal plants led us to attempt to induce such structures on a non-nodulating member of a family with known, nodulating genera. Nodulation in the Rosaceae by *Frankia* has been confirmed for *Cercocarpus, Chamaebatia, Cowania*, *Dryas* and *Purshia* (Schwintzer and Tjepkema, 1990). These genera are grouped in the tribe Dryadeae of the sub-family Rosoideae. *Fragaria* (strawberry) is also a member of this sub-family but assigned to the Potentilleae (Morgan *et al.,* 1994) and was chosen for study because of its economic importance. In addition, methods for the genetic transformation of strawberry are well established (James *et al.,* 1990). Because symbiotic relationships with arbuscular mycorrhizal fungi have been demonstrated to enhance nodulation (Patterson *et al.,* 1990), particularly under conditions where the plant is well supplied with assimilates (Sempavalan *et al.,* 1995), experiments were included in which plants were inoculated with *Glomus mosseae*.

The roots of axenic plants, grown on Murashige and Skoog media with potassium nitrate as the nitrogen source and supplemented with 2,4 dichlorophenoxyacetic acid (2,4-D) showed considerable deformation, in particular reduction in root length, deformation of the root tips, swelling, thickening and induction of hypertrophic growths with some of the larger hypertrophies developing vascularisation provided that cytokinin (benzyl amino purine, BAP) was also included in the growth medium (Figure 1). Intracellular infection of larger hypertrophies by *Frankia* was observed but only on plants grown on media with 2,4-D (0.5mg l^{-1}), BAP and pyruvate and then only in plants inoculated with both *Frankia* and *Glomus* (Figure 1).

However, penetration of the outgrowths (para-nodules) by hyphae of *Glomus* was not detected, although the roots of strawberry are readily infected by this AMF (Mark *et al.,* 1999). The role of this organism in the colonisation process is unknown at present. However, it is widely accepted that signal exchange and recognition between host plants and AMF, possibly involving host flavonoids, are initiated prior to infection (Gianinazzi-Pearson, 1996).

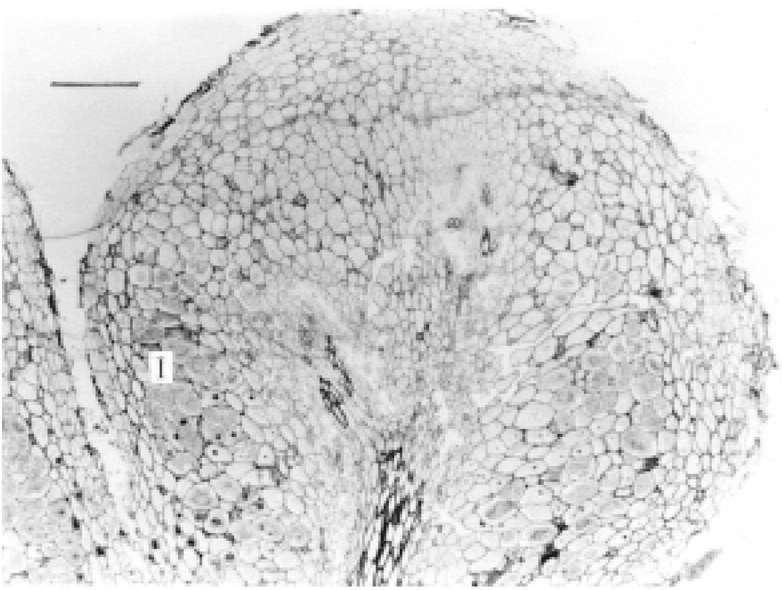

Figure 1. Light microscopy of section through a hormone induced para-nodule on strawberry roots inoculated with *Frankia* UGL020605s and *Glomus mosseae*, showing vascularisation and areas of *Frankia* infected cells (I). Plants were grown on M&S half strength medium supplemented with pyruvate (1.0 g l^{-1}), 2,4-dichlorophenoxyacetic acid (0.5 mg l^{-1}) and benzylaminopurine (0.5 mg l^{-1}).Bar = 100ìm

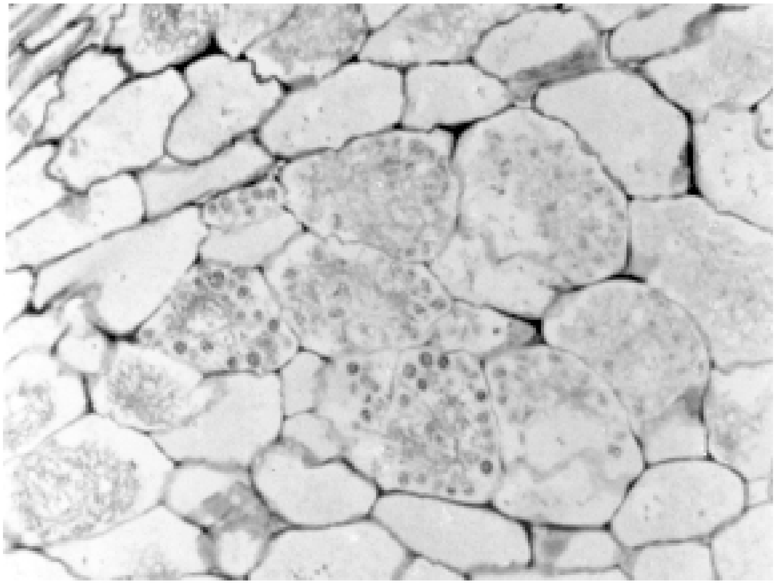

Figure 2. *Frankia* infected cells of strawberry para-nodules, showing *Frankia* mycelium and differentiation of vesicles.

Development of vesicles with septa was observed in some cells (Figure 2), a defining characteristic of *Frankia* in some conditions of culture and growth *in vivo* (Tjepkema *et al.,* 1981). These structures, with oxygen diffusion restricted by their specialised hopanoid-rich walls, are the primary site of nitrogen fixation in *Frankia in vitro* and in symbiosis with most host species. However, nitrogenase activity was not detected by acetylene reduction assay in any treatment. Vesicles may continue to be formed when cultures are supplied with mineral nitrogen at levels that suppress nitrogen fixation (Tjepkema *et al.,* 1981; Murry *et al.,* 1984) and this may explain why vesicles were present in para-nodules of strawberry plants grown with KNO_3 in the culture medium even though no nitrogenase activity was detected by acetylene reduction.

These experiments are the first demonstration of intracellular colonisation by *Frankia* of hypertrophic growths, induced by hormone treatment on the roots of a non-nodulating non-legume. However, as reported earlier for nodulation of other non-legumes by *Rhizobium* (Ridge *et al.,* 1993) the frequency of occurrence of such infections was low and when observed, was confined to larger, branched structures that had developed vascular bundles. Again, this observation is similar to that of Ridge et al. (1993) in their studies of para-nodulation of rice and wheat. It is of interest that auxin alone (2.4-dichlorophenoxyacetic acid) stimulated the formation of hypertrophic growths on strawberry but the formation of outgrowths that developed a vascular system was seen principally on the roots of plants with both auxin and cytokinin (benzylaminopurine) in the growth media.

CONCLUSION

Providing the proper balance of auxins and cytokinin is a critical factor for achieving the formation of root outgrowths with an organised structure, whether the nitrogen fixing organism is present or not. The actual route of penetration of the micro-organism into the outgrowth is not known, however, although it is possible that changes in the wall structure of epidermal cells, induced by auxin, may render them susceptible to penetration, followed by intracellular colonisation of the cells of the outgrowth and its conversion into a "paranodule". Both *Frankia* and *Rhizobium* secrete auxins and cytokinin and the occurrence of high levels of auxin and cytokinin in the root nodules of legumes and actinorhizal plants have long been recognised.

While it is conceivable that infection of the root outgrowths may involve stimulation of the release of inducing compounds by the roots, a process in which the presence of *Glomus* conceivably may play a role (Gianinazzi-Pearson, 1996), it is notable that Spencer et al. (1994) did not obtain evidence for the production of known nod-inducing factors by potato root cells susceptible to infection by rhizobia.

Finally, it should be noted that irregularity of infection of outgrowths is a feature not only of the study of infection of strawberry root outgrowths by *Frankia* but also of earlier studies of the formation of infected para-nodules by *Rhizobium* or associative bacteria on non-legumes (Ridge *et al.,* 1993). Further refinement of the experimental conditions for the induction of paranodules will increase further the value of these systems as experimental tool for investigation of the processes of nodule induction and infection.

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DYNAMICS AND REMEDIATION OF HEAVY METALS IN CONTAMINATED SOILS

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INTRODUCTION

The term 'heavy metal' in general includes elements (both metals and metalloids) with an atomic density greater than 6 g/cm^3 [with the exception of arsenic (As), boron (B) and selenium (Se)]. This group includes both biologically essential [e.g. cobalt (Co), copper (Cu), chromium (Cr), manganese (Mn) and zinc (Zn)] and non-essential [e.g. cadmium (Cd), lead (Pb) and mercury (Hg)] elements. The essential elements (for plant, animal or human nutrition) are required in low concentrations and hence are known as 'trace elements' or 'micro nutrients'. The non-essential metals are phytotoxic and/or zootoxic and are widely known as 'toxic elements'. Both groups are toxic to plants, animals and/or humans at high concentrations, and are refereed to as metal(loids) in this chapter.

Recently, literatures on heavy metals appear to have been dominated by their role as environmental contaminants. Indeed, six out of eleven most common contaminants at the U.S. National Priority List sites are metals, i.e., Pb, As, Cr, Cd, Ni and Zn, in decreasing order of frequency of occurrence (U.S.EPA, 1995). With increasing demand for safe disposal of wastes generated from agricultural and industrial activities, soil is not only considered as a source of nutrients for plant growth, but also used as a sink for the removal of contaminants from these waste materials. As land treatment becomes an important strategy in waste management, soil is increasingly being seen as a major source of heavy metals reaching the food chain, mainly through plant uptake and animal transfer. Such waste disposals have led to significant build up in soils of a wide range of metals, such as Cd, Cr, Cu, Hg, Pb and Zn, and metalloids, such as As, and Se. Entry of soil-borne metals into the food chain depends on the amount and source of metal input, the properties of the soil, the rate and magnitude of uptake by plants, and the extent of redistribution by grazing animals. The sequestration of metals by soils is controlled largely by the physico-chemical reactions of metals with soil components carrying surface charge and the biochemical transformations involving soil microorganisms.

Health authorities in many parts of the world are becoming increasingly concerned about the effects of heavy metals on environmental and human health. Historically, heavy metal toxicity to human health received attention primarily as a result of 2 series of widespread poisoning. First, the many cases of "Gasio-gas' poisoning, in which arsenic trioxide in wallpaper glue was converted into volatile poisonous trimethyl arsine or "Gasio-gas" $[(CH_3)_3As]$. Second, the hundreds of tragic cases of human poisoning of Minamatas Bay and Niigata in Japan (Minamata disease) in the late 1950s, believed to have occurred from the ingestion of fish containing methylmercuric compounds. Recently, high concentrations of heavy metals, such as As, Cd, Cu, Pb and Zn in soils, have often been reported in number of countries. For example, significant adverse impacts of As on human health have been recorded in Bangladesh, India and China and it is claimed that millions of people are potentially at risk from As poisoning. Similarly, Cd accumulation in the offal of grazing animals in New Zealand and Australia made it unsuitable for human consumption and affected access of meat products to overseas markets. Furthermore, bioaccumulation of Cd in potato, wheat, and rice crops has serious implications to local and international commodity marketing. Recently there has been concern about urban development of horticultural sites which contained toxic levels of Cu in soils resulting from excessive use of Cu containing fungicides. Similarly, Se toxicity in grazing animals and Pb accumulation resulting from the use of leaded fuel are widespread in many countries including India.

Unlike organic contaminants, most metals do not undergo microbial or chemical degradation and the total concentration of these metals in soils persists for a long time after their introduction. With greater public awareness of the implications of contaminated soils on human and animal health there has been increasing interest amongst the scientific community in the development of technologies to remediate contaminated sites. For diffuse distribution of metals (e.g. fertilizer-derived Cd input in pasture soils), remediation options generally include amelioration of soils to minimise the metal bioavailability. Bioavailability can be minimised through chemical and biological immobilisation of metals using a range of inorganic compounds, such as lime and phosphate (P) compounds, and organic compounds, such as 'exceptional quality' biosolid. The more localised metal contamination found in urban environments (e.g. Cr contamination in timber treatment plants) is remediated by metal mobilization processes that include bioremediation (including phytoremediation) and chemical washing. Removal of metals through phytoremediation techniques and the subsequent recovery of the metals or their safe disposal are attracting research and commercial interests. However, when it is not possible to remove the metals from the contaminated sites by phytoremediation, other viable options, such as *in-situ* immobilisation should be considered as an integral part of risk management.

In this article, we attempted to identify the major sources of heavy metals inputs to soils and then to discuss the key biogeochemical processes involved in controlling the dynamics of metals in soils. Various physical, chemical and biological techniques available for remediation of metals-contaminated sites are synthesized with an aim to develop integrated practical strategies at multi-scalar levels to manage contaminated soils. Future research needs, especially in the area of metal bioavailability and long-term remediation strategies are identified.

SOURCES OF HEAVY METALS INPUT TO SOILS

In terrestrial ecosystems, the soil is the main repository of contaminant chemicals. Heavy metals reach the soil environment through both pedogenic (or geogenic) and anthropogenic processes. Most metals occur naturally in soil parent materials, chiefly in forms that are not readily available for plant uptake. Often the concentrations of metals released into the soil system by the natural pedogenic (or weathering) processes are largely related to the origin and nature of the parent material. Apart from As (Mahimairaja *et al.,* 2005), Cd (Singh *et al.,* 1995) and Se (Dhillon and Dhillon, 2003), other elements (e.g. Cr, Ni, Pb) derived via geogenic processes have limited impact on soil. Unlike pedogenic inputs, metals added through anthropogenic activities typically have high bioavailability. Anthropogenic activities, primarily associated with industrial processes, manufacturing and the disposal of domestic and industrial waste materials are the major source of metal enrichment in soils (Table 1). Atmospheric pollution from Pb-based petrol is a major issue in many developing countries where there is no constraint on the usage of leaded gasoline.

Geogenic contamination of As in soils and water has been reported in many parts of the world (Mahimairaja *et al.,* 2005). One typical example is the extensive As-contamination of ground waters in Bangladesh and West Bengal in India.

Based on As geochemistry, three probable mechanisms have been offered for As mobility in ground waters of West Bengal and Bangladesh (Bose and Sharma, 2002):

(i) Mobilization of As due to the oxidation of As-bearing pyrite minerals. Insoluble As-bearing minerals such as arsenopyrite (FeAsS) are rapidly oxidized [Eq. (1)] when exposed to atmosphere, releasing soluble arsenite [As(III)], sulfate (SO_4^{2-}) and ferrous iron [Fe(II)] (Mandal *et al.,* 1996). The dissolution of these As-containing minerals is highly dependent on the availability of oxygen and the rate of oxidation of sulfide (Loeppert, 1997). The released As(III) is partially oxidized to arsenate [As(V)] by microbially mediated reactions (Wilkie and Hering, 1996).

$$FeAsS + 13Fe^{3+} + 8H_2O \rightarrow 14\ Fe^{2+} + SO_4^{2-} + 13H^+ + H_3AsO_4\ (aq) \qquad (1)$$

(ii) Dissolution of As-rich iron oxy-hydroxides (FeOOH) due to onset of reducing conditions in the subsurface. Under oxidizing conditions, and in the presence of Fe, inorganic species of As are predominantly retained in the solid phase through interaction with FeOOH coatings on soil particles. Onset of reducing conditions in such environments can lead to the dissolution of FeOOH coatings. Fermentation of peat in the subsurface releases organic molecules (e.g., acetate) to drive reductive dissolution of FeOOH, resulting in the release of Fe(II), As(III) and As(V) present on such coatings [Eq. (2)] (Nickson *et al.,* 2000).

$$8FeOOH\text{-}As_{(s)} + CH_3COOH + 14H_2CO_3 \rightarrow 8Fe^{2+} + As_{(d)} + 16HCO^{3-} + 12H_2O \qquad (2)$$

(where $As_{(s)}$ = sorbed As and $As_{(d)}$ = dissolved As).

(iii) Release of As sorbed to aquifer minerals by competitive exchange with phosphate ($H_2PO_4^-$) ions that migrate into aquifers from the application of fertilizers to surface soil (Acharya *et al.,* 1999).

However, the second mechanism involving dissolution of FeOOH under reducing conditions is considered to be the most probable reason for excessive As accumulation in groundwater (Smedley and Kinniburgh, 2002).

While sewage sludge is the major source of metal inputs in Europe, North America and a number of developing countries including India, P fertilizers are considered to be the major source of heavy metal input, especially Cd, in countries that use excessive amounts of P fertilizers such as Australia and New Zealand.

Phosphate compounds contain a range of metals as shown in Table 2. According to Nriagu (1984) "virtually every known element has been found, at least in trace amounts, in a phosphate mineral". Addition of P compounds to soils not only helps to overcome the deficiency of some of the metals, such as Mo, but also introduces toxic metals, such as Cd and F (McLaughlin *et al.,* 1996; Bolan *et al.,* 2005). In this regard Cd contamination of agricultural soils is of particular concern because this metal reaches the food chain through regular use of Cd-containing P fertilizers. This is one of the main reasons why this element has been studied extensively in relation to soil and plant factors affecting its bioavailability.

Table 1. Sources of heavy metals in soils and their expected ionic species in soil solution.

Metal	Density ($g\ cm^{-3}$)	Ionic species in soil solution	Contaminant sources	Toxicity[a]
Arsenic (As)	5.73	As(III): $As(OH)_3$, AsO_3^{3-}; As(V): $H_2As_4^-$, $HAsO_4^{2-}$	Timber treatment, paints, pesticides, geothermal	Toxic to plants, humans and animals
Cadmium (Cd)	8.64	Cd^{2+}, $CdOH^+$, $CdCl^-$, $CdHCO_3^+$, $CdSO_4^o$	Electroplating, batteries, fertilizers	Toxic to plants, humans and animals
Chromium(Cr)	7.81	Cr(III): Cr^{3+}, CrO_2^-, $CrOH^{2+}$,$Cr(OH)_4^-$; Cr(VI): $Cr_2O_7^{2-}$, CrO_4^{2-}	Timber treatment, leather tanning, pesticides, dyes	Cr (VI) toxic to plants, humans and animals[b]
Copper (Cu)	8.96	Cu^{2+} (II), Cu^{2+} (III)	Fungicides, electrical, paints, pigments, Timber treatment, fertilizers, mine tailings	Toxic to plants, humans and animals
Lead (Pb)	11.35	Pb^{2+}, $PbOH^+$, $PbCl^-$, $PbHCO_3^+$, $PbSO_4^o$	Batteries, metal products, preservatives, petrol additives	Toxic to plants, human and animal
Manganese(Mn)	7.21	Mn^{2+}, $MnOH^+$, $MnCl^-$, $MnCO_3^o$, $MnHCO_3^+$, $MnSO_4^o$	Fertilizer	Toxic to plants
Mercury (Hg)	13.55	Hg^{2+}, $HgOH^+$, $HgCl_2^o$, CH_3Hg^+, $Hg(OH)_2^o$	Instruments, fumigants, geothermal	Toxic to humans and animals
Molybdenum(Mo)	10.2	MoO_4^{2-}, $HMoO_4^-$, $H_2MoO_4^o$	Fertilizer	Toxic to animals
Nickel (Ni)	8.90	Ni^{2+}, $NiSO_4^o$, $NiHCO_3^+$ $NiCO_3^o$	Alloys, batteries, mine tailings	Toxic to plants, humans and animals
Zinc (Zn)	7.13	Zn^{2+}, $ZnSO_4^o$, $ZnCl^+$, $ZnHCO_3^+$, $ZnCO_3^o$	Galvanizing, dyes, paints, timber treatment, fertilizers, mine tailings	Toxic to plants

[a]*most likely to observe at elevated concentrations in soils and water.* [b]*while Cr(VI) is very mobile and highly toxic, Cr(III) is essential in animal and human nutrition and generally immobile in the environment*

Accumulation of Cd in soils through regular fertilizer use has been observed in many countries. For example, in New Zealand and Australia, most of the Cd accumulation in pasture soils has been derived from the use of P fertilizers containing high Cd concentration (Roberts *et al.,* 1994). The Cd in most P fertilizers originates mainly from the PRs used for manufacturing P fertilizers. It is important to stress that PRs deposits vary in their Cd content, leading to the variation in Cd contents of manufactured P fertilizers.

Table 2. Metal concentration in phosphate compounds from various sources (Adriano 2001; McLaughlin *et al.,* 1996; Syers *et al.,* 1986)

Phosphate compound[a]	*Concentration (mg kg^{-1})*								
	As	*Cd*	*Co*	*Cu*	*Zn*	*Mn*	*Ni*	*Pb*	*Hg*
GPR	*4*	*38*	*3*	*15*	*393*	*7*			
NFPR	*7*	*3*	*5*	*4*	*57*	*212*			
JPR	*12*	*4*	*<1*	*8*	*235*	*5*			
NCPR	*23*	*48*	*2*	*9*	*400*	*7*	*9-51*	*<1 – 51*	*0.4 – 2.1*
SPR	*5*	*11*	*3*	*6*	*178*	*91*			
MPR	*3*	*8*	*6*	*4*	*90*	*151*			
NIPR	*3*	*100*	*6*	*8*	*1010*	*122*			
APR	*7*	*12*	*4*	*12*	*560*	*2*			
MIPR	*2*	*10*	*<1*	*6*	*220*	*2*			
CRP		*2*	*4*	*5*	*95*	*100*			
IRP			*109*	*32*	*187*	*975*		*962*	
SSP			*77*	*15*	*165*	*890*		*488*	
TSP			*47*	*49*	*418*	*75*		*238*	
DAP			*16*	*7.2*	*112*	*307*		*195*	

[a]Phosphate rocks: GPR - Gafsa phosphate rock, NFPR - North Florida phosphate rock, JPR - Jordan phosphate rock, NCPR - North Carolina phosphate rock, SPR -Sechura phosphate rock, MPR- Mexican phosphate rock, NIPR - Nauru Island phosphate rock, ARP - Arad phosphate rock, MIPR - Makatea Island phosphate rock, CRP, Chatham Rise phosphorite, IPR - Indian phosphate rock; Phosphate fertilizers: SSP - Single super phosphate, TSP - Triple superphosphate, DAP - Diammonium phosphate.

The Cd in superphosphates is water soluble and high analysis P fertilizers, such as TSP, PAPR and ammonium phosphates generally contain lower Cd content relative to P. Although many countries have formulated threshold levels for Cd and other heavy metal accumulation in soils due to the use of municipal sewage sludge, such limits have not been established from fertilizer use. Based on the threshold level for sewage application (3 mg Cd kg^{-1} soil), the number of years required that would exceed the threshold level in soil through addition of various sources of P fertilizer is presented in Table 3. This indicates that although fertilizer addition represents the major source of Cd input to soils, at the normal annual rate of fertilizer input (40 kg P ha^{-1}) to pasture soils the rate of Cd accumulation appears to be very slow.

There have been increasing efforts in reducing the accumulation of Cd in soils through the use of low Cd-containing P fertilizers. This is achieved by either selective use of PRs with low Cd or treating the PRs during processing to remove Cd. Superphosphate fertilizer manufacturers in many countries are introducing voluntary controls on the Cd content of P fertilizers. For example, the fertilizer industry in New Zealand has achieved its objective of lowering the Cd content in P fertilizers from 340 mg Cd kg^{-1} P in the 1990s to 280 mg Cd kg^{-1} P by the year 2000. A number of PRs with low Cd contents are available which can be used for the manufacture of P fertilizers, but sources with higher Cd contents cotinue to be used in many countries for practical and economic reasons. Alternatively, since Cd has a low boiling point (BP = 789°C) it can be removed by calcining the PRs. Phosphoric acid used in the food industry is manufactured mostly only after the removal of Cd through calcination of the PRs. Calcination of PRs may not become a likely option in the fertilizer industry because it is expensive and calcination decreases the reactivity of PRs, making them less suitable for direct application as a source of P.

Table 3. Phosphorus (P) and cadmium (Cd) concentrations in various phosphate fertilizers and the calculated number of years required to exceed the threshold concentration of Cd (3 mg Cd kg^{-1}) in soils due to fertilizer application

Phosphate fertilizer	*Concentration*		*Years required to exceed the threshold limit*[a]
	P (g kg^{-1})	*Cd (mg kg^{-1})*	
Single superphosphate	*98*	*32*	*166*
Triple superphosphate	*190*	*70*	*152*
Diammonium phosphate	*200*	*10*	*1125*
North Carolina phosphate rock	*132*	*54*	*135*
Sechura phosphate rock	*131*	*12*	*614*
Egyptian phosphate rock	*130*	*10*	*732*
Gafsa phosphate rock	*134*	*70*	*107*

[a]At an annual fertilizer application rate of 40 kg P ha^{-1}

Large quantities of Cu are used in agriculture, horticulture and animal industries as a trace element nutrient, in many formulations of Cu containing fungicides, such as copper oxichloride and 'Bordeaux' mixture, and as a growth promoter in piggery and poultry units. Copper containing fungicides are quite effective in controlling many fungal diseases and are also permitted in 'organic' farming.

With increasing interest in 'organic' farming the widespread use of Cu fungicides is likely to continue in vineyards and citrus orchards. Accumulation of Cu in agricultural soils resulting from continuous use of Cu fungicides and sludge application has been reported in many countries.

Chromium is used as Cr(III) in the tannery industry and as Cr(VI) in the timber treatment industry. Cr(VI) is highly toxic and carcinogenic even when present in very low concentrations in water. Large-scale use of tannelised timber (treated with copper chromium arsenate, CCA) as fence post and in vineyards can also result in the release of Cu, Cr and As to soil environment. Of all the agri-based industries in India the leather industry appears to be the major source of pollution. Indiscriminate disposal of Cr-rich tannery wastes has led to extensive contamination of soils in many parts of India. In Tamil Nadu, where more than 60% of the tanneries operate, it has been estimated that more than 50000 ha of productive agricultural lands have already been contaminated with Cr and salts exceeding the maximum permissible concentrations (Ramasamy and Naidu, 2000). Soil sampled in the vicinity of tanneries in Vellore area has Cr concentrations of > 70000 mg kg^{-1} (Table 4). A number of highly contaminated sites also exist in Tamil Nadu.(Fig 1) The amount of Cr in the soils is particularly high around the closed (old) tanneries relative to the existing tanneries (Mahimairaja *et al.,* 2000c).

Table 4. Range in pH, EC, Cr and Na content of contaminated soils in Tamil Nadu (Mahimairaja *et al.,* **2000c)**

Location	*pH (1:5 H_2O)*	*EC (dSm^{-1})*	*Cr (mg kg^{-1})*	*Na (mg kg^{-1})*
Ambur	*8.11 - 8.57*	*0.15 - 12.3*	*924 - 16731*	*14216 -77711*
Vaniambadi	*7.68 - 8.87*	*0.43 - 20.6*	*569 - 79865*	*2405 - 74398*
Uncontaminated soil	*7.96 - 8.23*	*0.32 - 0.59*	*5.2 - 8.6*	*1022 - 2697*

In the majority of the groundwater samples collected from contaminated areas the Cr concentration exceeded the WHO's maximum permissible limit (50µg l^{-1}). Of greater concern was the finding that more than 85% of the Cr in most of the groundwater was in toxic Cr(VI) (Mahimairaja *et al.,* 2000a).

Figure 1. Chromium contaminated soil in Vaniambadi, Vellore district

Manure addition is increasingly being recognized as a major source of metal input to soils, with repeated applications having resulted in elevated concentrations of metals in soil. For example, the annual metal inputs to agricultural lands in England and Wales from animal manures amounted to 5247, 1821 and 225 Mg of Zn, Cu and Ni, respectively, which represent 25 - 40 % of the total inputs (Nicholson *et al.,* 1999). In New Zealand, an annual application rate of 2 - 5 kg Cu ha^{-1} through dairy shed effluent irrigation is sufficient to meet the Cu requirement for most pasture soils (Bolan *et al.,* 2002). However, repetitive applications of such effluent are likely to result in the buildup of excessive Cu in soils. Martinez and Peu (2000) estimated that 183 and 266 kg Cu and Zn, respectively, were added through 8 years of swine manure application, most of which accumulated in the surface layer.

Land application of sewage sludge is a major source of heavy metals accumulation in many countries including India. Land application of sewage sludge is a common method of disposal that is both economical and solves the disposal problem in a beneficial way, because the organic matter and nutrients are recycled back to the land. For example, 56% of approximately 6.9 m tons (dry weight) of sludge is land applied in US. Similarly in UK, 42% of the estimated 1.1 m tons of sludge produced annually is applied to agricultural land (Kirkham, 2004). Besides nutrients addition, the land application of sewage sludge also results metal(loid)s accumulation in soils, because it contains an abundance of As, Cd, Cr, Co, Cu, Fe, Hg, Mn, Ni, Pb, Se and Zn etc., Although all sludges contain a wide range of metal(loid)s in varying proportions, those from industrial areas generally have higher metal(loid)s concentrations than those mainly from domestic areas. However, domestic inputs of metals to the sewerage system are still significant. Owing to the relatively high concentrations of these metal(loid)s in sludges, they are usually the major source of metal(loid)s in the soils to which they are applied. The subsequent entry of these metal(loid)s into the food chain, through the crops grown on soils amended with sewage sludge may cause serious health hazards in animals and humans. Continuous application of untreated sewage effluent and sludge on agricultural fields is shown to cause heavy metal accumulation in soils of India (Kuhad *et al.,* 1990).

DYNAMICS OF HEAVY METALS IN SOILS

The dynamics of metals in soils depends not only on their physico-chemical interactions with inorganic and organic soil constituents but also on biological interaction associated, to a large part, with the microbial activity of the soil-plant system (Adriano, 2001). Traditionally most research has focused on the physico-chemical interactions of metals with soil components. Only in recent times the importance of microorganism-metal interaction in relation to environmental health and ecotoxicology has been realized (Alexander, 1999).

A. Physico-Chemical Processes

Metal ions can be retained in the soil largely by (ad)sorption, precipitation, and complexation reactions (Fig. 2). Sorption is defined as the accumulation of matter at the interface between the aqueous solution phase and a solid adsorbent (Sposito, 1984). This can include ion exchange, formation of surface complexes, precipitation, and diffusion into the solid. In many situations adsorption is believed to be the precursor for subsequent precipitation and it is difficult to separate the boundary between adsorption and precipitation processes.

Adsorption : Charged solute species (ions) are attracted to the charged soil surface by electrostatic attraction and/or through the formation of specific bonds (Barrow, 1985). Retention of charged solutes by charged surfaces is broadly grouped into specific and non-specific retention (Sposito,1984; Bolan *et al.,* 1999a). In general terms, non-specific adsorption is a process in which the charge on the ions balances the charge on the soil particles through electrostatic attraction. Whereas, specific adsorption involves chemical bond formation between the ions and the sorption sites on the soil surface (Sposito, 1984). If non-specific adsorption process solely controls metal adsorption then the adsorption capacity of the soil is dictated by its cation/anion exchange capacity. However, in many soils the amount of metal sorbed exceeds the cation/anion exchange capacity of the soils (Bolan *et al.,* 1999a). This infers that in addition to non-specific adsorption other processes, such as specific adsorption, precipitation and complex formation also contribute to metal retention in soils.

Both soil properties and soil solution composition determine the dynamic equilibrium between metals in solution and the soil solid phase. The concentration of metals in soil solution is influenced by the pH (Adriano 2001), and the nature of both organic and inorganic ligands (Bolan *et al.,* 1999b; Naidu *et al.,* 1994; Shuman, 1986). The effect of pH values > 6 in lowering free metal ion activities in soils has been attributed to the increase in pH-dependent surface charge on oxides of Fe, Al, and Mn, chelation by organic matter, or precipitation of metal hydroxides (Adriano, 2001). The effect of pH on the activity of metals in solution in naturally acidic soils is found to decrease with increasing pH. The gradual decrease in heavy metal activity with increasing pH especially in variable charge soils is attributed to increasing negative charge as measured by cation exchange capacity (CEC) (Shuman, 1986). In general, both the CEC and the total amount of metal removed from soil solution increase with increasing soil pH (Adriano, 2001).

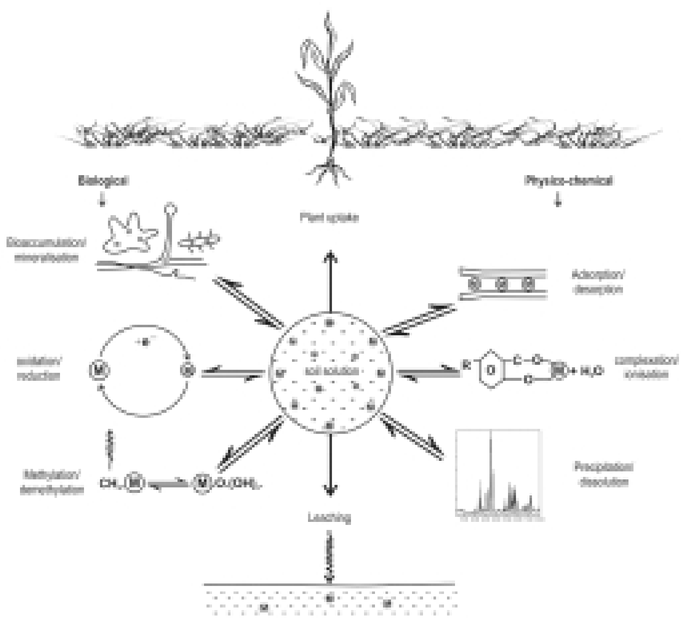

Figure 2. An overview of heavy metals dynamics in soil

Three reasons have been given for the effect of inorganic and organic anions on the adsorption of metals (Naidu *et al.,* 1994; Bolan *et al.,* 2004). Firstly, anions form complexes with metals, thereby reducing their adsorption onto soil particles. Secondly, the specific adsorption of ligand anions is likely to increase the negative charge on soil particles, thereby increasing the adsorption of heavy metal cations. And thirdly, specifically sorbed anions, such as phosphate ($H_2PO_4^-$) strongly compete with heavy metal anions, such as arsenate and selenate, resulting in their desorption. Phosphate-induced metal adsorption/desorption reactions in relation to (im)mobilization of heavy metals are discussed later in this chapter.

Complexation **:** Metals form both inorganic and organic complexes with a range of solutes in soils. A number of studies have examined the effect of inorganic anionic complex formation on the adsorption of Cd^{2+} by soils (Bolan *et al.,* 1999b; Naidu *et al.,* 1994). Most of these studies have indicated that chloride has often been found to form a complex with Cd^{2+} as $CdCl^+$, thereby decreasing the adsorption of Cd^{2+} onto soil particles (Naidu *et al.,* 1994). O'Connor *et al.,* (1984) showed that while the presence of Cl- ions decreased adsorption of Cd^{2+}, sulfate (SO_4^{2-}) ions increased Cd^{2+} adsorption relative to comparable concentrations of chlorate (ClO_4^-) in three calcareous soils. Cadmium-chloro complexation was identified as the active process reducing Cd^{2+} retention. They attributed the increased retention in the presence of SO_4^{2-} to the low Ca^{2+} ion activity available for competition with Cd^{2+} due to the formation of the soluble $CaSO_4^o$ complex.

In contrast to inorganic ligand ions, Haas and Horowitz (1986) found that Cd^{2+} adsorption by kaolinite, a variable charge mineral, was enhanced by the presence of organic matter which was attributed to the formation of an adsorbed organic layer on the clay surface. As might be expected, the organic component of soil constituents has a high affinity for metal cations because of the presence of ligands or groups that can form chelates with metals. With increasing pH, the carboxyl, phenolic, alcoholic and carbonyl functional groups in soil organic matter dissociate, thereby increasing the affinity of ligand ions for metal cations. The general order of affinity for metal cations complexed by organic matter is as follows (Adriano 2001):

$$Cu^{2+} > Cd^{2+} > Fe^{2+} > Pb^{2+} > Ni^{2+} > Co^{2+} > Mn^{2+} > Zn^{2+}$$

The extent of metal-organic complex formation however, varies with a number of factors including solution pH and ionic strength, nature of the metal species, dominant cation, and inorganic and organic ligands present in the soil solution. The formation of aqueous complexes of Cd with low-molecular-weight organic acids (LMWOA) from root exudates is expected to dominate the solution chemistry of Cd in rhizosphere. Based on differential pulse anode stripping voltametric and cation exchange resin extraction data, the dissolved Cd in soil solutions was found to be almost completely complexed with organic matter (Sauve *et al.,* 2000). Krishnamurti *et al.* (1997) observed significant solubilization of Cd from neutral to slightly acidic soils when extracted with acetic, succinic, oxalic and citric acids, suggesting that Cd release is related to the stability constant of the Cd-LMWOA complex.

Precipitation **:** Precipitation appears to be the predominant process of metal immobilization in high pH soils in the presence of anions, such as SO_4^{2-}, carbonate (CO_3^{2-}), hydroxide (OH^-) and H_2PO_4, especially when the concentration of heavy metal ion is high (Adriano 2001). Metalloids, such as Cr and As that form anionic species at field soil pH have been reported to form precipitates with cations, such as Ca^{2+} (Avudainayagam *et al.,* 2001). Co-precipitation of metals especially in the presence of iron (Fe) and aluminum (Al) oxyhydroxides has also been reported and often such interactions lead to significant changes in the surface chemical properties of the substrate. Precipitation as metal phosphates is considered to be one of the primary mechanisms for the P-induced immobilization of metals, especially in substrates containing high concentration of metals. This will be discussed later in this chapter.

Liming is often found to increase the retention of metals. For example, Bolan and Thiyagarajan (2001) have observed an increase in the retention of Cr(III) with an increase in pH due to liming, which they attributed to the formation of $Cr(OH)_3$. The increase in pH due to liming is also likely to increase the negative charge of these variable charge soils which may have enhanced Cr(III) adsorption.

Solid Phase Speciation **:** Irrespective of the nature of interaction between the metals and soil colloidal particles, following adsorption, metal ions redistribute amongst organic and mineral soil constituents. Fractionation studies suggest that the majority of the metals are associated with organic matter, Fe and Al oxides, and silicate clay minerals in soils. Factors affecting the distribution of metal among different forms include pH, ionic strength of the soil solution, the solid and solution components and their relative concentration and affinities for the metal, and aging. A large number of sequential extraction schemes have been used for soils, generally attempting to identify metals held in any of the fractions that include: soluble, adsorbed/exchangeable, carbonate-bound, organic-bound, amorphous ferromanganese hydrous oxide-bound, crystalline ferromanganese hydrous oxide-bound, and residual or lattice mineral-bound.

Metal fractionations using the sequential extraction techniques have primarily been used to identify the fate of the metals applied in sewage sludges and in soils contaminated with smelters and mine drainage wastes (Dudka and Chlopecka 1990). These studies suggest that treating the soils with sludges or wastes shifts the solid phases of the metals away from immobile fractions to forms that are potentially more mobile, labile and bioavailable. For example, Dudka and Chlopecka (1990) found that with sewage sludge application the residual forms of Cd^{2+}, Cu^{2+}, and Zn^{2+} in soil decreased from 34 - 43% to 6 - 34%, with a corresponding increases in the readily bioavailable forms. Whereas the treatment of metal contaminated soils with P compounds tends to cause the opposite effect in relation to solid phase metal fractions (Basta *et al.,* 2001; Bolan *et al.,* 2004).

A logical approach to minimize plant uptake and subsequent contamination of the food chain is to render the metals in the soil immobile. The phytoavailability of the different forms of the solid phase species generally decreases in the order: soluble > exchangeable/adsorbed > organic-bound > carbonate-bound > ferromanganese hydrous oxide-bound > residual or refractory (i.e., fixed in mineral lattice). Immobilization of metals, such as Pb, Zn and Cd could be achieved by additives, such as zeolites (Chlopecka and Adriano 1997), apatite (Basta *et al.,* 2001), Mn oxides (Hettiarachchi *et al.,* 2000) and clay-hydroxy Al polymers (Mench *et al.,* 1994) that may not produce any detrimental by-product nor alter the physicochemical environment of the soils to affect plant growth.

Elaborate sequential extraction schemes have frequently been used to identify the distribution of different species of the metal amongst the various fractions (Krishnamurti, 2000). However, very few attempts have been made to identify the particular species of the metal that contributes to bioavailability (Krishnamurti and Naidu, 2000). Physiologically-based in vitro chemical fractionation schemes are increasingly being used to examine the biovailability of metals. These schemes include Physiologically Based Extraction Test (PBET), Potentially BioAvailable Sequential Extraction (PBASE) and Gastrointestinal (GI) Test. These improved tests are capable of predicting the bioavailability of metals for both plant uptake and certain soil organisms.

Leaching and Runoff : Soils receiving organic byproducts such as sewage sludge and livestock/poultry manures for many years have been shown to contain high concentration of a range of metals including As, Cd, Cu, Pb and Zn, particularly near the soil surface

(Bolan *et al.,* 2004). These studies indicate a potential for manure-treated soils to serve as non-point (i.e., diffused) source of metal pollution through leaching and runoff.

The metal(loid)s in sewage sludge can runoff and contaminate surface waters or move to ground water through cracks or holes left by roots and worms. Under field conditions, a substantial portion of less-strongly adsorbed metals, like Cd, can leach out of the zone of incorporation of sludge. McBride *et al.* (1999) observed an elevated concentration of Cu, Zn, Mo, Cd, As, Cr, Ni, Sb, Ag, Hg and Sn in the ground water collected at a field site that had been heavily loaded with sewage sludge. For most of the heavy metals, the increased leaching was in response to the high metal loadings.

In a multi-location trial conducted in Haryana, India, Wiger *et al.* (2004) observed a marked increase in the total Zn (from 370 to 1000 mg kg^{-1}) and Cu (from 118 to 220 mg kg^{-1}) concentration, in soils due to the application of sewage sludge. However, the increase in Pb and Cd concentration was below the detection limit. They also observed high metal concentration throughout the soil profile due to extensive leaching. This leaching was probably enhanced by the coarse-textured sandy loam soil. High mobile concentration of Zn and Ni in the 60 - 90 cm layer indicates a significant risk of ground water contamination. However, the impact of sewage sludge on metal accumulation and on physico-chemical properties of soils are highly variable as determined by other edaphic and environmental factors. Similarly, Jeevan Rao and Shantaram (2004) examined the effect of long term disposal of urban solid waste (sewage sludge) on soils and found that substantial increase in the total and DTPA-extractable metal content, particularly Pb, Ni and Cr. Therefore, sewage borne metal(loid)s in soil could contaminate the ground water due to constant and continuous leaching.

L'Herroux *et al.* (1997) observed that repeated applications of swine manure slurry increased the concentrations of Mn from 0.05 to 14 mg L^{-1}, Co from 0.8 to 50 mg L^{-1}, and Zn from 17.3 to 100 mg L^{-1} in the drainage water. Similarly, Moore *et al.* (1998) observed increases in soluble As, Cu and Zn in runoff with increasing metal loading through poultry manure application, obtaining a good relationship between DOC and soluble Cu concentration in the runoff. However, treating the manure with $Al_2(SO_4)_3$ decreased the runoff losses of these metals, which was attributed to sorption of metals onto $Al(OH)_3$ formed upon hydrolysis of $Al_2(SO_4)_3$.

Studies on migration of metals in soils after sewage sludge and manure slurry applications have linked metal mobility with DOC (Japenga *et al.,* 1992). Although soluble organic metal fraction is not readily bioavailable to plants it is relatively mobile and the application of metal-rich biosolid and animal manure has been shown to enhance the leaching of metals in soils. For example, del Castilho *et al.* (1993) observed a positive relationship between soluble metal concentration and DOC in soils treated with cattle manure slurry. Li and Shuman (1997) observed that leaching metal-contaminated soils with poultry litter extract increased the water-soluble fractions of Cu and Zn, with a corresponding decrease in exchangeable fractions, indicating that poultry manure application enhances the solubilization and mobilization of metals. Acidification caused by manure application due to nitrification also results in the release of soil metals (Japenga *et al.,* 1992; del Castilho *et al.,* 1993). Hyun *et al.* (1998) obtained linear relationship between organic carbon and soluble Cd in solution for sludge-treated soils indicating that majority of the Cd remained as metal-organic complexes. Thus while organic matter in biosolids and manure byproducts provides some buffer against metal bioavailability, it does not prevent the metal from being more mobile.

B. Biological Processes

The dynamics of metals in soils depends not only on their physico-chemical interactions with inorganic and organic soil constituents but also on biological interaction associated, to a large part, with the microbial activity of the soil-plant system (Adriano, 2001). Traditionally most research has focused on the physico-chemical interactions of metals with soil components. Only in recent times the importance of microorganism-metal interaction in relation to environmental health and ecotoxicology has been realized (Alexander, 1999).

Two approaches have been used to examine the interaction between microbes and metals in soils: (i) the influence of metals on microbial population and functions (e.g., biological nitrogen fixation); and (ii) the influence and the role of microbes on the transformation of elements (e.g., bioaccumulation) (Alexander, 1999). A large number of studies have examined the toxic effects of metals on microbial population and functions, the environmental factors affecting the toxicity, and the mechanisms involved in the development of metal-resistance in microorganisms. Microorganisms control transformation of metals by various mechanisms that include bioaccumulation, oxidation/reduction and methylation/demethylation (Alexander, 1999). Such transformation plays a key role in the behaviour of certain metals such as As, Cr, Hg and Se in soils/sediments.

***Bioaccumulation*:** Micro organisms exhibit a strong ability to sequester metals from substrate containing very low concentration. Both bacteria and fungi are involved in bioaccumulation of metals, which is mediated by two processes: (i) sorption (i.e., biosorption) by microbial biomass and its byproducts; and (ii) physiological uptake through metabolically active and passive processes.

Gram-positive bacteria posses cell walls with strong chelating properties. Metal-loaded bacterial cells have been shown to act as nuclei for the precipitation of crystalline metal deposits when they are incorporated with contaminated sediments (Alexander, 1999). The metabolically independent sorption may account for the most significant portion of total uptake. For example, Surowitz et al. (1984) found up to 90 % of total Cd uptake by Bacillus subtilis was located in the cell wall, 3-4 % on the cell membrane, and the reminder in the soluble fraction of the cell.

A wide range of binding groups, such as carboxyl, amine, hydroxyl, phosphate, sulfhdryl have been implicated in the biosorption of metals. Living or dead biomass can act as biosorptive agent; the magnitude of the phenomenon is directly related to biomass density. Bacteria are capable of producing large quantities of extracellular polymers that can form either capsules or loose aggregates around individual cells. In many cases, these are of a polysaccharide nature with anionic properties and are implicated in the removal of soluble metal ions from solution by ion-exchange process (Alexander, 1999). For example, macrofungi, such as Agaricus can bioaccumulate Cd and Hg from soils/compost containing low concentration of these elements. Many fungal products, such as glucans, mannans, melanins, chitins, and chitosans can act as efficient biosorption agents.

Microbial oxidation/reduction : Arsenic, Cr, Fe, Hg, Mn and Se are some of the metals that are most commonly subjected to microbial oxidation/reduction (redox) reactions. In general, metals are less soluble in their higher oxidation state, whereas in the case of non-metal and metalloids, the solubility and mobility depend on both the oxidation state and the ionic form (cation vs anion) (Adriano, 2001).

The redox reactions are grouped into two categories, assimilatory and dissimilatory.In assimilatory reactions, microorganisms assimilate only those elements which they need to make protein and body tissue. The substrate will serve a role in the physiology of the organism by acting as terminal electron acceptor and permitting growth, such as O_2 for aerobes, simple organic molecules for fermentative microbes. In the dissimilatory reactions the elemental substrate has no known role in the physiology of the species responsible for the reaction, and represent merely casual reductions coupled to enzymatic or microbial oxidations of some other substrates.

Selenium occurs in organic forms, and therefore is subject to microbial redox reactions. Although Fe and Mn do not occur in organic forms in soils, microorganisms mediate their transformation through redox reactions. Redox reactions involving Fe and Mn in particular have generally been attributed to indirect action of microorganisms (e.g., electron donors are thought to be reduced fermentation products), although there has been some evidence suggesting the use of these metals as electron acceptors. For example, oxidation of Fe and Mn occur spontaneously in the absence of microbial activity when reduced environments are exposed to oxygen (Alexander, 1999).

In living systems Se tends to be reduced rather than oxidized. Selenium is reduced under both aerobic and anaerobic conditions. Dissimilatory selenate reduction to Se^{o} is the major biological transformation for remediation of Se oxyanions in anoxic sediments. Selenate [Se(VI)] is more mobile than selenite [Se(IV)] because the former is strongly adsorbed onto soil minerals and organic matter under near neutral pH conditions. When Se(IV) and Se(VI) are introduced into moderately reducing conditions they are quickly transformed through microbial processes to Se^{o} and/or organic Se compounds. Selenite is readily reduced to the elemental state by chemical reductants, such as sulfide and hydroxylamine, or biochemically by systems, such as gluthione reductase. Hence precipitation of Se in its elemental form, which has been associated with bacterial dissimilatory selenate reduction, has great environmental significance. Since both selenate and nitrate can be used as terminal electron acceptors by many microorganisms, presence of nitrate in the system inhibits the reduction of Se (Frankenberger and Losi, 1995).

Arsenic in soils and sediments can be oxidized to arsenate [As(V)] by bacteria. Since [As(V)] is strongly retained by inorganic soil components, microbial oxidation results in the immobilization of As. Under well-drained conditions As would be present as $H_2AsO_4^-$ in acidic soil and as $HAsO_4^{2-}$ in alkaline soils. Under reducing conditions, arsenite [As(III)] dominates in soils, but elemental arsenic (As^{o}) and arsine (H_2As) can also be present. Arsenite is much more toxic and mobile than As(V). The distribution and mobilization of As species in the sediments is controlled by both microbially mediated transformation of the As species and by adsorption.

While Cr(III) is strongly retained onto soil particles, Cr(VI) is very weakly adsorbed and is readily available for plant uptake and leaching to groundwater (James and Bartlett, 1983). Cr(VI) can be reduced to Cr(III) in the environments where a ready source of electrons is available (Eq. 4). Suitable conditions for Cr(VI) reduction occur where organic matter is present to act as an electron donor, and Cr(VI) reduction is enhanced in acid rather than alkaline soils (Bartlett and Kimble 1976; Bolan *et al.,* 2003g).

$$2Cr_2O_7 + 3C^o + 16H^+ \rightarrow 4Cr^{3+} + 3CO_2 + 8H_2O \quad (4)$$

A number of studies have shown that addition of organic matter-rich soil amendments enhances the reduction or transformation of certain metals, such as Cr and Se (Frankenberger and Losi, 1995; Alexander, 1999). For example, Ajwa *et al.* (1998) noticed greater loss of Se from inorganic fertilizer-borne Se than from manure-borne Se, which they attributed to manure-facilitated volatilization due to the reduction of Se. Similarly, Losi *et al.* (1994) have noticed that the addition of cattle manure resulted in the reduction of Cr(VI) to less toxic and less mobile Cr(III). Various reasons could be attributed to the enhanced reduction (i.e., lowering in valency) of Cr(VI) in the presence of the organic manure compost, including the supply of carbon and protons and the stimulation of microorganisms that mediate and facilitate the reduction of Cr(VI) to Cr(III) (Losi *et al.,* 1994). At the same level of total organic carbon addition, Bolan *et al.* (2002) observed significant difference in the extent of Cr(VI) reduction between various organic manure composts. The extent of Cr(VI) reduction increased with increasing level of DOC added through manure addition, which has been identified to facilitate the reduction of Cr(VI) to Cr(III) in soils. For example, the hydroquinone groups in organic matter have been identified as the major source of electron donor for the reduction of Cr(VI) to Cr(III) in soils (Elovitz and Fish, 1995). The increase in Cr(VI) reduction in the presence of organic manure addition may also result from enhanced microbial activity. Losi *et al.* (1994) have shown that the addition of manure compost caused a larger increase in the biological reduction than chemical reduction of Cr(VI), indicating that the supply of microorganisms is more important than the supply of organic carbon in enhancing the reduction of Cr(VI) when compost is added.

The biochemistry of microbial redox reactions of metals elements has not been completely characterized. In some systems (e.g., Se), metal transformation is coupled with the cytochrome system. Also specific metal-active enzymes may play a role in metal reduction. For example, the Se reducing organism Thauera selenatis reduces selenate to selenite using a selenate reductase and selenite reduction to Se° appears to be catalyzed by periplasmic nitrite reductase. However, Se reduction in a *Pseudomonas sp* is part of the anaerobic respiration process (Rech and Macy, 1992).

Methylation/demethylation : The redox reactions of metals such as As, Se and Hg also include methylation/demethylation reactions. Methylation is considered to be the major process of volatilization of As, Hg and Se in soils and sediments, resulting in the release of poisonous methyl gas. Though methylation of metals occurs through both chemical (abiotic) and biological processes, biological methylation (biomethylation) is considered to be the dominant process in soils and aquatic environments. Thayer and Brinckman (1982) grouped methylation into two categories: trans-methylation and fission-methylation. Trans-methylation refers to the transfer of an intact methyl group from one compound (methyl donor) to another compound (methyl acceptor). Fission-methylation refers to the fission of a compound (methyl source), not necessarily containing a methyl group. This is then captured by another compound and the resulting molecule is reduced to a methyl group.

At present there is substantial evidence for the biomethylation of Se in soils and aquatic systems (Frankenberger and Losi, 1995). Microorganisms in soils and sediments act as biologically active methylators. Organic matter provides the source of methyl donor for both biomethylation and abiotic methylation in soils and sediments.

Selenium biomethylation is of interest because it represents a potential mechanism for the removal of Se from contaminated environments, and it is believed that methylated compounds, such as dimethyl selenide (DMSe) is less toxic than dissolved Se oxyanions. Fungi predominate among the Se methylating microbes in soils although some bacterial isolates have also been identified. Hydrogen oxidizing methanogens such as Methanobacterium omelianskii are involved in the reductive methylation, while methylotrophic bacteria carry out demethylation. Dimethylselenide can be demethylated in anoxic sediments as well as anaerobically by an obligate methylotroph similar to Methanococcides methylutens.

Five different volatile forms of reduced Se have been detected: hydrogen selenide (H_2Se), methaneselenol (CH_3SeH), dimethyl selenide (CH_3SeCH_3), dimethyl selenyl sulfide (CH_3SeSCH_3), and dimethyl diselenide ($CH_3SeSeCH_3$). The relatively high vapour pressure of these compounds enhances the transformation of Se from soils and sediments to aqueous and vapour phases. However, the rapid oxidation of the first two in this list and lower vapour pressure of the last two leave CH_3SeCH_3 as the most significant contributor to atmospheric Se input (Frankenberger and Losi, 1995). Anaerobic demethylation reaction may result in the formation of toxic and reactive H_2Se from less toxic DMSe. Although H_2Se undergoes rapid chemical (possibly bacterial) oxidation under oxic conditions, it can exist for long periods in an aerobic environment. Aerobic demethylation of DMSe will yield selenate, thereby retaining Se in the system.

Arsenic in soil is also subject to biological transformation resulting in the formation of organo-arsenicals and other compounds. Inorganic As can undergo microbially mediated biochemical transformation, i.e., the hydroxyl group of arsenic acid [$AsO(OH)_3$] is replaced by the CH_3 group to form MMA, DMA and TMA. The pathway of As(V) methylation initially involves the reduction of As(V) to As(III), with the subsequent methylation of As(III) to dimethylarsine by coenzyme S-adenosylmethionine (Frankenberger and Losi, 1995). Methylation is often enhanced by sulfate-reducing bacteria.The driving force for the reduction and methylation reactions of As in sediments is normally the degradation of organic matter by bacteria (such as Desulfovibrio sp) coupled with reduction and use of sulfur in sulfate as the terminal electron acceptor. In addition to bacteria, several fungal species also have shown their ability to reduce As. Inorganic As is incorporated by autotrophic organisms such as algae, and then transported through the food chain. Arsenic becomes progressively methylated during this transfer. Therefore, methylation of As is considered a major detoxifying processes for these microorganisms (Adriano, 2001). The methylated As species is also subject to volatilization and photochemical reactions that may eliminate As from soil.

Demethylation of methylarsenicals can occur both under aerobic and anaerobic conditions. Anaerobic demethylation reactions may result in the formation of toxic and reactive AsH_3 from less toxic DMA, whereas aerobic demethylation of DMA is likely to yield As(V), thereby retaining As in the system. Although A_sH_3 undergoes rapid chemical oxidation under oxic conditions, it can exist for long periods in an aerobic environment. Because demethylation process often produces CO_2 in addition to CH_4, it is preceded by oxidative assimilatory pathways used in substrate metabolism rather than by dissimilatory lyses.

Methylation of Hg occurs both under aerobic and anaerobic conditions (Eq. 5). Under anaerobic conditions Hg^{2+} ions can be biologically methylated to form either monomethyl or dimethyl mercury. Methylated Hg species are highly toxic and more biologically mobile than the other forms. Methylation occurs both enzymatically and non-enzymatically; inorganic Hg^{2+} ions are required before biological methylation reaction to produce methylmercury could proceed.

$$Hg^{2+} + 2\ R\text{-}CH_3 \rightarrow CH_3HgCH_3 \rightarrow CH_3Hg^+ \qquad (5)$$

REMEDIATION OF HEAVY METAL CONTAMINATED SOILS

Remediation of metal-contaminated soil involves physical, chemical and biological approaches that may achieve either the partial/complete removal of metal from soil or reduction of its bioavailability in order to minimize toxicity. A large variety of methods has been developed to remediate metal(loid)s-contaminated sites and are grouped into physical, chemical and biological methods. The selection and adoption of these technologies depend on the extent and nature of metal-contamination, type of soil, characteristics of the contaminated site, cost of operation, availability of materials and relevant regulations.

A. Physical remediation

Major physical in situ treatment technologies to remediate metal(loid)s-contaminated sites include capping, soil mixing, soil washing and solidification. The simplest technique for reducing the toxic concentration of metal in soils is mixing the contaminated soil with uncontaminated soil. This results in the dilution of metal to acceptable levels. This can be achieved by importing clean soil and mixing it with metal-contaminated soil or redistributing clean materials already available in the contaminated site. Another dilution technique, especially in cultivated soils relies on deep ploughing, during which the vertical mixing of the contaminated surface soil with less contaminated subsoil reduces the surface contamination, thereby minimizing the potential for metal uptake by plants and ingestion of metal by grazing animals. However, in this method the total concentration of metal in soil will remain the same.

Soil washing or extraction has also been widely used for the remediation of metal(loid)-contaminated soils in Europe. For example, Tokunaga and Hakuta (2002) evaluated an acid-washing process to extract the bulk of As(V) from a highly contaminated (2830 mg As kg^{-1} soil) Kuroboku soil (Andosol) so as to minimize the risk of As to human health and the environment. Amongst the acid extractants, the phosphoric acid (9.4%) was proved to be the most promising as an extractant, achieving 99.9% As extraction. Recently, chelating compounds are also used to enhance the solubilization of metals and subsequent removal either by washing or plant uptake. This is further discussed under chemical remediation section.

The success of soil washing largely depends on speciation of metals present in the contaminated soils, since it is based on the desorption or dissolution of metals from the soil inorganic and organic matrix during washing with acids and chelating agents. Although soil washing is suitable for off-site treatment of soil, it can also be used for on-site remediation using mobile equipment. The high cost of chelating agents and choice of extractant may restrict their usage to only small-scale operations.

Metal-contaminated soil may be bound into a solid mass by using materials such as cement, gypsum, or asphalt. However, there are issues associated with the long-term stability of the solidified material. Capping the contaminated sites with clean soil is used to isolate contaminated sites as it is cheaper than other remedial options (Kookana and Naidu, 2000). Such covers should obviously prevent upward migration of contaminants through capillary movement of soil water. The depth of such cover or 'cap' required for contaminated sites should be carefully assessed. Using a simulated experiment, Kookana and Naidu (2000) have demonstrated that when the water table is deeper than 2 m from the surface of cap, the upward migration of As through the cap is likely to be less than 0.5 m in 5 years. Where the water table is shallow enough to supply water to the surface (i.e., 1.5 to 2 m in most soils), dissolved As could take <10 years to reach the surface. They have also indicated that when the cap is of a different soil type than the underlying contaminated soil, coarse textured cap is very effective in reducing the capillary rise and therefore, the cap should always be designed to include a coarser layer to break the capillary continuity.

B. Chemical remediation

Remediation, based on chemical reactions, is becoming increasingly popular largely because of high rate of success. A number of methods have been developed mainly involving adsorption, immobilization, precipitation and complexation reactions. However, such methods are often expensive for remediation of large areas. Two approaches are often used in chemical remediation of metal(loid)s-contaminated soils: (i) immobilization of metal(loid)s using inorganic and organic soil amendments in order to reduce their bioavailability; (ii) mobilization of metal(loid)s and their subsequent removal through plant uptake (phytoremediation) or soil washing. In this section the immobilization techniques used for remediation of metal-contaminated soil is discussed. The second approach is discussed under phytoremediation.

Chemical immobilization is achieved mainly through adsorption/ precipitation of metals in contaminated sites through the addition of soil amendments. The mobilization of metal(loid)s in soils for plant uptake and leaching to groundwater can be minimized by reducing their bioavailability through chemical and biological immobilization (Bolan *et al.,* 2004). Recently there has been interest in the immobilization of metal(loid)s using a range of inorganic compounds such as lime, P fertilizers (e.g., phosphate rocks) and alkaline waste materials, and organic compounds such as biosolids (Knox *et al.,* 2000; Basta *et al.,* 2001).

Phosphate compounds: A large number of studies have provided conclusive evidence for the mitigative value of both water-soluble (e.g., diammonium phosphate, DAP) and water-insoluble (e.g., apatite, also known as PR) P compounds to immobilize metals in soils, thereby reducing their bioavailability for plant uptake and mobility for transport (Bolan *et al.,* 2003a, 2003c, 2003f). Phosphate compounds enhance the immobilization of metals in soils through various processes including: direct metal adsorption by P compounds, phosphate anion-induced metal adsorption, direct precipitation of metals with solution P as metal phosphates, and precipitation and/or occlusion through the liming action of P compounds, such as PR.

Depending on the source, soil application of P compounds can cause direct adsorption of metals onto these compounds through increased surface charge and enhanced anion-induced metal adsorption. Adsorption of metals onto hydroxyapatite surfaces has been observed for a number of metals including Cd, Cu, Ni, Sr and Zn (Bolan and Duraisamy, 2003; Bolan *et al.,* 2003a). Metal adsorption onto apatite is facilitated through the exchange of Ca^{2+} from the apatite particle with the metal cations in soil solution. However, in the case of Zn and Cd, surface complexation and co-precipitation are the most important mechanisms, with ion exchange and solid state diffusion also possibly contributing to the overall adsorption process by hydroxyapatite.

$$Ca_{10}(PO_4)_6(OH)_2 + xCd^{2+} \rightarrow (Cd_x,Ca_{10-x})(PO_4)_6(OH)_2 + xCa^{2+} \quad (6)$$

Anion-induced metal adsorption has been reported for a number of cations. It has been shown that Zn^{2+}, Cd^{2+} or Cu^{2+} adsorption by variable charge components in soils, such as Al and Fe oxides can be enhanced by low or moderate enrichment of oxides with P (Bolan *et al.,* 1999a). Several mechanisms can be advanced for phosphate-induced metal adsorption by soils, including: (i) increase in negative charge; (ii) co-sorption of phosphate and metal cation as an ion pair; and (iii) surface complex formation of metal on the P compound. A number of studies have shown that specific adsorption of anions increases the net negative charge of variable charge surfaces in soils. The amount of surface charge acquired through specific adsorption depends on the nature of anion adsorbed, pH and electrolyte concentration of the solute. While enhanced sorption of a number of metals via increased surface charge especially in the presence of phosphate ions has been demonstrated (Bolan *et al.,* 1999a), much work is still needed to provide conclusive evidence for mechanisms (ii) and (iii).

Precipitation as metal phosphates has been proved to be one of the main mechanisms for the immobilization of metals, such as Pb and Zn in soils (Bolan *et al.,* 2003a). These fairly stable metal-phosphate compounds have extremely low solubility over a wide pH range, which makes P application an attractive technology for managing metal-contaminated soils. The formation of the new solid phase (i.e., precipitates) occurs when the ionic product in the solution exceeds the solubility product of that phase. Recent studies using X-ray absorption fine structure spectroscopy (XFAS) indicate that formation of surface precipitates may occur even when solution concentration is undersaturated with respect to homogeneous precipitation of pure metal precipitate phase. In typical arable soils, precipitation of metals is unlikely, but in highly metal-contaminated soils, this process can play a major role in the immobilization of such metals.

The ability of apatite to immobilize Pb in solution or Pb in contaminated soils through precipitation as Pb phosphates has been well documented (Bolan *et al.,* 2003a). Such precipitates are more commonly manifested as hydroxypyromorphite or as chloropyromorphite. Two processes for the reaction of dissolved Pb with apatite have been proposed. First, Pb^{2+} can react with apatite through hydroxyapatite (HA, $Ca_{10}(PO_4)_6(OH)_2$) dissolution (Eq. 7), followed by precipitation (Eq. 8) of pure hydroxypyromorphite ($Pb_{10}(PO_4)_6(OH)_2$). Second, Pb^{2+} can substitute for Ca^{2+} in apatite (Eq. 9).Thus (Ca,Pb) apatite could be potentially formed by adsorption of Pb or by dissolution of HA followed by coprecipitation of mixed apatites.

$$Ca_{10}(PO_4)_6(OH)_2(s) + 14H^+(aq) \rightarrow 10Ca^{2+}(aq) + 6H_2PO^{4-}(aq) + 2H_2O \quad (7)$$

$$10Pb^{2+}(aq) + 6H_2PO_4^-(aq) + 2H_2O \rightarrow Pb_{10}(PO_4)_6(OH)2(s) \quad (8)$$

$$Ca_{10}(PO_4)_6(OH)_2(s) + xPb^{2+} \rightarrow (Ca_{10-x})\ Pbx)\ (PO_4)_6(OH)_2(s) + xCa^{2+} \quad (9)$$

Two important implications of Pb-phosphate interactions deserve to be noted: (i) the immobilization of Pb^{2+} as insoluble phosphates in soils regulates the quantity of Pb that annually cycles in ecosystems. Formation of Pb phosphates may be one of the buffer mechanisms regulating the concentration of Pb in natural waters; and (ii) Pb bound to phosphate is unavailable to plants. This interaction has the beneficial effect of reducing potential consequences from dietary intake of Pb by humans and herbivorous animals, as demonstrated by physiologically-based extraction techniques.

Recent studies have indicated that application of high levels of water-soluble P compounds, such as DAP (2300 mg P kg^{-1}) was very effective in immobilizing Cd, Pb and Zn in contaminated soil (McGowen *et al.,* 2001). Activity-ratio diagrams indicated that the DAP decreased solution concentrations of these metals by forming metal-phosphate precipitates having low solubility products.

In addition to the formation of new solid phases discussed above, metal immobilization may also ensure from the formation of metal oxyhydroxides due to the buffering capacity (or liming action) of hydroxyapatite. Unlike soluble P fertilizers, PRs neutralize acidity during the dissolution reactions in soils and thus can also have some liming effect. The potential value of PRs as a liming material in mitigating acid mine drainage has been documented both under laboratory and field conditions (Evangelou and Zhang, 1995). Treating acid mine drainage with PRs not only neutralizes the acidity through their buffering action but also reduces the solution concentration of metals through precipitation and ion exchange reactions.

Liming materials **:** Liming has been considered as an important management tool in reducing the toxicity of metals in soils. In addition to the traditional agricultural lime, studies have examined the potential value of other liming materials as immobilizing agent in reducing the bioavailability of a range of metals in soils. In this regard Cd contamination of agricultural soils is of particular concern because this particular metal reaches the food chain through the regular use of Cd-containing fertilizer materials, such as single superphosphates. Also it remains mobile even at about neutral pH.

Low soil pH and soils of low CEC favour a greater uptake of soluble Cd by plants. The Cd in soils can be immobilized by increasing the soil pH through the addition of liming materials. One benefit arises from the antagonistic effect from Ca^{2+} added through liming, which may serve to depress Cd^{2+} uptake by competing for exchange sites at the root surface. Limited Cd uptake may also arise from increases in Cd adsorption caused by increases in pH that induce increases in negative charge. However, adsorption may decrease with an increase in Ca^{2+} concentration due to a decrease in activity coefficient, increase of inorganic complexation and increase in Ca^{2+} competition. The resultant effect of liming on Cd adsorption and uptake largely depends on the relative change in pH and Ca^{2+} concentration in soil solution.

Liming, as part of the normal cultural practices, has often been shown to reduce the concentration of Cd and other metals in edible parts of crops. Addition of other alkaline materials such as coal fly ash has also been shown to decrease the Cd contents of plants (Adriano *et al.,* 1982). In these cases, the effect of liming materials in decreasing Cd uptake by plants has been attributed to both decreased mobility of Cd in soils and to the competition between Ca^{2+} and Cd^{2+} ions on the root surface. It is also possible that above pH 7, solubility and uptake of Cd can be enhanced due to facilitated complexation of Cd with humic or organic acids (Bolan *et al.,* 2003d).

The uptake of Pb by plants is often found to decrease with liming, which is attributed to increased adsorption/precipitation at high pH, and competition between Pb and other cations for uptake. Basta and Tabatabai (1992) observed positive correlation between Pb sorption by soils and soil pH. Once again, Ca^{2+} addition through liming causes an inhibition of the translocation of Pb from root to shoot.

For metallic oxyanions liming (pH) effect may vary. For example, Se is quite bioavailable in well-aerated, alkaline soils where it occurs primarily as selenates [Se(VI)]. In acid soils, selenites [Se(IV)] are formed which are sparingly soluble and generally unavailable to plants. In general, liming the soil could enhance the uptake of Se by plants (Adriano, 2001).

Removal of Cr(III) from industrial effluent is achieved using lime or magnesium oxide to precipitate as chromic hydroxide. Precipitation is reported to be most effective at pH 8.5-9.5 due to the low solubility of chromic hydroxide in that range. This method can decrease Cr concentrations to very low levels and hence precipitation systems are very widely accepted by major tanneries. Recently, Bolan and Thiyagarajan (2001) examined the effect of liming materials on the adsorption and plant availability of Cr(V) and Cr(III) species. Addition of liming materials to soils increased the retention of Cr(III) but had the opposite effect on the retention of Cr(VI). The liming materials were found to be effective in reducing the phytotoxicity of Cr(III) but not Cr(VI). Addition of the liming materials decreased the concentrations of the soluble Cr(III), a main reason for the decrease in the phytotoxicity of Cr(III).

Organic amendments : The major sources of organic composts include biosolid and animal manures. Traditionally biosolid is viewed as one of major sources of metal accumulation in soils. Advances in the treatment of sewage water and isolation of industrial wastewater in the sewage treatment plants have resulted in a steady decline in the metal content of biosolid. Furthermore, stabilisation using alkaline materials has resulted in the immobilisation of metals in biosolid.

Most manure products contain low levels of heavy metals (except Cu and Zn in swine manure and As in poultry manure). Furthermore, recent advances in the treatment of manure byproducts have resulted in reduced bioavailability of metals. For example, 87% reduction in Cu and Zn in the waste water from swine houses was obtained after treatment with lime slurry, ferric chloride or polymer. Similarly treatment of poultry manure with alum [$Al_2(SO_4)_3$] decreased the concentration of water-soluble Zn, Cu and Cd. Hence, unlike, sewage sludge application, where land application is limited based on allowable metal loadings, regulations governing livestock and poultry manure byproducts are generally based on total N and P loading. Manure byproducts that are low in metal content can be used to immobilise metal contaminants in soils.

Although a number of studies have examined the role of biosolid as a source of metal contamination in soil, only limited work has been reported on the beneficial effect of organic amendments as a sink for the immobilisation of metals in soils. Recent studies have shown that alkaline-stabilized biosolid that are low in total and/or bioavailable metal content (known as ’exception quality’ biosolid or ’designer sludge’) can be used as an effective sink for reducing the bioavailability of metals in contaminated soils and sediments. Immobilization of metals by such amendments is achieved through adsorption, complexation and redox reactions.

Addition of organic amendments has often been shown to increase the cation exchange capacity of soils, thereby resulting in increased metal adsorption. Bolan *et al.* (2003b) observed that Cd adsorption increased with increasing level of biosolid addition in a soil containing low level of organic matter, whereas in the case of the soil having high organic matter, adsorption decreased at the highest level of biosolid addition. Unlike in the case of inorganic amendments, such as phosphate or lime addition, the increase in surface charge due to biosolid addition was not reflected in the adsorption of Cd^{2+}.

The presence of phosphates, aluminium compounds and other inorganic minerals in some organic amendments, such as typical municipal sewage sludge, is also believed to be responsible for the retention of metals, thereby inducing the 'plateau effect' in metal uptake by crops and preventing the increased metal availability suggested in the 'time bomb' hypothesis (Kuo, 1986). Such observations imply that the sequestration capacity of biosolids of municipal-type sludge origin might be indefinite even after oxidation/ mineralization of the organic matter component due to the residual effects of the mentioned components.

Metals form both soluble and insoluble complexes with organic constituents in soils which apparently depends on the nature of the organic matter. For example, Zhou and Wong (2001) observed that Cu^{2+} adsorption by an acidic soil and a calcareous soil decreased with the addition of sewage sludge, which they attributed to the formation of soluble Cu-organic complexes. Similarly, Bolan *et al.* (2003e) observed that while the adsorption of Cu^{2+}, as indicated by the difference in the total Cu concentration in soil solution, was not affected by biosolid addition, the complexation of Cu, as indicated by the change in free Cu^{2+}concentration, increased with increasing level of biosolid.

A number of studies have shown that addition of organic matter-rich soil amendments enhances the reduction of metals/metalloids such as Cr and Se. For example, the addition of cattle manure has resulted in the reduction of Cr(VI) to less toxic and less mobile Cr(III) (Losi *et al.,* 1994).

In a Cr-contaminated soil, Mahimairaja *et al.* (2000b) showed that coir pith and poultry manure markedly reduced the concentration of soluble plus exchangeable-Cr which represent toxic forms of Cr in soils (Fig. 3). While 61 (clay loam) to 75 (silt clay loam) per cent reduction in the concentration of soluble plus exchangeable-Cr was observed with the application of coir pith, a reduction of 62.3 (clay loam) to 68 (silt clay loam) per cent was achieved due to poultry manure addition.

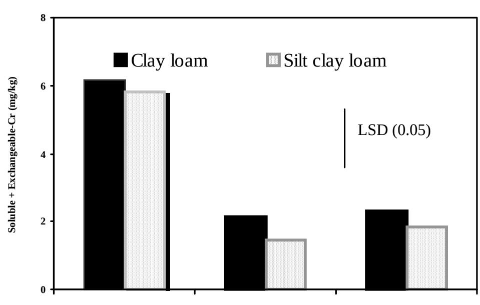

Figure 3. Effect of biological wastes on soluble and exchangeable - Cr in soils

Through multi-location field trials Singaram *et al.* (1992) evaluated the potential of different amendments for remediating the Cr-contaminated soil in Tamil Nadu. Their field experiment with maize has shown that the application of composted coirpith at a rate of 10 t ha^{-1} performed better than pressmud, FYM and gypsum in reducing the bioavailability of Cr. Biosolids can be combined with other materials that have a high calcium carbonate equivalent to restore metal-affected ecosystems, despite the presence of metals in them. Biosolids can be combined with alkaline materials such as limestone and cyclonic ashes as a means of increasing the pH of the soil and reducing metal availability and thereby reducing risk.

Metallic oxides and cyclonic ashes: Iron, Al and Mn oxides commonly occur in soils and react with heavy metals (Knox *et al.,* 2001). The OH-OH distance in Fe, Mn, and Al oxides matches well with the coordination polyhedra of many metals. Such hydroxyl groups form an ideal template for bridging metals. Reactions with metals can be promoted when these (hydrous)oxides are combined with alkaline materials (Mench *et al.,* 1998).

Naidu *et al.*(2003) adopted a risk reduction strategy with the aim to reduce the mobility of As through chemical immobilization. Ferrous salt was used to generate in situ mineral phases to immobilize As. This reaction requires oxygen to be available to the soil and also generates considerable amounts of acid, which may be counter productive to As immobilization in poorly buffered soils. The increased acidity could be neutralized by the amendment with lime. The redox conditions of the soil also influence the speciation of As. Following initial detailed laboratory studies, a mixture of Fe/ Mn/gypsum was used as the stabilizing chemical, and the application of the mixed chemical led to significant decline in mobile As. Subsequent studies involving aging of the treated soil showed complete elimination of risk posed by As.

The results of a field experiment conducted by Xie and Huang (1998) on an As-polluted soil (*Typentiaqualf*) in China have shown that the application of Fe (as $FeCl_3$ @ 25 mg Fe kg^{-1} soil) or Mn (as MnO_2 @ 25 mg Mn kg^{-1} soil) had markedly lowered the total water soluble As [As(III) + As(V)] (24-26%) and As(III) (17-82%) in the soil and made the rice plants grow better than the control treatment, resulting in higher rice grain yield and lesser As content in rice husk. This was attributed to the oxidation of As(III) to As(V) by MnO_2 and the subsequent strong adsorption of As(V) by Fe and Mn oxides.

Cyclonic ash by-products originate from the fluidized bed burning of coal refuse (mine pile material) from the former coal mine in Beringen (North East of Belgium). The burnt material contains only about 30% coal; the remaining fraction is inorganic and mainly consists of schists. The schists are burned by heating in an electronically guided fluidized bed oven at ca. 800^{0}C. During combustion, the schists undergo partial breakdown and recrystallization. Changes in minerals are summarized by Vangronsveld *et al.* (1999). By use of air suction (air current) most of the particles with a median diameter of less than 0.2 mm (clay fraction) are separated in a cyclone, thus the term cyclonic ashes (about 25 % of the total ash fraction). The cyclonic ashes (mainly the modified clay fraction) were shown to be very reactive in sequestering metals. The pH of the product is strongly alkaline. The high pH arise from the presence of MgO and CaO which are formed during the heating of $CaCO_3$ and $(Ca, Mg)CO_3$ minerals present in the schists, which upon hydrolysis form the hydroxides $Ca(OH)_2$ and $Mg(OH)_2$. These hydroxides also have high capacity for sequestration of metals.

Chelating compounds **:** When a metal ion combines with an electron donor, the resulting substance is called complex or coordination compound. If the substance which combines with the metal contains two or more donor groups so that one or more rings are formed, the resulting structure is called metal chelate, and the donor is called chelating agent. The term 'chelate' is derived from the Greek word 'chela' which means 'claw' and it is so named because these species can coordinate at several or all positions around a central metal ions by literally wrapping themselves around the metal ion. Chelating agents which have high affinity for metal ions can be used to enhance the solubilization of metals in soils through the formation of soluble metal chelates. A number of synthetic chelating agents are available which include EDTA, EDHA, DTPA and EHPG.

The value of chelating agents in enhancing the availability of metals such as Fe, Cu and Zn has been well recognised in plant nutrition and various chelated compounds are available as nutrient sources. Recently the potential value of chelating agents in the remediation of contaminated soils through mobilization of metals has been explored. These compounds have been found to be very effective in the solubilization of metals such as Cu and Pb, thereby enhancing their subsequent uptake by plants. However, a number of issues need to taken into consideration while using chelates to accelerate the remediation of metal contaminated sites. The addition of these chelating agents is likely to induce the solubilization of other than the target metals which may be phytotoxic (eg. Al and Mn). The increased solubilization of metals can result in their increased leaching to groundwater, especially in the absence of active plant growth. Alkaline hydrolysis of metals with the chelating compounds induces the formation of metal hydroxy precipitates. Some of the chelating compounds are subjected to microbial degradation, thereby affecting their long-term effectiveness.

C. Biological remediation

Biological remediation techniques are broadly grouped into two categories - bioremediation(using microorganims) and phytoremediation (using higher plants).

Bioremediation **:** Bioremediation of soils contaminated with organic compounds such as pesticides and hydrocarbons is widely accepted in which native or introduced microorganisms and/or biological materials such as compost and animal manures are used to detoxify or transform contaminants. There have been increasing interests in the application of this technology for the remediation of metal(loid)s-contaminated soils, especially for those metal(loid)s which undergo biological transformation. Though it has several limitations, this technology holds continuing interest because of its cost-effectiveness. The unique aspect in the bioremediation is that it relies mainly on natural process and does not necessarily require the addition of any chemical amendments other than microbial cultures and biological wastes. Existing and developing in situ bioremediation technologies may be grouped into the following two broad categories (NRC, 1997).

i. Intrinsic bioremediation - where the essential materials required to sustain microbial activity exist in sufficient concentrations that naturally occurring microbial communities are able to degrade the target contaminants without the need for human intervention. This technique is better suited for remediation of soils with low levels of metals over an extensive area.

ii. Engineered bioremediation - relies on various approaches to accelerate in situ microbial degradation rates. This is accomplished by optimizing the environmental conditions by adding nutrients and/ or electron donor/acceptor, thus promoting the proliferation and activity of existing microbial consortia. It is favoured for highly contaminated localized sites.

Three approaches could be used in the bioremediation of metal-contaminated soils: (i) metals could be immobilized into microbial cells through bioaccumulation; (ii) toxic metal forms [eg., As(III) and Cr(VI)] could be transformed to less toxic forms [As(V) and Cr(III)] and (iii) metal compounds could be removed from the soil by volatilization.

The mechanisms involved in these approaches have been discussed under metal dynamics in soils. Briefly, microorganisms exhibit a strong ability to accumulate (bioaccumulation) metals from substrate containing very low concentrations of this element. Bioaccumulation is activated by two processes, viz., biosorption of metals by microbial biomass and its by-products; and physiological uptake of metals by microorganisms through metabolically active and passive processes. For example, heterotrophic bacteria have been found to oxidize toxic As(III) in soils and sediments to less toxic As(V) and thus could play an important role in remediation of contaminated environment (Wakao *et al.,* 1988). A variety of microbes could transform inorganic metal forms into its metallic hydride or methylated forms. Due to their low boiling point and/or high vapour pressure these compounds are susceptible for volatilization and could easily be lost to the atmosphere. Methylation is considered as a major biological transformation through which As, Se and Hg are volatilized and lost.

***Phytoremediation* :** Phytoremediation employs plants and their associated root-bound microbial community to remove, contain, degrade or render harmless environmental contaminants (Raskin *et al.,* 1997; Robinson *et al.,* 2003). This terminology applies to all plant-influenced biological, chemical, and physical processes that aid in remediation of contaminated medium (Cunningham and Lee, 1995). It involves soil-plant system in which metal(loid)s-accumulating plants are grown in contaminated sites. It is considered as an economically feasible and environmentally viable technology for remediating metal(loid)s-contaminated systems. The effectiveness of this technology is however, variable and highly site-dependent.

In phytoremediation, plants are exploited as a bio-pump that use sun's energy to remove water and contaminants from the soil to the above ground portion, and return of some of the products of photosynthesis back into the root-zone in the form of root exudates that are involved in the im(mobilization) of contaminants. Transpiration is the driving force for phytoremediation. By removing water from the medium, plants help to reduce erosion, runoff and leaching, thereby limiting the movement of contaminants off-site. Some contaminants are taken up in the transpiration stream, where they may be metabolized, and may be eventually volatilized. By removing the excess water from the soil profile, plant roots may also create an aerobic environment where metal(loid)S mobility is reduced and biological activity is enhanced. Plants stimulate microbiological activity in the root-zone by providing a carbon source from root exudates and decaying root materials (Robinson *et al.,* 2003).

Phytoremediation technologies have been grouped into various categories that include phytostabilization, rhizofiltration/ phytoextraction and phytovolatilization (Cunningham *et al.,* 1995). In phytostabilization, transpiration and root growth are used to immobilize metal contaminants by reducing leaching, controlling erosion, creating an aerobic environment in the root-zone, and adding organic matter to the substrate that binds metals. It involves the establishment of metal(loid)-tolerant vegetation on the contaminated site that is left in perpetuity. The stabilization of metals in the root-zone could be achieved through the addition of organic matter as well as soil amendments. An example is the precipitation of Pb-P compounds in roots and the rhizosphere of *Agrostis capillaris* (Cotter-Howells *et al.,* 1999). In rhizofiltration, the roots can be used to adsorb or absorb metal(loid)s, which are subsequently removed by harvesting the whole plant. In this case metal(loid)s tolerance and translocation of the metal(loid)s to aerial parts are largely irrelevant. In phytoextraction, plants can be grown on contaminated soil and the aerial parts enriched with metal(loid)s harvested. In this case, plants need to be tolerant only if the soil metal(loid)s content is very high, but they need to accumulate very high concentrations in their aerial parts. Phytoextraction involves repeated cropping of plant until the metal(loid)s concentration in the soil has reached the acceptable (targeted) level.

The success of phytoextraction technology may also depend on a shift from our current paradigm of remedial targets based on total metal concentrations towards the concept of "bioavailable contaminant stripping (BCS)" (Hamon and McLaughlin, 1999). In most cases even under optimal conditions, phytoextraction could take a long time to cleanup metal-polluted soils to accepted target values. BCS offers a viable alternative by targeting to extract only the most labile metal pools that serve as a short-term source of potential risk to the environment via leaching or uptake in organisms. However, before BCS can be integrated in regulatory policy methods are required to establish the long-term fate of the remaining non-labile metal fractions. Elucidating the dissolution kinetics of metal-bearing phases (e.g. Fe oxides, layer silicates, phosphates, etc.) in the soil will be crucial to understanding/predicting the potential of metal remobilization after termination of phytoextraction strategy.

Certain plants, termed '*hyperaccumulators*' (Brooks *et al.,* 1977) accumulate inordinate concentration of metal(loid)s in their above ground biomass. These plants may even accumulate metal(loid)s that are non-essential and often toxic to plants. The minimum concentration of metals required for a plant to be classified as hyperaccumulator was set at 1000 mg kg^{-1} (0.1%) on a dry weight basis (Ma *et al.,* 2001). The hyperaccumulation of metal(loid)s involves uptake of the soluble metal(loid) species by the root system, translocation to the aerial parts, and storage in a non-toxic form in the aerial portions. This process necessarily requires tolerance to high concentrations of metal(loid)s.

At present there are about 400 species of known terrestrial plants that hyperaccumulate one or more of several metal(loid)s (Robinson *et al.,* 1995). For example, recently, *Ma et al.* (2001) discovered an As-hyperaccumulating plant, ladder brake (*Pteris vittata* L.), a terrestrial fern, which accumulates large amounts (23 000 mg kg^{-1} - dry weight basis) of As from soils. The unique property of As hyperaccumulation by Chinese brake fern is of great significance in the phytoremediation of As-contaminated soils. Therefore, the potential of this fern for phytoremediation of As-contaminated soil was assessed by Tu *et al.* (2002) in a glasshouse experiment using soils from an abandoned wood preservation site. The results have shown that the Chinese brake accumulated huge amounts of As from soil, and its As concentration increased with growth period reaching as high as 13800 mg As kg^{-1}. Another silver fern [*Pityrogramma calomelanos* (L.) Link] has also been reported to hyperaccumulate As up to 8350 mg kg^{-1} dry mass from soil containing 135 mg kg^{-1} (Francesconi *et al.,* 2002). The plant occurs in tropical and subtropical regions of the world and is widely distributed in Thailand where it favours open, high rainfall areas. Some selected hyper accumulators of metal(loid)s reported in the literatures are presented in Table 5.

Table 5. Hyperaccumulators of metal(loid)s

Metal(loid)s	Plants
As	Chinese brake fern (*Pteris vittata*), Fern (*Pteris cretica*), Bent grass (*Agrostis tenuis)*, Silver fern (*Pityrogramma calomelanos*), Watercress (*Lepidium sativum*).
Cd	Alpine pennycrest (*Thlaspi caerulescens*), Cardaminopsis halleri,Eel grass (*Vallisneria spiralis*), Water hyssop (*Bacopa monnieri*)Water hyacinth (*Eichhornia crassipes*) Hydrilla(*Hydrilla verticillata*),Duck weed (*Lemna minor*), Giant duckweed (*Spirodela polyrhiza*).
Co	Eel grass of Africa (*Haumaniastrum robertii*).

Cr Duck weed (*Lemna minor*), Ceratophyllum demersum, Giant reed (Arundo donax), Cattail (*Typha angustifolia*), Alfalfa (*Medicago sativa*), Water hyssop (*Bacopa monnieri*),Pistia stratiotes,Water fern (*Salvinia molesta*), Spirodela polyrhiza.

Cu *Aeolanthus biformifollus,* Lemna minor, Vigna radiata,Creosote bush (*Larrea tridentate*), Water hyssop (*Bacopa monnieri*),Indian mustard (*Brassica juncea*).

Hg Lemna minor, Water lettuce (*Pistia stratiotes*), Water hyacinth (*Eichhornia crassipes*), Hydrilla (*Hydrilla verticillata*).

Mn *Alyxia rubricaulis, Macademia neurophylla*

Ni *Phyllanthus serpentines*, *Lemna minor*, *Salvinia molesta, Brassica juncea,Spirodela polyrhiza.*

Pb *Brassica juncea,* Water hyacinth (*Eichhornia crassipes*),Hydrilla (*Hydrilla verticillata*),Sunflower (*Helianthus annuus*)*Lemna minor*, *Salvinia molesta*, *Spirodela polyrhiza*

Se *Astragalus* sp., *Lemna minor*

Zn *Alpine pennycrest* (*Thlaspi caerulescens*), *Brassica juncea*

Studies conducted at Tamil Nadu Agricultural University, India showed that the following crops and varieties are tolerant to Cr and rendered reasonable yields in Cr-contaminated soils (Ramasamy *et al.,* 2000).

Rice (*Oryza sativa*) : TRY-1, CO43, Paiyur-1 and ASD-16

Maize (*Zea mays*) : CO1

Finger millet (*Eleusine coracana*) : CO12, CO13

Fodder grass : BN-2

Desmanthus (*Desmanthus vergatus*)

Sugarcane (*Saccharam officinalis*) : COG-94076, COG-88132 AND COC-771

Korai grass (*Cyperus corymbosus*)

Flower plants and plantation trees offer another avenue for the remediation of metal(loid)s contaminated soils. In a field experiment, for example, flower crops viz., gundumalli (*Jasminum sambac*), jathimalli (*Jasminum grandiflorum*), tuberose (*Polianthus tuberosa*) and nerium (Nerium oleander) were found to accumulate large amounts of Cr, besides showing tolerance to high soil-Cr (Mahimairaja *et al.,* 1999). With regard to plantation trees the tolerance towards Cr was in the order: Casuarina > Acacia > Eucalyptus (Sakthivel *et al.,* 2000).

Phytoremediation of boron contaminated site in New Zealand using Willow, Poplar and Eucalyptus trees is depicted in Figure 4. The figure demonstrates clearly how phytoremediation helps the contaminated site becomes part of the landscape by transforming the bare pile into an actively growing 'green' cover. The major advantage using flower crops and plantation trees is the avoidance of heavy metals-entry into the food chain. Therefore, the potential of non-edible commercial crops should be further exploited for remediation of the metal contaminated soils.

Figure 4. On-going phytoremediation (using Willow, Poplar and Eucalyptus) of boron contaminated site in New Zealand. A) Before remediation, B) After Remediation

An immediate strategy is to improve pollutant accumulation by plants by manipulating biochemical/physiological mechanisms relevant to this process. A possible approach is to employ transgenic techniques to impart into the host plant desirable features from a hyperaccumulator species. Research efforts have been concentrating on Cd, Zn, Pb, Ni, Hg and Se but may be extended to other contaminants (e.g. As, Cu, Cs, Sr, V, and organics).

Breeding of hyperaccumulator species to improve their biomass and other features relevant to crop culture has been considered as an alternative strategy, but is probably less effective in relation to the phytoextraction strategy that can be achieved with this approach within a reasonable time. In particular, challenges include improving the ease by which contaminants are mobilized in the soil, taken up by the roots and translocated to other plant parts. To enhance contaminant mobilization, transgenic plants may be developed that exude ligands into the rhizosphere that are more selective for specific metals (Ma and Nomoto, 1996). The identification of an increasing number of genes encoding for metal transporters in hyperaccumulator plants may provide the genetic resource to increase the phytoextraction potential of certain plants.

Phytovolatilization is an inherent process in the phytoremediation of organically-contaminated soils. However, phytovolatilization as applied to inorganic contaminants is still in its infancy. Phytovolatilization has some potential for remediating soils contaminated with Hg, Se, B, and possibly other elements. Recent efforts have concentrated on developing transgenic species with increased potential for volatilizing Hg (Meagher and Rugh, 1996) and Se (Terry, 1996). Future work will focus on generating libraries of mutant merA genes involved in volatilization of Hg, and identifying mutants that reduce toxic metal ions such as Pb^{2+}, Cu^{2+}, and Cd^{2+} (Meagher and Rugh, 1996). For Se, recent efforts include screening and testing of hypervolatilizing species and genetic engineering of these plants. Previous results indicate that the conversion of selenate to volatile Se species may be rate-limited by several enzymes in the Se volatilization pathway. Using *Brassica juncea*, genetic engineering is being employed to develop transgenic plants to promote activities of potentially rate-limiting enzymes (Terry, 1996).

Phytoremediation has several advantages over other remediation and metal(loid)s extraction technologies. The cost involved in phytoremediation is much lower than other technologies such as soil removal, capping and ex-situ cleansing, etc. Other advantages include the ultimate fertility of the cleaned site, the high public appeal of ’green’ technology, and the possibility of producing secondary products that offset the cost of the operation or even produce a small profit. However, some of the basic plant physiological processes such as low biomass production and shallow root growth, nonetheless, limit the scope of phytoremediation. Only surface contamination can be removed or degraded and the cleanup is restricted to areas that are amenable to plant growth. Most importantly, it may take a long time for site remediation to be effective. Phytoremediation can only be used if it meets environmental regulation during the operation as well as its end point.

D. Natural Remediation

Traditionally, the use of unenhanced (or non-invasive) natural processes as part of a site remediation strategy is called natural attenuation (NRC, 2000). Thus the U.S. EPA coined the term monitored natural attenuation (MNA) when NA is employed within the context of a carefully controlled and monitored site cleanup strategy to be able to achieve site-specific remediation objectives within a time frame that is more reasonable than that offered by other more invasive methods (U.S. EPA, 1999). We propose a new twist in the definition by arguing that adding to the soil inexpensive amendments that is cost effective and minimally invasive can accelerate natural processes. These materials can be incorporated into contaminated soils to speedup and optimize, in the case of metals, their immobilization as mediated by key processes such as (adsorption, precipitation, complexation and redox reactions.

Natural remediation (NR) is well established as a remedial strategy for a few organic chemicals, primarily BTEX (Benzene, Toulene, Ethylene, Xylene) (NRC, 2000). However, these processes cannot destroy metals but in some cases can immobilize them. Natural remediation can be managed for both organic and inorganic contaminants. The kinetics of NR can vary widely between the organics and metals. The important parameters to gauge NR also vary between these two groups of contaminants. For organics (e.g., BTEX), the commonly used parameter is the total concentration (or mass) in the affected plume and NA, even if accelerated, may take months to years depending on site and contaminant properties. Also certain organics may degrade into daughter by-products that are more toxic and recalcitrant (e.g., TCE, trichloroethylene degrading to vinyl chloride). Whereas with metals, they are generally persistent and immutable, so the "bioavailable" fraction in the soil could be the most relevant parameter for NR. Unlike common organics, the kinetics of NR for metals can be relatively much shorter, i.e., in a matter of days (Adriano *et al.,* 2004).

For widespread contamination by metals (e.g., fertilizer-derived Cd input in pasture soils), remediation options generally include amelioration of soils to minimize metal solubility and eventual bioavailability. Bioavailability can be minimised through immobilization of metals using a range of inorganic compounds, such as lime and phosphate (P) compounds (e.g., apatite rocks), and organic compounds, such as 'exceptional quality' biosolid (Knox *et al.,* 2000; Basta *et al.,* 2001). These amendment materials are fairly abundant and inexpensive and therefore such technology could be economically feasible.

CONCLUSIONS AND FUTRUE RESEARCH NEEDS

Two approaches can be used to successfully remediate metal contaminated soils. One involves the immobilization of metals, thereby reducing their bioavailability. The other involves the mobilization of metals, thereby increasing their bioavailability and subsequent removal by microorganisms (bioremediation) and/or higher plants (phytoremediation). Since one of the primary objectives of remediating contaminated sites is to reduce the bioavailability of metals, in-situ immobilization using some of the soil amendments that are low in heavy metal content may offer a promising option. However, a major inherent problem associated with immobilisation techniques is that although the heavy metals become less bioavailable, their total concentration in soils remains unchanged. The immobilised heavy metal may become plant available with time through natural weathering process or through breakdown of high molecular weight organic-metal complexes. Whereas in the case of mobilization of metals using soil amendments, the solubilized metals are subject to leaching losses and subsequent groundwater contamination unless they are actively taken up by higher plants.

Metal biotoxicity in soils is determined by the fraction of the metal that is bioavailable. This has implications to our current regulatory policies that are generally based on total metal content. It is important to emphasise that there is a dynamic equilibrium amongst various fractions in soils and any depletion of the available pool due to immobilisation, plant uptake or leaching losses will result in the continuous release from other fractions to replenish the available pool. This is one of the main reasons why there is some reluctance towards using bioavailable pool in soils for regulatory purposes by environmental agencies in monitoring contaminated sites. In addition the bioavailable pool is sensitive to edaphic and environmental conditions as solubilisation of metals from sparingly soluble compounds responds to soil pH, redox potential, temperature, etc.

Numerous heavy metal contaminated sites have been reported in many countries. Long-term field experiments are needed to examine the potential value of compost and other soil amendments in sequestering and mitigating the phytotoxic effect of these toxic heavy metals so that more diverse land use can be facilitated.

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APPLICATION OF WEATHER FORECAST FOR DIFFERENT SECTORS

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Weather and climate forecasts are being increasingly used to benefit decision making in more and more weather sensitive sectors of the economy including agriculture. The underlying source of climate variability induced fluctuations in Indian economy is variation in agricultural production related to rainfall. Though precipitation and temperature determine type and performance of any crop at a given location, role of other meteorological elements in crop's growth, development and yield can not be undermined. Short-term episodes of dryness may be of little consequence to crops but its continuance at sensitive pheno-phases may drastically reduce the yield potential or even ruin the crop. Identifying the onset and cessation of rainfall, in different temporal ranges, is very important to determine onset and cessation of crop growing period as well as plan irrigation in a manner to reap maximum harvest. Hence, prediction of precipitation in medium and extended ranges is very crucial in farm management as well as for assessing damage potential of soil moisture stress to crop's growth, development and yield. No aviation activity is possible without meteorological support and there is growing application of weather and climate information in important sectors such as water management, disaster management, defense, power, health etc. in India in the recent past.

Predicting weather

A forecast of a forthcoming sequence of weather events is nothing but a statement of the probability of occurrence of such events. Its reliability decreases with increasing interval of time. The atmospheric processes are very complex, and weather exhibits continuous changes even over short intervals. In case of a forecast 'the uncertainty' or 'the reliability' factor also enters. The deterministic weather forecasting remains to be the most challenging task despite the rapid advancements. This is all the more difficult to accomplish over the tropical Asian monsoon region due to its unique geographical location and lack of conventional meteorological observations in the surrounding oceanic sectors.

Forecasting weather is initial value problem. One needs to define the initial state of the atmosphere, through current meteorological observations, to prognosticate its future trends using numerical weather prediction (NWP) models. The current global weather observing system is composed of a complex array of surface and space based measurement devices. To describe the initial state of the atmosphere, it is necessary to run the NWP model in a data assimilation mode. In this procedure, the data from a diverse global observing system are continuously/intermittently assimilated every six hours.The data types include: surface and upper air measurements of wind, temperature, pressure, geo-potential height of pressure surface, humidity and rain rate and clouds as observed from below or estimated from satellites/radars. Major amount of wind data is derived from tracking the motion of tropical stratocumulus and cirrus clouds from global geostationary satellites. In addition, polar orbiting satellites provide global temperature / moisture soundings from radiation measurements, cloud liquid water estimates, rainfall rates etc. A vast array of marine surface observations from ships provides global coverage. Also, arrays of floating buoys that carry surface meteorological instruments provide very useful surface weather observations over data sparse oceanic regions.Global communication satellites transmit these data sets by collecting from land based communication networks spread over several countries transmit the global observational data in real-time to the global weather centres and this service is known as the global telecommunication system(GTS).

Forecast Model

T-80L18 Global forecast model is a Spectral Model with a triangular truncation at 80 waves in the horizontal and has 18 layers in the vertical (T80L18). The forecast model is an adapted version of the NCEP's (National Centers for Environmental Prediction, USA) forecast model. The model is run once a day with 00 UTC initial conditions and generates forecasts up to 7 days. A higher resolution global model T-170L28 (75x75 km resolution in the horizontal and 28 layers in the vertical) has recently been installed. The model uses a simple land-surface scheme which includes: (i) exchange coefficients computations based on Monin Obukov similarity theory, (ii) Penman Monteith method of evapo-transpiration over land which includes vegetation effects (Pan, 1990), (iii) prognostic surface temperature equation of Arakawa (1972), (iv) 3 layer of surface and soil temperature prediction based on Bhumralkar (1975), (v) interactive bucket hydrology, (vi) evaporation by bulk method over ocean and (vii) Charnock's roughness length computation of ocean.

The input fields at 18 levels in the vertical are generated on terrain following sigma surfaces by the GDAFS for the production of 120hr global scale forecasts on real-time basis. They include divergence, vorticity, virtual temperature, specific humidity, log of surface pressure and orography.

Model Output

The model output from the Global Data Assimilation-Forecast System (GDAFS) include the following important fields besides many other parameters. The following parameters are produced at 12 standard pressure levels viz. 1000, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70 and -50hPa, for synoptic assessment of the forecasts at 24hourly interval.

i) Wind Field (Flow Pattern)

ii) Geopotential Height

iii) Temperature

iv) Specific Humidity

v) Vertical Velocity

In addition, Mean Sea Level Pressure(MSLP) and its 24hrly changes from the initial time distribution; Rainfall(accumulated for 24hrs) in quantitative terms; Weekly cumulative rainfall; Weekly Sub-Divisional Rainfall Distribution; Location specific surface weather elements viz. Rainfall, MSLP, Maximum and Minimum Temperatures and Surface Wind (speed and direction) and Humidity etc., are also produced for issuing forecast.

Meso-scale Models

Meso-scale modeling for real time forecasting is evolving in India. At National Centre for Medium Range Weather Forecasting (NCMRWF), high resolution meso-scale models such as MM5 and ETA are run on real time basis for forecasting meso-scale weather systems such as western disturbance, tropical cyclones, thunderstorms, heavy rainfall episodes etc. Using the initial conditions from T-80 global circulation model of NCMRWF, the MM5 model is run at 90, 30 and 10 km resolution and ETA model is run for 32 km resolution, for different regions of the country. The location specific weather forecast is prepared using inputs from global circulation model, meso-scale model, statistical interpretation of these numerical models and synoptic interpretation of graphical outputs of these model as well as experience of synoptic meteorologist. The real challenge lies in preparation of skillful forecast for smaller spatial domain. Indian meteorologists are striving hard to generate this at district level at least three to four days in advance of the weather event.

Extended/Seasonal range Prediction

Seasonal prediction of monsoon rainfall can be done using statistical, empirical and dynamical methods. Precipitation prediction, for a particular day, for specified locations, for months or season in advance has no notable skill. However, there is some skill in predicting anomalies in the weather at this scale. The predictability of seasonal climate anomalies, which results primarily from the influence of slowly evolving boundary conditions and most notably sea surface temperature (SST) (e.g. El Nino and La Nina) hinges on our understanding of the impacts of variation in ocean temperature on the atmospheric circulation.The inherent variability of the atmosphere and lack of understanding of major components of the climate system require seasonal climate forecast to be expressed in probabilistic terms. The forecasts are made for three equi-probable categories of below-normal (dry conditions), near-normal (around the average), and above-normal (wet-conditions). A probability is assigned to each category, indicating the chance of the particular category to occur during the target season.

Statistical method employed for predicting seasonal mean prediction of large homogenous regions of the country has serious limitations, underlying the need for development of dynamical or dynamical-statistical techniques for predicting precipitation & temperature in the extended range. Observational evidences and modeling results indicate that ocean thermal response, snow/ice conditions (polar and mountains) and soil wetness has bearing on internal variability of atmospheric circulation and precipitation in tropics through their impact on location and intensity of diabatic heat sources. Anomalous boundary conditions can be more effective in producing circulation anomalies in tropics, because tropical circulation is dominated by the planetary scale Hadley, Walker and monsoon circulations and changes in the boundary conditions can alter the locations and intensity of these systems. They can also influence the amplitude and phase of planetary waves in mid-latitudes that in turn can influence the tracks and intensity of cyclone scale disturbances. The boundary forcing determines the rather complex physical mechanisms for anomalies in the circulation patterns. The Asiatic Monsoon is a dynamically stable circulation system and its inter annual variability is largely determined by the slowly varying boundary conditions.

Efforts are ongoing to search good predictors having strong relationship with atmospheric anomalies and precipitation during monsoon season. Sea Surface Temperature (SST), especially over the Arabian Sea has been found to have strong bearing on the health of monsoon. The SST anomalies for the excess rain years are relatively warmer than deficient rain years during pre-monsoon and are colder during post monsoon. The warmer SST anomalies over equatorial pacific has been found to cause a shift in heavy precipitation regime from the extreme western pacific to central pacific near the international data line. There are large number of other factors such as synoptic scale disturbance (lows, depressions, and storms), the monsoon tough, quasi-periodic oscillations and their interaction with extra-tropical circulation which causes intra-seasonal variability in the precipitation.

Considerable progress has been made in the recent past towards prediction of seasonal rain forecast. The difficulties in making successful predictions arise because the inter-annual variability of the monsoon partly stems from planetary scale variations of the atmosphere – ocean – Land System and partly arises from the regional scale inherent dynamical variability of the sub seasonal and synoptic scales transients whereas the planetary scale component is predictable through boundary forcing, the regional component being chaotic in nature, is less predictable. The precise contribution of the internally generated dynamical variability to the total variability of the modeled monsoon is very difficult to assess and may be itself variable on year to year basis.

The numerical (dynamical) modeling can provide medium range (3-10) days forecast with reasonable accuracy. But beyond this, i.e. in the extended range forecast, the skill of these dynamical models is still not satisfactory. To avoid uncertainties associated with single dynamical model forecast, the focus is now on multi-model ensemble/super ensemble forecast.Some attempts are already made and some are in progress in this direction in Europe and America to provide seasonal scale forecast.Global coupled/ atmospheric modeling at coarse resolution could not provide the detailed climatic features at regional scale and thus it is important to downscale the global model products to regional scale. Further, improvement in forecast skill in extended range prediction is expected using statistical-dynamical model with outputs from regional climate model.

Dynamical long range forecast or statistical-dynamical hybrid models have not been developed over India so far, though in USA and Europe, the emphasis is on development of long range forecast techniques through coupled ocean-atmosphere numerical model outputs. At National Centre for Medium Range Weather Forecasting (NCMRWF), an experimental extended range (monthly) prediction system is being developed. The model chosen for the purpose is the operational global T80L18 spectral model with comprehensive model physics. Model climatology has been prepared for each month by integrating the model for several past years. The model climate is reasonably good and essential climatological features are well represented.

Real-time tests of the monthly prediction system were carried out in the monsoon seasons of last four years. For real-time runs, 10-member ensemble runs (five initial conditions and two SST prediction for each initial data) are made and persistent SST anomalies and SST predictions from Space Application Centre (SAC) were used during monsoon months. Probability of occurrence of Excess, normal, or deficient rainfall (anomalies computed based on model climate) for six homogenous regions of the country are computed. Performance of the monthly prediction system for monsoon months, so far, has been mixed. Several improvements have been planned to improve the skill of the prediction system.

Several seasonal integrations and sensitivity studies have been carried out to understand the monsoon intra-seasonal variability. Real-time Experimental Seasonal Prediction runs for the Monsoon seasons of 2003 and 2004 were carried out in the month of May. Persistent SST anomalies and Climatological SST values were used for the ensemble integration of the T80 Global Model. The NCMRWF model analysis has been studied to understand the propagation of Madden-Julian Oscillation (MJO) over the South Asian region and is compared with model simulations. Several more real-time and hind cast runs need to be carried out to evaluate the skill of seasonal prediction at NCMRWF.

Applying forecast for farm management

Despite the wave of technological advances in the agricultural sector the weather remains a major risk. From sowing through harvest; sunshine hours, temperature, precipitation and wind can all affect the quality and quantity of a crop. The relationship between weather and crop yield is often complex. For example, drought badly affects water-dependent crops, but also, excessive precipitation can flood the soil, leading to a restricted oxygen supply to the roots and a higher incidence of disease. Pesticides are vital in guarding against damage to crops, and for the agrochemical industry, wet years result in higher revenues as spores find it easier to survive in wet or humid conditions.

Adequate technological tools have been developed to achieve the task of translating weather information into profitable agro-management decisions. Crop model based decision support system can be made use of for developing information to aid in weather based crop and irrigation management. As crop-soil simulation models are designed to predict crop-level responses, a large proportion of the work described in the literature in which such models are used, is in relation to various management options of a single crop. Much of this modeling work has focused on understanding the interaction between the various factors influencing the crop growth and development, such as water and nutrient supply, biotic stresses and the time of planting and harvesting of the crop in relation to the prevailing environment. This has led on to using the models to find optimum management practices for these factors in particular environment, generally with the purpose of maximizing yields. CERES-Rice model incorporated in DSSAT is attempted for its use in crop and irrigation management in some of the agro-climatic zones.

Crop management needs detailed level of interaction between crop genotype, the soil, the aerial environment including weather forecast, and crop management practices. The information generated on the various components of the production system and their interactions is being used for the development of crop simulation models along with specific information generated for the purpose. Through crop growth simulation modeling it became possible to simulate a living plant through mathematical and conceptual relationships that govern its growth in the soil atmosphere continuum. In recent years, attempts have been made to integrate crop simulation models into decision support systems to provide users a better understanding of the possible outcomes of their decisions and assist them in developing viable management strategy. This stresses the need for making a distinction between strategic and tactical models for farm level decisions.

At a decision making level, the tactic may be defined as a series of short term decisions made on the basis of knowledge or forecast of soil moisture, of the plant and of climate conditions. In such a case, it is important that the farmer is able to anticipate the evolution of the function indicators of the soil and the plant in order to simulate their effects on plant development and yield. The strategic decisions are based on weather forecasts in extended and seasonal ranges and pertains to selection of cultivar, its planting/harvesting periods, contingency planning etc.

Decision Support System For Agrotechnology

Adequate technological tools need to be available to achieve the task of translation of the weather information into advisories for profitable management decisions. The crop model based approach to decision making is already being accepted by agricultural scientists as a viable tool for developing information for weather and climate dependent crop and irrigation management on farm level. Crop simulation model based expert system/decision support system can help in timely and knowledgeable decision making in preparation of farm advisories. A well validated crop simulation model can simulate crop growth, development and yield with reasonable accuracy so as to enable it as a high potential viable tool for optimal crop cultivation. The usability of such models in making tactical decisions for different cultural operations for a given crop at a given vegetative stage with inputs of weather forecasts for different temporal ranges in conjunction with information on soil, water and other production management details is now well established. Realizing these facts, NCMRWF is making an initiative in exploring the opportunity to use the crop growth models and Decision Support System for Agrotechnology Transfer (DSSAT) to help in farm management.

The crop growth models developed can be useful in crop management, if phenological stages are accurately simulated in necessary detail needed for practical applications and management strategies and the scheduling of management actions must be linked with the details of the phenological and morphological development of the plant. The management decisions that can be directly linked to crop phenology are: (1) irrigation application that should be made at strategic phenophases to achieve maximum water use efficiency, (2) fertilizer application that can be based on tissue analysis at early, mid, and maximum tillering and at panicle initiation, (3) herbicide application, which can be based on the leaf stage of the crop and also the target weeds, (4) invertebrate pest control, which must take place before a given leaf stage, and (5) harvest.

The DSSAT, developed by International Benchmark Sites Network for Agro-technology Transfer contains crop-soil simulation models, databases for weather, soil and crops and strategy evaluation programs integrated with a user friendly interface on microcomputers. Validation of DSSAT and its crop models was accomplished through a global network of benchmark sites involving systems users operating in diverse biophysical and socio-economic environments. Standard procedures to describe sites and soils and to record observations of weather and crops for validation were established with the minimum data set. A schematic of DSSAT components is presented below;

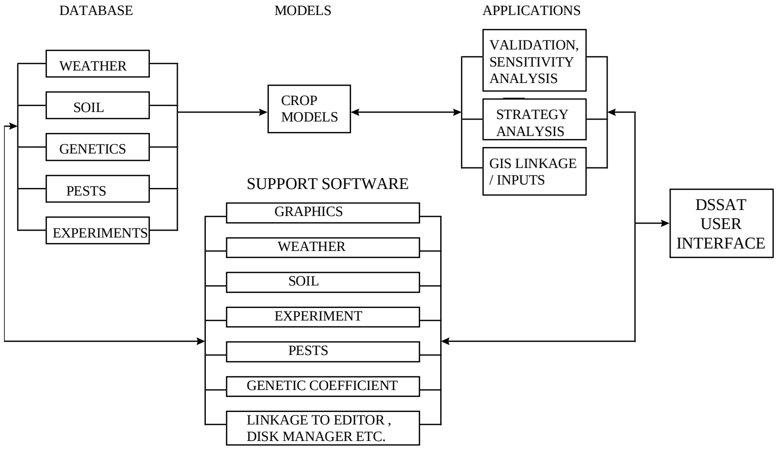

Figure 1. Schematic drawing of DSSAT components.

DSSAT was designed for users to easily create "experiments" to simulate, on computers, outcomes of the complex interactions between various agricultural practices, soil and weather conditions and to suggest appropriate solutions to site specific problems. DSSAT relies heavily on crop simulation models to predict the performance of crops for making a wide range of decisions.

Crop models

The IBSNAT crop models are daily incrementing, process oriented functional models. These are designed to use a minimum set of soil, weather, genetic and management information. These models simulate the effects of weather, soil, water, cultivar and nitrogen dynamics in the soil and the crop, on crop growth and yield. Inputs and outputs to the crop models have been standardized and documented to increase the efficiency of sharing data, to allow the introduction of other crop models and to allow application programs to be used with any of the crop models. Crop models included in DSSAT are: **CERES** (Crop Estimation through Resource and Environment Synthesis) family of crop models for wheat, barley, maize, sorghum, millet and rice; **CROPGRO** (CROP GROwth) family of crop models for soybean, drybean, peanut and chickpea; **SUBSTOR** (SUBterranean STORage) models for cassava, aroid and potato; and for sugarcane, tomato, sunflower and pasture. To simulate growth, development and yield, the models take into account the following processes:

(1) phenological development, especially as it is affected by genotype and weather. The models simulate the effects of photoperiod and temperature on the timing of panicle initiation and the duration of each major growth stage

(2) extension growth of leaves, stems and roots

(3) biomass accumulation and partitioning, especially as phenological development affects the development and growth of vegetative and reproductive organs

(4) water balance that simulates the daily evaporation, runoff, percolation and crop water uptake under fully irrigated conditions, and rainfed conditions

(5) soil nitrogen transformations associated with mineralization/immobilization, urea hydrolysis, nitrification, denitrification, ammonia volatilization, losses of N associated with runoff and percolation and uptake and utilization of N by the crop.

Plant protection

Weather derivatives are growing rapidly as a risk management tool for controlling pests and diseases. Growth and development of pests are typically dependent on heating and cooling degree days, humidity/wetness and radiation (cloud) over a season. Degree-day based models can be easily adapted for applications in pest management. Because so many insects require a critical amount and duration of heat to advance through their developmental life cycles, integrated degree day indices over an extended period are a good way to predict the need to use pesticides. The degree days used in energy are quite similar to those in agricultural applications, so that it is a natural progression to adapt weather derivatives to managing costs of insect control.

One of the most obvious areas of application for weather derivatives to hedge farm operators against the costs associated with repeated applications of chemicals. The major causes of repeat applications of pesticides are:

1. Accumulated degree days allow a large number of insect life cycles
2. High rain after application washes away chemicals
3. Low temperatures after application slow insect development so insects emerge after chemicals have had time to disperse

Phenology models are statistical measures that relate climate variations to insect development: "Phenology models predict time of events in an organism's development. Development of many organisms, which cannot internally regulate their own temperature, is dependent on temperatures to which they are exposed in the environment. Plants and invertebrates, including insects and nematodes, require a certain amount of heat to develop from one point in their life-cycle to another, e.g., from eggs to adults. Because of yearly variations in weather, calendar dates are not a good basis for making management decisions. Measuring the amount of heat accumulated over time provides a physiological time scale that is biologically more accurate than calendar days." These models cover a wide range of insect pests. Each insect requires a certain number of degree days to develop. The consumption of pesticides to control these pests will be a function of degree days. Phenology models can be used to design weather hedges for providing embedded weather-based options to end users of chemical products. There are many possible applications. One that seems potentially very useful is to protect farmers against the costs of multiple applications of chemical due to weather. For many insect pests, two factors make an application of chemicals ineffective:

1. If DD's are so low that the pesticide has dispersed before insects emerge
2. If heavy rains wash pesticide out before it can be effective.

Irrigation management

Development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rain-fed conditions or deficit irrigation is weather dependent. In order to develop irrigation schedules under various management conditions one needs to calculate reference evapo-transpiration, crop water requirements, crop irrigation requirements. The development of irrigation schedules and evaluation of rainfed and irrigation practices are based on a daily soil-water balance. Practical tool are available to carry out standard calculations for evapotranspiration and crop water use. Weather forecast (temperature, precipitation and wind speed) is key input for calculations of crop water requirements and irrigation requirements.

Agro-meteorological Advisory Service (AAS)

In order to carry out farm operations, a farmer not only needs weather forecast in different temporal ranges he also needs advice on available farm management options which are at his disposal in view of prognosticated weather situations. The NCMRWF in collaboration with the India Meteorological Department (IMD), Indian Council of Agricultural Research (ICAR) and State Agricultural Universities (SAUs) is rendering Agro-Meteorological Advisory Service (AAS) to the farming community, at the scale of Agro climatic Zones, based on location specific medium range weather forecast. This is a unique service as no other NWP Centers in the world is providing information on observed weather, weather forecast and advice on the actions to be taken by the farmers for different crops and livestock. The country is divided into 127 agro climatic zones with each zone covering about 3 5 districts. At present NCMRWF has established AAS units in 107 agro climatic zones. In the state of Tamil Nadu AAS units are functioning at Coimbatore, Chennai, Namakkal, Aduthurai, Kovilpatti, Pechiparai and Kannivadi. SAU's have appointed Nodal Officers at each of these units for its smooth implementation. It is proposed to open AAS unit one each in 127 agro climatic zones of the country by NCMRWF.

The location specific forecasts valid for 4 days for six meteorological variables, viz., total precipitation, average cloudiness, average wind speed, predominant wind direction, maximum temperature and minimum temperature are provided by NCMRWF to AAS units. In addition forecast for weekly cumulative rainfall is also provided. These forecasts of weather elements are subjected to refinement through statistical and synoptic techniques to obtain final location specific weather forecast. They are disseminated biweekly to AAS units on every Tuesday and Friday over telephone, Fax and/or email. NCMRWF is maintaining its web page (www.ncmrwf.gov.in) on which daily weather charts and output from mesoscale models are regularly updated for easy access of the users.

AAS units translate weather forecast into agrometeorological advisory. The Agromet Advisory Bulletins comprising of expert advice on crops, animals, soils and weather are made available to the farming community. These advisories contain location specific and crop specific farm level advisories prepared in local language containing description of prevailing weather, soil & crop condition, and suggestions for taking appropriate measures to minimize the loss and also, optimize input in the form of irrigation, fertilizer or pesticides. These AAS bulletins are disseminated to the farmers of the region through mass media, such as T.V., All India Radio and Newspapers in vernacular language and also through personal contact with the progressive farmers through extension workers. Agricultural universities also conduct certain Public Awareness programs to educate farmers about usage of Agro advisories. The AAS set-up exhibits a multi-institutional multidisciplinary synergy to render an operational service for the use of farming community. By locating AAS units at State Agricultural Universities or their Regional Research Stations and ICAR Institutes it is possible to incorporate research output in formulating the agro advisories. It also enables use of existing manpower already available at the agricultural Centre. The Nodal Officer of the AAS Unit, generally an Agrometeorologist, in co-operation with an inter-disciplinary group of agricultural and extension specialists, such as, Plant Pathologists, Soil Scientists, Entomologists, Horticulturists, Agronomists etc., formulate the agro advisories. Agrometeorological observatories have also been set up at all the AAS units. Some of these AAS units have automatic weather stations also. The observations recorded at these stations are sent to NCMRWF on bi-weekly basis for guidance in preparing the location specific forecast and also carry out verification studies.

POTASSIUM – AN INTEGRAL PART FOR SUSTAINED SOIL FERTILITY AND EFFICIENT CROP PRODUCTION

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Potassium (K), along with nitrogen (N) and phosphorus (P), is one of the three essential plant macronutrients, and is taken up by crops from soils in relatively large amounts. Potassium increases yield and quality of agricultural produce, enhances the ability of plants to resist biotic (e.g. diseases, pests and insect attacks) and abiotic stresses (e.g. cold and drought stresses). Proper K nutrition assists in the development of a strong and healthy root system and increases the uptake and nutrient use efficiency of nitrogen and other nutrients.

The importance of K stems from its multiple role in the plant: it is involved in the activation of more than 60 enzymatic systems in the plant cell, in the synthesis of proteins, vitamins, starch and cellulose which are responsible for optimal plant metabolism, plant growth and strong vegetal tissues. Potassium helps in the photosynthesis process, and is also responsible for the opening and closing of the leaf stomata, which regulate the water status in the plant. It plays an essential part in the formation of starch and in the production and translocation of sugars.

Potassium not only increases yields, but also enhances crop quality. It improves the nutritive value of grains, tubers and fruits by increasing the content of protein and oil in the seeds, the starch content in tubers and seeds and the vitamin C and sugar content in the fruits. With an adequate supply of K, cereals produce plump grains and strong straws. Potassium also improves the flavor and color of the fruits and increases tubers and fruits size. In addition, it increases the resistance during storage and transportation, thus extending shelf life. The requirements for K to achieve better quality may be larger than those for highest yield. Such is the case for fruits, cotton, potato, tobacco, ornamentals and some food crops.

The strategy of K application should bring in account not only crops' immediate response as yield increments, but also in other benefits such as improvement of soil fertility and the ability to withstand biotic and abiotic stresses. The use of K may bring a reduction in the use of pesticides, insecticides and fungicides and should be counted as a component of the integrated pest management (IPM).

The removal of potassium from the farm ecosystem at harvest is larger as yields increase. Under sub-optimal fertilization rates, it is often observed that soils become K-deficient over time. At IPI's field experiments we often find a negative K balance since the additions of K seldom matches K removals. There is an urgent need to budget K application in order to avoid further declination of soil fertility.

Potassium balance in India's farming system indicates a large deficit: K output (K removed in crops' yield, animal produce, K leaching) is higher than K input (FYM, composts, crop residues). Simple calculation shows that if organic manures need to supply all K requirements, there is a need for a very large application rate as K content in these materials is as low as 0.5-3%.

Sustainability of farm systems depends largely on soil's fertility and health. Mining of soil K may lead to lower nutrient use efficiencies of N and P and reduced fertility, thus negatively contributing to sustainability.

This paper presents results obtained from IPI experiments in India with various collaborators in different agro-climatic regions.

Potassium - an essential nutrient

Potassium (K), along with nitrogen (N) and phosphorus (P), is one of the three essential plant macronutrients, and is taken up by crops from soils in relatively large amounts. Vegetal tissues contain in average 2 to 10% of K, therefore K is required in large proportions by the growing plant. Potassium increases yield and quality of agricultural produce, enhances the ability of plants to resist diseases, insect attacks, cold and drought stresses and other adverse conditions. It helps in the development of a strong and healthy root system and increases the efficiency of the uptake and use of N and other nutrients. In addition, K has an important role in livestock nutrition (Kafkafi *et al.,* 2001; Marschner, 1995; Mengel and Kirkby, 1987).

The importance of K stems from its multiple role in the plant: it is involved in the activation of more than 60 enzymatic systems in the plant cell, in the synthesis of proteins, vitamins, starch and cellulose which are responsible for a normal plant metabolism, plant growth and strong vegetal tissues. Potassium helps in the photosynthesis process, during which the sugars and energy that the plant needs for its development are created. Potassium is also responsible for the opening and closing of the leaves stomata, which regulate the water status in the plant. It plays an essential part in the formation of starch and in the production and translocation of sugars, thus being of special value to carbohydrate-rich crops, e.g. sugarcane, potato and sugar beet. The increased production of starch and sugar in legumes benefits the symbiotic bacteria and thus enhances the fixation of N (Kafkafi *et al.,* 2001; Marschner, 1995; Mengel and Kirkby, 1987).

Potassium not only increases yields, but also enhances crop quality. Potassium is the "quality nutrient": it improves the nutritive value of grains, tubers and fruits by increasing the content of protein and oil in the seeds, the starch content in tubers and seeds and the vitamin C and sugar content in the fruits. With an adequate supply of K, cereals produce plump grains and strong straws. Potassium also improves the flavor and color of the fruits and increases tubers and fruits size. In addition, it increases the resistance during storage and transportation, thus extending shelf life (Usherwood, 1985).

Potassium benefits

Crops response to K should be measured not only in yield increments, but in quality and stress tolerance as well. Potassium regulates plant metabolism and promotes vigorous growth. This ensures a healthy and sturdy crop, which is more resistant to different stresses, like drought, frost, pests and diseases.

Quality

The quality of agricultural products comprises many characteristics, such as nutritional, organoleptic, hygienic and functional properties. Often the amount of K required for optimum yield is also sufficient to secure good quality. However, the need to enhance fruit quality is sometimes more critical than other aspects of yield production, especially when quality secures the best economic return. In such cases more K is needed to ensure quality than is needed for maximum yield. Such is the case for fruits, cotton, potato, tobacco, turfgrasses, ornamentals and some food crops (Kafkafi *et al.,* 2001).

The crucial importance of K in quality formation stems from its role in promoting synthesis of photosynthates and their transport to fruits, grains, tubers, and storage organs and to enhance their conversion into starch, protein, vitamins, oil etc. (Mengel and Kirkby, 1987). With a shortage of K many metabolic processes are affected, like the rate of photosynthesis, the rate of translocation and enzyme systems (Marschner, 1995; Mengel, 1997). At the same time, the rate of dark respiration is increased. The result is a reduction in plant growth and in crop quality. Potassium influences on quality can also be indirect as a result of its positive interaction with other nutrients (especially with N) and production practices (Usherwood, 1985).

Drought

Potassium controls water uptake, transport and utilization. It regulates plant transpiration by controlling stomatal opening, thus maintaining turgor, and reducing water loss and wilting. Plants adequately supplied with K wilt less under water stress because K has the major responsibility for turgor changes in the guard cells of stomata during stomatal movements. The better the K supply of plants the more rapid is the stomata movement: Potassium lowers the amount of water lost through the leaves (transpiration) through regulation of stomata opening and closure (Beringer and Trolldenier, 1978; Marschner, 1995; Mengel and Kirkby, 1987). The osmotic effect of K also helps to extend the shelf life of leafy vegetables in particular.

Potassium helps to better use of water due to its multiple benefits to roots, leaves and the whole plant. Regarding the positive effects on roots, K promotes a rapid seedling development, providing good early growth and quick cover of the soil thus decreasing water evaporation from soil. Potassium helps in deep root growth: roots penetrate deeper into the soil and make use of subsoil moisture. Lastly, the more K inside the root cells, the more strongly roots attract water from the soil due to greater osmotic gradient (Beringer and Trolldenier, 1978; Marschner, 1995; Mengel and Kirkby, 1987).

Regarding the positive effects for the water regime at the whole plant level, K has an osmotic effect in the plant sap, thus maintaining cell turgor and retaining more water in the plant. Potassium also induces earlier maturity, ensuring that the crop will get through the critical pollination period earlier, escaping drought periods (Beringer and Trolldenier, 1978).

While in good years response to K may be modest, in adverse years its contribution will be substantial. Potassium provides some insurance protection against difficult conditions. The positive effects of K application on crop yields under drought conditions are illustrated in the following table, which presents the results of a groundnut experiment conducted in Junagadh, Gujarat (India) by the International Potash Institute (IPI) and the Gujarat Agricultural University (Golakiya *et al.,* 1998).

Table 1. Effect of K application and cyclic dry spells on groundnut yields (Golakiya *et al.,* 1998).

Dry Spell	*Yield (kg/ha)*		*Yield increase*
	0 kg K_2O/ha	*60 kg K_2O/ha*	*%*
Control	*1,957*	*2,150*	*9.8*
Single	*1,486*	*1,613*	*8.5*
Double	*835*	*1,039*	*24.0*
Triple	*485*	*613*	*26.0*

Groundnut yields were lower in dry years than in wet years but the yield increases due to K application were higher in dry years. Potassium cannot protect against extreme droughts but helps to maintain yield levels in years of water stress. Good K management can help farmers to reduce risks related to drought.

Pests and diseases

It has been recognized for decades that K enhances a plant's ability to resist pest and diseases. This is not isolated to a few crop species, but comprises a wide range of both plants and pathogens. The role of K in crop resistance to diseases was extensively examined in an IPI review of 2450 literature references (Perrenoud, 1990). The results showed that adequate amounts of K decreased the incidence of fungal diseases by 70%, of bacterial diseases by 69%, of insects and mites damage by 63% and of viruses by 41%.

Potassium enhances plant growth, ensuring a healthy crop, free from stresses and much more resistant to attack from pests and diseases. Potassium promotes vigorous growth to help plants outgrow or escape damage, and also hasten early maturity, thus reducing ineffective time for disease organisms.

Adequate K nutrition provides thicker cell walls, stronger stems and stalks, and avoids sugar and unused N accumulation in the leaves. Due to all these effects, plants are more resistant to entry and infection by fungi, bacteria and viruses, and plants become less palatable to insects (Kafkafi *et al.,* 2001).

Potassium applications may not only result in higher yields as a response to nutrition deficiencies, but also result in lower levels of infestation from yield-limiting diseases. Application of K fertilizer is not a substitute for fungicides, but an important component in the integrated pest management (IPM), allowing reductions in the fungicide doses and thus decreasing pesticide and hazardous residues in food crops. This is in tune with stricter pesticide residue regulations and the increased awareness of the consumers for healthy and residue-free food.

Nitrogen and potassium relationship

Potassium and N are strongly associated in plant processes and should be considered in conjunction. Firstly in terms of uptake, both nutrients are needed in large amounts at the same time. N is mainly taken up as the nitrate anion NO_3^- and K as the cation K^+. The balanced uptake of these nutrients in positive and negative charged forms achieves neutrality in the plant. Nitrogen application and uptake stimulates uptake of K and may be impeded if K is limiting (Marschner *et al.,* 1996).

Within the plant the complex formation of protein from nitrate and its distribution around the plant are highly dependent upon adequate K supply. If "normal optimum" rates of N are applied in the absence of sufficient K, full response to N will not be obtained and residues of N may remain and be leached at the end of the season (Marschner, 1995).

Adequate K reserves are essential to achieve the best possible response to N and increase maximum N efficiency. Where K reserves had been depleted by not applying K in the past, applying the larger amounts of N is both uneconomic and would have left a large residue of nitrate at risk to loss by leaching. Large doses of fertilizer are economically justified in the presence of K.

The ratio of N:K in plants plays an important role in the host/ pathogen relationship. Plants supplied with excessive N/deficient K have usually a high content of low molecular assimilates such as sucrose and amino acids because of impaired phloem transport and N metabolism (Marschner, 1995; Marschner *et al.,* 1996). The soft and often injured tissue gives easy access to invading pathogens and exhibit less chewing resistance. The content of repelling secondary plant substances such as phenolic compounds is rather low (Perrenoud, 1990).

IS THERE ENOUGH POTASSIUM IN THE SOIL ?

Potassium content in the soil is in average 1-5%. Its primary source is the structural minerals of the soil such as micas and feldspars. The supply of total K in soils is quite large; yet, relatively small amounts are available for plant growth at any one time. Four fractions of K exist in an equilibrium in the soil system: 1) Potassium as a component of soil minerals, 2) Fixed K, 3) Exchangeable K and 4) Water soluble K (Sparks, 2002). The water soluble K is available immediately to the plant and is susceptible to leaching. Plant roots can absorb only the K ions (K^+) dissolved in the soil solution, which constitute only 0.1% of total soil K. The exchangeable K fraction derives from the soil colloids (clays and humus), represents 0.1 to 2% of total soil K and is also available to the plant during the crop cycle. The fixed K and mineral K are present in the soil in very much greater proportions (90 to 98% of total K) and may provide a potential supply to fractions 3 and 4. However, fixed K is only released in low exchangeable K conditions, and mineral K is only released after weathering, which is a very slow process (Mutscher, 1995; Sparks, 2002).

The various fractions and the passage between the different fractions depend on the sand and clay components, and on clay types; availability is also influenced by moisture. The vermiculite, illite and smectite clays have very high natural levels of fixed and exchangeable K. The sandy and organic soils have much lower reserves of K, and in coarse textured soils, the soluble K is very susceptible to leaching below the root zone (Mengel and Kirkby, 1987).

With depletion of the exchangeable fraction, the K release rate from this fraction decreases as well. This restricts the replenishment of solution K. There is also a substantial decrease in the K release from the non-exchangeable or slowly available fraction. K uptake of plants and thus plant growth declines rapidly with decreasing K release. Furthermore, depleted soils possess a much higher K fixation capacity than soils well supplied with K. To rehabilitate K depleted soils is costly. Experiments with Indian soils showed that it requires up to 5 times more units of K to increase the soil K by one unit in contrast to soils with a good K status where 1.2 units of K was enough to increase the soil K content (Srinivasa Rao and Khera, 1995).

In most of the intensive cropping systems, K balance is negative since the additions of K seldom match the K removals resulting in larger dependence on soil K supply. Under such conditions there is greater pressure on non-exchangeable K for meeting the K requirement of crops (Pasricha and Bansal, 2002). Long-term intensive cropping, in the absence of K inputs, adversely affected the K supply to crop plants and consequently crop yields.

Potassium removal and replenishment in the farming system

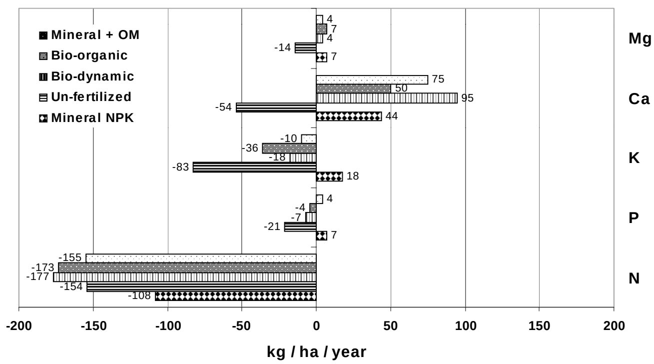
Potassium in fruits and agricultural produce is taken away from the farm ecosystem at harvest, thus high quantities of K are removed from the soil. The higher the yields, the higher the uptake of K. The result: the K levels tend to decline over time, and soils can become deficient in K. Without any replenishment of the K natural reserves, yields and sustainability cannot be maintained in the long term. Usually, the net removal of K is considerably greater than the input, even where organic manures are applied. For example, wheat crop removes approximately 30 kg of K per ton yield. A potato crop yielding 70 ton/ha, containing 4 ton of K per ton tubers, removes 280 kg of K/ha. A citrus orchard also removes K in very large quantities by harvest, requiring as much as 400 kg/ha supplied annually by soils (1% K in fruit times 40,000 kg fruit/ha harvested) (IFA,1992).

It is very important to supply the plants with the three essential macronutrients (N, P and K) in a balanced way. For a proper crop development, plants need to take up these nutrients at the required levels, not only at their absolute required quantities, but also at their relative ratio. The ratio between N, P and K uptake should be balanced: for example, over-fertilization with N may lead to an excessive vegetative growth relative to the fruit development; a P deficiency can be a limiting factor of crop yields, even if N and K are at the appropriate levels. An ideal and balanced ratio for vegetables is 1:0.3:1.3 N:P_2O_5:K_2O. Over- fertilization with N and P must be avoided not only from the economic point of view, but also to protect our environment. Excess nitrates that are not taken up by plants can be leached downwards to the groundwater thus polluting the aquifer. The unused P can be carried away to lakes, rivers and water reservoirs and can cause algae and weed growth, thus depleting the water oxygen supply and killing fish and desirable vegetation ("eutrophication"). In contrast with N and P, K poses no environmental hazard or threat (Kafkafi *et al.,* 2001).

The need to feed an increasing population in less available arable land demands for a higher productivity. However, in order to achieve a higher yield, the plant has to absorb more nutrients and ultimately, more nutrients are removed from the field with the harvest. The record harvest of maize and soybean in the Midwest USA during 2004 provides an excellent example of removal rates of P and K. On an average, removal of P and K from 1 hectare of soybean reached 52-88 and 92-148 kg P_2O_5 and K_2O, respectively, while in maize it reached 92-154 and 68-108 kg P_2O_5 and K_2O, respectively (PPI-PPIC, 2005).

Organic manures play a role in improving or maintaining K levels in some extent, but the content of K in manures is low (0.5-3%). A wasted resource of our time is sewage (sludge or biosolids from municipal wastewater treatment plants), and while it has vast potential, it largely remains unacceptable because the water authorities are unable to control the heavy metal content. If there is a negative balance of K in the soil, it is possible to turn it positive by applying inorganic fertilizers like potassium chloride or potassium sulfate.

Organic farming is another trend in cropping systems. A different balance between inputs and outputs is achieved, but doubts over the sustainability of the system arise. In 21 years of long-term experiment conducted by FiBL (Forschungsinstitut für Biologischen Landbau) in Switzerland, four basic treatments were compared: two organic systems (biodynamic and bio-organic), and two conventional systems (manure+mineral fertilizers and mineral fertilizers exclusively). The results show that yields were 20% higher with the two non-organic treatments. Depletion of nutrients was highest at the two organic treatments (Figure 1), suggesting mining of soil N and K at a level of 170 and 35 kg N and K_2O/ha, respectively (Mader *et al.,* 2002).



Nutrient balance in organic farming 1978-1998
(Mader et al., 2002)

Figure 1. Nutrient balance in organic farming 1978-1998. (Mader *et al.,* **2002)**

Potassium and sustainability of the farming system

Concerning the nutrient ratio in fertilizer use, Tamil Nadu has a better N:K ratio in fertilizer use as compared to the other states in India. The current K:N ratio in TN is N:K = 1:0.66. The KN ratio in All-India is N:K = 1:0.13 (Fertiliser Association of India, 2004).

The obvious preference for N fertilizers and the sparse use of K contradict the ratio at which crop plants absorb and remove the nutrients from the field. Potassium is removed by the crop at about the same quantity as N. Therefore, if per 1 kg N applied only 660 g K_2O are applied, as currently in Tamil Nadu, but crops remove both nutrients at almost equal quantities, substantial soil K mining has to be assumed. Farmers remove annually more K from the field than they return with K fertilizers.

K budget in India farming indicates large deficit of K, i.e., K output (crops' yield, animal produce, K leaching) is higher than K input (manures, composts, crop residues). In 1998, it was estimated that a total of 13.7 million t K_2O/ year was removed by crops in India against a K fertilizer consumption of only 1.57 million t K_2O. After considering all the organic and inorganic additions, a net deficit of 7.05 million t K_2O per year has been estimated, which means a depletion of Indian soils at the rate of 37.5 kg K_2O/ha/year (Pasricha and Bansal, 2002).

Organic manure cannot compensate for the export of nutrients via cash crops and nutrient losses. Simple calculation shows that if organic manures need to supply all K requirements, there is a need for a very large application rate as K content in these materials is as low as 0.5-3%. It is also clear that with the widespread misuse of farmyard manure as fuel, the increasing deficit in the K balance cannot be closed with more use of organic manure, because of its restricted availability as soil amendment.

A crop of rice contains about 34 kg K_2O/ton produce, about 30 kg in the straw and only 4 kg in the grain (IFA, 1992). It is obvious that the management of the crop residues will influence the K balance in the soil. When the whole crop is harvested, as is the common situation in India (the straw is used for fuel, cattle feed, etc), larger amounts of K are removed and higher doses of K fertilizer will be required to maintain an adequate supply in the available form for the next crop. A simple balance calculation of soil K in intensive rice systems typical to large areas in Asia was made by Dobermann and Witt (2000). Clearly, the removal of straw from the field has a significant impact on nutrient balance (Table 2).

Table 2. Estimated average input-output balance of K (kg/ha) in intensive rice systems of South and Southeast Asia with an average yield of 5.2 t/ha (Dobermann and Witt, 2000)

Factor	*Input*	*Output*
	(kg/ha)	
Fertilizer	*17*	
Farmyard manure	*5*	
Net removal with grain		*13*
Net removal with straw		*35*
Balance	*-26*	

The negative balance may lead to insufficient soil K levels and decrease in the yield, as K may become a limiting factor. Sustainability of farm systems maybe questioned in the light of the actual K mining from soil, which endanger arable soil fertility. This deterioration of soil health is opposed to sustainability principles of maintaining long-term soil fertility of agricultural production systems.

Potassium and the environment

To ensure healthy and nutritious plant growth, adequate supplies of K must be maintained in the soil by judicious use of fertilizers and manures. There are no environmental risks associated with this nutrient (Beringer, 1992). In fact, K makes a positive contribution to the environment by balancing other nutrients, especially nitrate, to make sure they are taken-up and used by plants efficiently so avoiding losses which might be harmful. Potassium helps plants reach optimum productivity. High yielding grain crops leave more residues on the land. These residues cover the soil and protect it from the forces of erosion.

Potassium is not associated with any environmental or health concerns. It has no known deleterious effect on the quality of natural and drinking waters and it does not induce eutrophication in rivers and lakes. Potassium ions leached into deeper soil layers and finally reaching the aquifers presents no ecological threat, and K in drinking water and/or food is no hazard for human health provided renal function is normal (Beringer, 1992; Mengel, 1997). A diet high in K has no harmful effect and is recommended for people suffering from hypertension.

The European Union has amended the regulations that stipulate target limits and maximum limits for a range of substances in drinking water. There are no longer any limits for K in these regulations reflecting the benign nature of this element in the environment and to human health (Kafkafi *et al.,* 2001). Potassium is not lost to the atmosphere, as can occur with some N fertilizers under certain soil and environmental conditions. Potassium fertilizers do not contain any of the heavy metals that are considered toxic and environmentally hazardous, and are not referred to as potential hazards in relation to radioactive elements (Kafkafi *et al.,* 2001).

Potassium responses in Tamil Nadu

According to a wide review on K status of Indian soils, based on the soil content of available K and non-exchangeable K, Subba Rao and Srinivasa Rao (1996) classified the red and lateritic soils of

Tamil Nadu as medium in available K but low in reserve K. Field, horticultural and plantation crops responses have been frequently reported in these soils (Subba Rao and Srinivasa Rao, 1996). The results of the experiments recently conducted by the International Potash Institute (IPI) and the Tamil Nadu Agricultural University (TNAU) support this diagnosis, and are presented here below.

The effect of K application on sugarcane yield and quality was studied in experiments conducted at Bhavanisagar Research Station by IPI and TNAU (Karthikeyan *et al.,* 2003). The results showed that with a judicious combination of irrigation level and balanced fertilization of K, along with N and P, it was possible to increase the productivity of the cane along with juice quality, with a good economic return to the farmer. Application of 225, 65 and 112.5 kg/ha of N,

Table 3. Effect of K application and different irrigation regimes on brix content in the juice, commercial cane sugar content in the juice and sugar yield at Bhavanisagar (Karthikeyan *et al.,* **2003)**

Irrigation (IW/CPE ratio)	***K levels (kg K_2O/ha)***	***K_0 0***	***K_1 56.25***	***K_2 112.5***	***K_3 168.75***	***Mean***
Brix content in the juice of sugarcane						
I_1		*18.7*	*19.0*	*20.0*	*20.1*	***19.5***
I_2		*20.0*	*21.2*	*21.3*	*21.5*	***21.0***
I_3		*21.1*	*21.6*	*22.0*	*22.4*	***21.8***
Mean		***19.9***	***20.6***	***21.1***	***21.3***	
*CD (P=0.05): I = 0.18 ; K = 0.21 ; I * K = 0.37*						
Commercial cane sugar content in the juice (%)						
I_1		*11.4*	*11.5*	*11.6*	*11.8*	***11.6***
I_2		*12.1*	*13.2*	*13.4*	*13.4*	***13.0***
I_3		*13.0*	*13.5*	*13.8*	*14.1*	***13.6***
Mean		***12.1***	***12.7***	***12.9***	***13.6***	
*CD (P=0.05): I = 0.17 ; K = 0.19 ; I * K = 0.34*						
Sugar yield (t/ha)						
I_1		*6.74*	*7.32*	*8.30*	*8.62*	***7.74***
I_2		*10.8*	*12.4*	*14.1*	*14.1*	***12.8***
I_3		*14.3*	*16.1*	*18.1*	*18.7*	***16.8***
Mean		***10.6***	***11.9***	***13.5***	***13.8***	
*CD (P=0.05): I = 0.32 ; K = 0.41 ; I * K = 0.69*						

P_2O_5 and K_2O respectively under 1.0 IW/CPE ratio of irrigation throughout the cane growth resulted in better nutrition of sugarcane on sandy clay loam soils of western zone in Tamil Nadu (Table 3).

Table 4. Grain yield (kg/ha) of rice as influenced by graded levels of K and method of application at two locations in Tamil Nadu, Aduthurai and Pattukottai (Dakshinamoorthy, 2005)

kg K_2O/ha		***Kalathur soil series (Aduthurai)***				***Maddukur soil series (Pattukottai)***			
	Application	***S1***	***S2***	***S3***	***Mean***	***S1***	***S2***	***S3***	***Mean***
K0		*4136*	*4476*	*4845*	*4486*	*6560*	*6373*	*6587*	***6507***
K50		*4053*	*4026*	*4191*	*4090*	*6640*	*6320*	*6320*	***6427***
K100		*4217*	*4710*	*5010*	*4646*	*7547*	*7440*	*6960*	***7316***
K150		*4710*	*4822*	*4953*	*4828*	*6320*	*6800*	*6773*	***6631***
K200		*4181*	*4612*	*5007*	*4600*	*6827*	*6587*	*7067*	***6827***
Mean		***4259***	***4529***	***4801***	***4530***	***6779***	***6704***	***6741***	***6741***
CD (p=0.05)		*K-253*	*S-196*	*K*S-NS*		*K-514*	*S-NS*	*K*S-NS*	

S_1: N and K all at planting; S_2: N and K in four equal splits, at planting, at active tillering, at panicle initiation and at first flowering; S_3: N and K in three splits, one at planting as soil application, one as foliar spray at flag leaf stage and the balance as foliar spray at grain development.

The effects of K doses and method of application on rice yield and quality were studied in experiments conducted at two research stations by IPI and TNAU (Dakshinamoorthy, 2005). The results showed there were significant increases in yield for K levels up to 100 kg K_2O/ha at both sites (Table 4). Regarding the grain quality, the results have shown that with increasing level of K application, the chaffy grain count was reduced, indicating the importance of K for grain development (results not presented).

Delivering, educating, sharing

Potassium fertilization is experimented by IPI in various regions in the world, in a large array of crops, demonstrating the effect of K on yield, quality, N and P use efficiency and resistance of plant to pathogens. There is an acute need to build and fortify stable highway bridges between research and extension. Through our network of coordinators, IPI is trying to reach out to farmers, dealers, extension officers, farmers' cooperatives and foundations. Recently extension activity in India was designed for women farmers. Quantifying these communication channels is complex. We reach thousands of farmers, hundreds of dealers, and many dozen of extension officers, research fellows and others – modifying the required communication structure as needed.

The messages for each audience are different, yet integrated. Dealers in India show interest in basic plant nutrition, whilst extension officers in China are keen to learn automation of fertigation systems. Farmers in Brazil are exploring the possible effect of K on suppression of Asian rust disease; whilst researchers in Bulgaria are interested in foliar application of K in order to sell their products tin the European Union.

The new Information Technology developments enable us to upload knowledge and content and make it available to all. Currently, IPI has 3 web sites: 1) www.ipipotash.org , 2) www.ipichina.org (in Chinese) in cooperation with the Ministry of Agriculture, China and 3) www.cnptia.embrapa.br/projetos/ipi/ in cooperation with the Ministry of agriculture, Brazil (EMBRAPA).

Our large-scale activities in Asia are now supported with a new initiative of extension work. Through our support in the International Rice Research Institute (IRRI), we are now entering the new phase of creating overall recommendations for SSNM in some 20 rice-growing areas, holding workshops and training courses on SSNM in six countries toward building research–extension–private-sector partnerships for further dissemination of the practices to farmers.

IPI has long history in producing leaflets, brochures, reports, manuals, extension kits and organizing workshops, training courses, farmers' days, symposia and conferences.

The need for a strong advisory systems that would help the farmers in utilizing the best knowledge available by science, is vital and most rewarding. IPI, through its vast scientific publications and experience in extension work, is striving to assist and share this experience with national and regional entities.

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CHANGING FACE OF SOIL FERTILITY AND NUTRIENT MANAGEMENT

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About 200 M t of foodgrain produced by India's farmers is intended to feed the country's billion plus people - one-sixth of the world's population. With a population growth rate roughly estimated at two percent a year, this translates into more than 18 million new mouths to be fed each year or 26 babies born per thousand people every year. If this rate of population growth continues unabated, India will overtake China in population, but not in agricultural and industrial progress. This is a matter of great concern.

India could produce three times more foodgrain by fully exploiting the potential of its 50 M ha of irrigated land. However, this increase in the yield would be accompanied by a similar increase in nutrient removal by crops, and so the nutrient requirement would increase by the same proportion. This growth will be a great challenge because the compound growth rates in respect of production and productivity of principal crops in India present a gloomy picture (Table 1).

Table 1. Compound growth rates (% per year) of production and productivity of principal crops from 1981/82 to 2000/01

	Production		*Productivity*	
Crops	*1981-82 to 1989-90*	*1990-91 to 2000-01*	*1981-82 to 1989-90*	*1990-91 to 2000-01*
Rice	*3.55*	*1.74*	*3.47*	*0.92*
Wheat	*3.57*	*3.27*	*3.10*	*2.21*
Total cereals	*3.03*	*1.86*	*2.90*	*1.36*
Total pulses	*1.52*	*-0.04*	*1.61*	*0.55*
Total foodgrains	*2.85*	*1.66*	*2.74*	*1.28*

Source: "Agricultural Statistics at a Glance" 2001, Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Govt. of India, New Delhi

Tamil Nadu is one of the agriculturally important states of southern India having 5.5 million hectares of net cultivated area of which 54 percent is irrigated. Major soils of the state are red, laterites, black and alluvial soils. The principal crops grown are rice, sorghum, finger millet, maize, pulses, oilseeds, cotton, sugarcane, plantation crops like coconut, rubber, tea, coffee, fruits, vegetables, spices, tubers etc., The share of area under food grains to gross cropped area is 56 percent. A variety of cropping systems are in practice in the state (Table 2),

Fertilizer Scenario

Despite phenomenal rise in fertilizer use in India from 65000 tonnes in 1951 to 17.4 Mt (11.3 N+4.4 P_2O_5+1.7 K_2O Mt) in 2002, a rise of almost 270 times, nutrient additions generally fall short of requirements. From the point of intensity of fertilizer use, which is a better measure of adequacy of fertilizer application across crops and regions, India's position is not very comfortable as is its ranking in total fertilizer consumption. Even in South Asia, India uses far less fertilizer ha^{-1} $year^{-1}$ than Sri Lanka, Bangladesh and Pakistan and in most cases, soil nutrient balances in India are negative with an annual deficit of 9-10 Mt N+P_2O_5+K_2O- between crop removal and fertilizer application. Nutrient wise apportioning of the 95 kg NPK consumption ha^{-1} $year^{-1}$ does not indicate match with the crop requirements. For instance, crops K requirements are near identical to N; for P these are three to five times less than either N or K. Corresponding to need, use of N (60 kg ha^{-1}) and P (23 kg ha^{-1}) is, respectively 7 and 2.6 times higher than K (8.8 kg ha^{-1}). Precariously poised K use with respect to N and P has been in existence for the last 30 years. On an average, K use has been only one seventh of N and about one-third of P. Although one may justify less emphasis on K management in terms of existing soil fertility scenario, in the long run its continuous mining is bound to flare up in intensity. Indeed, such are results on NPK balance and their influence on sustainable growth in productivity of crops. Generally, inclusion of K in fertilizer treatment improved productivity.

Table 2. Tamil Nadu at a Glance

Net area sown	5.64 M ha
Area sown more than once	0.99 M ha
Total cropped area	6.63 M ha
Total irrigated area	3.64 M ha
Percentage of irrigated area	53.6 %
Area under foodgrains	3.68 M ha
Area under pulses	45,000 ha
Area under oilseeds	0.57 M ha
Area under sugarcane	0.31 M ha
Area under cotton	78.0 Thousand ha
Area under tobacco	7 Thousand ha

Fertilizer consumption ($N+P_2O_5+K_2O$) M t	0.94 ($0.50N+0.21\ P_2O_5+0.23K_2O$)
Fertilizer consumption ($N+P_2O_5+K_2O$) kg/ha^{-1}	141.5 ($76.2\ N+31.0\ P_2O_5+34.4\ K_2O$)
$N-P_2O_5-K_2O$ Ratio	Rabi 2.3:0.9:1 Kharif 2.0:0.9:1 Average 2.2:0.9:1
Soil testing labs	39 (24 STL + 15 mobile) Capacity 952,000 samples
Nutrient Balance, 000 t	(+] 78N, [+] $35P_2O_5$, [-] 236 K_2O
Productivity t /ha	Rice 3.4, P. Millet 1.52, Maize 1.62, Ragi 1.72, G. Nut 1.77, Sugarcane 107, Cotton 285

Some trends in fertilizer nutrient consumption in India are shown in Table 3.

Table 3. A summary of developments in fertilizer consumption in India

	Item	1960-61	1970-71	1980-81	1990-91	2001-02
1	Consumption (000 t)					
	Nitrogen (N)	212	1,479	3,678	7,997	11,310
	Phosphorus (P_2O_5)	53	514	1,214	3,221	4,382
	Potassium (K_2O)	29	236	624	1,328	1,667
	Total	294	2,256	5,516	12,546	17,360
2	Consumption (kg/ha^{-1})					
	N	1.39	8.92	21.22	43.1	58.7
	P_2O_5	0.35	3.26	7.00	17.3	22.8
	K_2O	0.19	1.43	3.60	7.2	8.7
	Total	1.93	13.61	31.82	67.6	90.2
3.	Ratio of P_2O_5 & K_2O (N=1.0)	0.37:0.16	0.37:0.16	0.33:0.17	0.40:0.17	0.39:0.14
4.	Highest consumption in a state (kg/ha^{-1}) $N+P_2O_5+K_2O$)	6.58 Kerala	40.24 Punjab	117.9 Punjab	161.9 Punjab	173.4 Punjab

Even though India is the third largest fertilizer user, average rate of nutrient application is 90 kg/ha^{-1} (65% as N, 25% as P_2O_5, 10% as K_2O), the consumption is highly concentrated in certain areas and large areas receive very little fertilizer. Out of 496 districts (sub-units of a state), 25% of total fertilizer is consumed in 38 districts, 50% in 99 districts and 75% in 197 districts. The average rate of application is also indicative of few well-fertilized areas and large areas receiving very small rates of application as shown below and in **Fig 1**.

Fig 1. Distribution of districts according to level of fertilizer consumption. Figures pertain to consumption/ha in terms of kg N + P_2O_5 + K_2O

Less than	100 kg N+P_2O_5+K_2O	used in 61% districts
Between	100-200 kg N+P_2O_5+K_2O	used in 31% districts
Greater than	200 kg N+P_2O_5+K_2O	used in 8% districts

There is thus a large untapped potential. Its exploitation requires an area-wise constraint analysis because if the fertilizer use pattern is highly skewed, there must be reasons for this.

There is little resemblance between the pattern of NPK removal by crops and their consumption through fertilizers with N dominating nutrient additions and K dominating removals (**Fig.2**).

The fertilizer consumption in the country ranges from 1.1-325 kg N ha^{-1}, 0.8-153.8 kg P_2O_5 ha^{-1} and 0.2-129 kg K_2O ha^{-1}. There is disparity in consumption ratio of NPK (6.8:2.8:1 in 2001-02), which is more pronounced in the northern states (29.1:10.9:1) indicating highly imbalanced use of fertilizers.

There are a lot of disparities in the fertilisers consumption pattern both between and within the eco-regions of the total 525 districts in India. Nineteen districts consume more than 200 kg ha^{-1}, 35 districts between 150-200 kg, 75 districts between 100-150 kg and 132 districts between 50-100 kg ha^{-1}. Further 84 districts account for 50 per cent of the total consumption. Average consumption of the plant nutrients both in the western and eastern zones are far below the national average of 90 kg ha^{-1} although these states have high potential of using more mineral fertiliser.

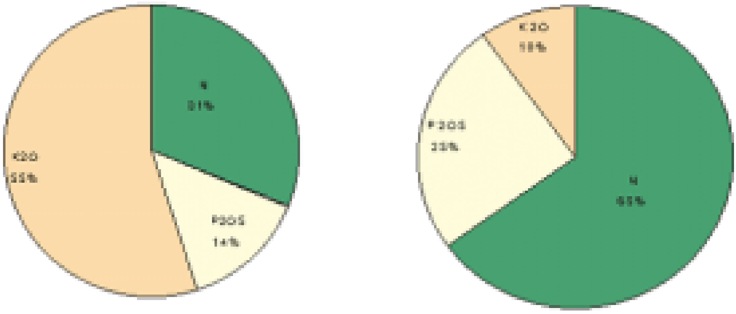

Fig 2. The contrasting pattern of nutrient removal (left) and nutrient consumption in Indian agriculture (right)

The current fertilizer use in Tamil Nadu is 112 kg ha^{-1} consisting of 60.1, 24.6 and 27.3 kg ha^{-1} N, P_2O_5 and K_2O respectively, the N:P_2O_5:K_2O use ratio being 2.2:0.9:1.0. While most of the nitrogen is applied in the form of urea, the major phosphatic and potassic sources continue to be DAP (46% P_2O_5) and muriate of potash (60% K_2O), respectively. This ratio is certainly much better than the northern states mainly because southern region has high value crops where the crops are being fed better than the cereals, oilseeds and pulses dominated cropping systems in the northern region. The data on NPK use pattern in southern states are given in Table 4.

Table 4. Statewise consumption of P_2O_5 and K_2O in relation to N (2001) in southern region

State in descending order of P	N applied kg ha^{-1}	kg P_2O_5 applied/ 100 kg N	State in descending order of K	N applied kg ha^{-1}	kg K_2O applied/ 100 kg N
Karnataka	54.5	53.8	Kerala	26.2	83.2
Kerala	26.2	48.9	Tamil Nadu	76.2	45.1
Pondicherry	317.4	47.3	Pondicherry	317.4	39.7
Andhra Pradesh	86.8	46.1	Karnataka	54.5	32.5
Tamil Nadu	76.2	40.7	Andhra Pradesh	86.8	19.1
All India	58.7	38.8	All India	58.7	14.8

Miseries of Nutrient Management

Low factor productivity : After enjoying the fruits of Green Revolution, a decline in the rate of growth of foodgrain production has been observed during recent past in respect of productivity and input response or factor productivity. According to **NAAS (1997)** the 90s have witnessed a depressed rate of growth of yield and production levels. Rice production and productivity increased at an annual compound growth rate of 3.62 and 3.19 per cent in 80s which fell, respectively to 1.61 and 1.34 per cent in 90s (up to 1996-97). Wheat productivity decreased from 3.1 in 80s to 2.32 percent in the 90s.

Inadequate and unbalanced use of fertilizers : The fertilizer consumption in the country ranges from 1.3-299 kg N, 0.5-89 kg P_2O_5 and 0.2-95 kg K_2O ha^{-1}. There is disparity in consumption ratio of NPK (8.5:3.1:1 in 1998-99), which is more pronounced in the northern states (37.1:8.9:1), indicating highly imbalanced use of fertilizers.

Application of fertilizer nutrients is highly skewed in favour of N with K application being infinitesimally small.

Nutrient mining : For last 25 years, the Indian soils have been experiencing on an average a net negative balance @ 8-10 Mt of nutrients $annum^{-1}$ If any plant nutrient, whether a major or a micronutrient, is deficient, crop growth is likely to be affected. At least until recently, "the nutrient mix which gives the optimum economic return" was the norm in North America, Europe and other regions with intensively managed agriculture. Advisory programmes were supported by a large number of field trials and by the advisory services of governments and of the fertilizer industry activities which are now greatly reduced.

In developing countries like India the scarcity of finance led to different economic considerations. The return per hectare was of less importance than the highest short-term return on the money invested in fertilizers. The least available nutrient, generally nitrogen, offering the highest return, was applied preferentially. Nitrogen fertilizers tend to be preferred by farmers, because of their relatively low cost per unit of nutrient, their widespread availability, and the quick response of the plant. This might have been the right choice at the start, but after several years of mining them, other nutrients started limiting the crop growth as well, thus depressing the efficiency of the N applied. In the meantime, unbalanced fertilizing practice had become a deep-rooted habit.

Data related to nutrient balance in Tamil Nadu agriculture given in **Table 5** indicate heavy mining of potassium due to inadequate K supplementation.

Table 5. Balancesheet of NPK in Tamil Nadu Agriculture

State	Nutrients (000 t)			Mining index (R/A)
	Addition	Removal	Balance	
N	483.7	405	78.7	0.84
P_2O_5	145.1	111	34.1	0.76
K_2O	162.2	398	-235.8	2.45
NPK Total	791	914	-123	1.16

Source : Savithri & Santhy (2001)

Current levels of N and P applied are sub-optimal and unbalanced, both under irrigated and rainfed conditions. The increasing gap is one of the major causes of soil nutrient depletion, declining soil productivity and decreasing yield response to applied urea. Per year, about 28 Mt of nutrients are removed by crops while only 18 Mt are applied.

In a 1995 FAO document *"Rice and the Environment: Production Impact, Economic Costs and Policy Implications"* it is stated that incorrect fertilizer use in much of Asia, unbalanced in favour of nitrogen, results in lodging, greater weed competition and pest attacks, with paddy yield losses of about 20 per cent, but reaching as much as 50 per cent.

Fertilizer use has been increasing rapidly in India over many years but there is a stagnation of crop production. This seems to be due largely to the incorrect use of fertilizers. Farmers have been applying high amounts of nitrogen, but only small quantities of phosphate. Other fertilizers, such as potash and micronutrients are hardly used at all. Organic sources are not being properly integrated with mineral fertilizers. Under such conditions, the soil is getting depleted and it takes now more nitrogen every season to obtain the same crop.

Low fertilizer use efficiency : It is estimated that the response in terms of kg foodgrain per kg of nutrient declined from 16.0 in seventies to 8 in ninties. It is well documented that fertilizer N use efficiency seldom exceeds 40 per cent under lowland and 60 per cent under upland conditions. In case of P and micronutrients fertilizers, the efficiency hardly exceeds 20 and 2 per cent, respectively even in the best-managed package of practices.

Declining crop responses to fertilizers are inevitable if the application of nutrients is repeatedly unbalanced and does not correspond to the needs of the soil and the crops grown upon it. A crop's overall demand and the amount removed from the soil must be replaced sooner or later if soil fertility levels are to be maintained. Unless the plant nutrients removed by the harvested crops and otherwise lost to the ecosystem are replaced, the agricultural production system cannot be sustained indefinitely.

The oldest continuous fertilizer experiment in the world at Rothamsted in the U.K. shows that, where mineral fertilizers have been continuously used for *more than 150 years,* the soil is more productive now than at any time in the past. At the Askov experimental station in Denmark, after 90 years, the plots receiving NPK fertilizers had an 11 per cent higher organic C content than the control plots. In Japan **(Suzuki, 1997)** in a long-term trial, after 50 years of NPK fertilization there was no decrease over the years in the fertilized plots. The yield without fertilizer was about 40 per cent of that of the fertilized plot. At Grignon, in France, wheat grown on plots without fertilizer since 1875 yields about 700 kg ha^{-1} whereas NPK fertilized plots give over 7000 kg ha^{-1}. The findings of the long-term fertilizer experiments of India are in conformity with these observations.

The importance of soil amendments as a support for balanced fertilization should not be forgotten. Most of the nitrogenous fertilizers, especially ammonium sulphate and to a lesser extent ammonium nitrate, acidify soils, although some soils are naturally able to cope. The use of organic residues at normal levels of application may help; they are unlikely to avoid acidification but may slow the process. The acidifying effects of nitrogenous fertilizer can be corrected if lime is economically available and is applied. In a long-term experiment at Ranchi, with the continuous application of fertilizers without lime, yields fell to zero. When the soil pH was kept near to the optimum, the system became sustainable. In the humid tropics, the lime requirements are high and the effect may not last long due to leaching losses. Unfortunately in many developing countries agricultural lime is not available at an economic cost. It may be necessary to take other measures (which?) to alleviate of aluminum toxicity and/or calcium deficiency.

Changing Soil Fertility Scenario

Indian agriculture is operating under the pressure of multi nutrient deficiencies. Nitrogen deficiency in soils is almost universal. In the plains, medium-high yields cannot be obtained anywhere without N application. Phosphorus deficiencies are not far behind those of N as in 95 per cent districts, the P fertility is either low or medium. This is alarming because P is the backbone of balanced fertilizer use.

Many years ago, it was found that out of 361 districts, soils in 47 districts were of low K status, in 192 were medium and in 22 districts were high in K fertility. Since then K deficient areas have increased and crops in many areas are responding to K where they were not responding some years ago. Although K deficiency is not as widespread as that of N and P, many research data show that soils which are initially rich in K (high K soil test) become K-deficient due to heavy removal of K by harvested crops and inadequate K application. Crops in general remove as much or more K than they remove N but average consumption of K_2O ha^{-1} is still 8.7 kg while that of N is 58.7 kg ha^{-1} at a highly unbalanced N:K_2O ratio of 7:1. In the long-term fertilizer experiments, there are indications that when exchangeable K is not rapidly replenished, crops start drawing on the non-exchangeable K, resulting in soil mining and depletion of soil K reserves.

With intensive cultivation of high yielding varieties deficiencies of secondary and micronutrients caused declining productivity of crops in many soils. Among secondary nutrients, sulphur deficiency is an important problem in many states and soils in 130 districts are considered to be suffering from S deficiency to varying extent. Indications are that S deficiencies will become even more important in coming years and in such areas the balanced fertilizer use will have to include S alongwith NPK application. Though it is believed that magnesium deficiency occurs in acid soils or where exchangeable Mg is below 1 meq 100 g^{-1} or less than 10 per cent of soil CEC is occupied by Mg^{++} but the problem seems to be of greater magnitude than expected. It is a problem not only in several acid soil areas in the south and north-east but the crops grown in intensive agricultural areas in Indo - Gangetic plains have shown significant responses to applied magnesium. These indications emphasize the need for looking the importance of Mg from plant nutrition view point. It is felt that balanced fertilization with NPK in soils with marginal Mg availability would need Mg fertilization as a corrective measure for hidden or apparent deficiency of magnesium. Soil scientists should seriously look into this problem.

Among micronutrients zinc deficiency was found most common problem. Its deficiency, 48 per cent assessed based on analysis of 2.50 lakh surface soil and 44 per cent based on 25400 plant samples and 69% through biological responses in 5800 field experiments confirmed that 50 per cent of the Indian soils are deficient in zinc and about 20% soils had hidden hunger. Response to zinc application in wheat, rice, maize, barley, finger millet, oilseeds, pulses, pearl millet and cash crops were highly economical **(Singh 1999)**.

Next to zinc, boron deficiency is wide spread in many soils leading to low crop yields. Of the 36825 surface samples analyzed, 33 per cent soil samples were found to be deficient in available boron. Its deficiency in divergent soils was found to be 2 per cent in hot arid ecoregion with desert and saline soils. While extensive deficiency (39-68%) has been recorded in red and lateritic soils and leached and acidic soils of hot semi-arid eco-region with shallow and medium black soils, hot sub-humid eco-region with alluvium derived soils, hot sub-humid to humid (inclusion of per-humid) eco-region with alluvium derived soils, warm per-humid eco-region with brown and red hill soils and warm per-humid eco-region with red and lateritic soils and highly calcareous soils of hot sub-humid eco-region with alluvium derived soils and warm sub-humid to humid with inclusion of per-humid eco-region with brown forest and podzolic soils covering Bihar and of hot arid eco-region with desert and saline soils in Saurashtra. Unfortunately, we have not done desired research on this important nutrient probably because the soil and plant analysis for B needs special care and precaution. So the micronutrient researchers in India seem satisfied with the research confined to Zn, Fe, Cu and Mn. It is now important to look into emerging problems of B under actual field conditions seriously for which systematic delineation of B deficient areas basd on reasonable number of soil and plant analysis and assessment of B requirements of crops grown in varying soils and management practices would essentially be needed.

Iron deficiency in calcareous soils of Bihar, Tamil Nadu, Gujarat, Madhya Pradesh, Punjab and Haryana is common in rice, wheat, maize, sorghum, finger millet, lentil, chickpea, soybean, urdbean, groundnut, sunflower and sugarcane. Soil application of iron proved strikingly inferior to three foliar sprays of 1-2 per cent and un-neutralised ferrous sulphate solution. Green manuring or use of FYM in rice markedly decreases the severity of Fe chlorosis in rice. For sorghum both soil and foliar application of Fe proved equally efficient. Soil application of zinc, boron and sulphur was found more effective than their foliar application and vice-versa for iron and manganese. The current emphasis to double the food production to meet the food requirement of ever increasing country population will further accentuate emergence of multi-micro and secondary nutrient deficiencies in various soils. Nutrient indexing programme needs to be initiated to forecast multi-nutrient deficiencies precisely for adopting timely suitable corrective measures in given soil-crop-management systems, agro-ecological regions. Systematic research is needed to enhance use efficiency of micronutrient fertilizers.

Nutrient Management Strategies

The objective of nutrient management strategies is to achieve the required crop yield in an efficient, economical and sustainable manner through removal of constraints including nutrient deficiencies. The concepts set out by TAC (1989), which are quite relevant to many countries state that "The goal of sustainable agriculture should be to maintain production at levels necessary to meet the increasing aspirations of an expanding world population without degrading the environment". A major constraint to sustainability in India is poor soil fertility. A crop's overall demand and the amount removed from the soil must be replaced sooner or later if soil fertility levels are to be maintained. In the world as a whole but especially in the developing countries like India, year after year, far more nutrients are being extracted from soils than are being replenished.

Correction of nutrient deficiencies and toxicities is a basic requirement but in order to be effective, these need the support of complimentary inputs. Integrated technologies for increasing productivity and sustainability of agriculture need to be adopted. For example soil amendments (gypsum in sodic soils, lime in acid upland soils), moisture conservation in the semi-arid and arid regions, efficient application of water in irrigated areas, use of organic manures in coarse-textured soils pave the way for higher nutrient use efficiency. Putting fertilizer without lime in an acid soil or without gypsum in a sodic soil is not a sound decision. It is unfortunate that the marketing and distribution of soil amendments has received far less attention than that of fertilizers in India. If constraints are to be removed, then the inputs and resources needed to do so should be easily available to the cultivators.

Rational use of fertilizer and manure for optimum supply of all essential nutrients for agricultural production which simultaneously ensures efficiency of fertilizer use, promotes synergistic interactions and keeps antagonistic interactions out of the crop production system would be essential and inevitable for balanced fertilization. Balanced fertilization enhances crop yield, crop quality and farm profits; corrects inherent soil nutrient deficiencies, maintains or improves lasting soil fertility, avoids damage to the environment and restores fertility and productivity of the land that has been degraded by wrong and exploitative activities in the past. It is not a static but a dynamic concept. It should not mean that every time a crop is grown, all the nutrients should be applied in a particular proportion; rather fertilizer application should be tailored to the crop needs keeping in view the capacity of these soils to fulfill these needs. To achieve this, it is necessary to keep an overall balance in a total cropping system. This may indicate the need for the application of different nutrient at specific times, in a particular order to derive the maximum benefit from the application of a given quantity of nutrients".

Katyal (2001) based on the past 20 year trends of nutrient consumption in India estimated 1999 consumption of 18.07 Mt of fertilizer NPK to increase in 2020 to 29.07 Mt (20.74 N + 6.77 P_2O_5+ 2.06 K_2O Mt). Against this projected use, crop uptake related removals calculated by the method suggested by Tandon and Narayan (1990) summed up to 37.46 Mt of NPK (11.87 N + 5.27 P_2O_5 + 20.32 K_2O Mt). The aggregate negative balance of 8.39 Mt of NPK represented excess use of 8.9 Mt of N and 1.5 Mt of P_2O_5 and a deficit of 18.3 Mt of K_2O. Alarming statistics of K mining of soils parallel the strikingly low use of K than crop needs. Also, it appears that typically N and to some extent P is being used in excess of crop removal.

Besides this, continuous mining of secondary and micronutrients has depleted nutrient reserves of soil. Apparently, in India, the main environmental hazard is the depletion (mining) of soil nutrients due to inadequate replenishment rather than pollution due to their excessive use. Depleting a soil of its nutrient reserves is also degradation of the environment while improving soil fertility is part and parcel of improving the natural resource base, and hence, the environment itself.

Some environmentalists claim that nutrient inputs to agriculture are too high, causing severe damage to the environment. However, one should not forget that the primary goal of agriculture is to produce enough food of reasonable quality for a rapidly growing population. The relationship is simple: increased food production implies larger nutrient off-take from agricultural land through the harvested products. It may be obtained by increasing the area or the yield (output per unit area). Since the good soils are mostly cultivated already the most realistic long term strategy is to increase amounts and/or efficiency of applied nutrients. The fact that soil and water resources are very limited, resources on a global scale makes high productivity and large yields per unit area even more important in the future. High productivity and large crop yields require efficient nutrient utilization, which is one of the main goal of the balanced fertilization concept.

Balanced Fertilization : Concept

The idea of balanced fertilization is not new. In fact Justus von Liebig, a German chemist, defined the Law of the Minimum in 1967. He outlined the need to provide plants with a correct balance of nutrients. Liebig recognized that any one deficiency could limit growth and leave other available nutrients unused or poorly utilized by the plant. This concept is equally applicable in today's modern agriculture. The process of balancing crop nutrients involves adjustment of fertilizer recommendations to a particular crop yield goal, fertilizer availability, or resource level of the farmer. This process can be achieved using response curves established through well conducted research.

In fact, the principle of the Law of the Minimum can be applied to any factor that could limit yield (water, farmer, management, temperature, soil physical constraints, etc.). These types of limiting factors are found in every farmer's field. This lends credibility to the saying that "every field has something limiting yield". Liebig's Law of the Minimum focused only on plant nutrients, but the principle fits other conditions in cropped fields. Agricultural extension agencies should use this knowledge to assist farmers in adapting to different cropping situations and to focus on correcting limiting factors. This tool will enable farmers to obtain their highest yield, fertilizer use efficiency, and profit.

Balanced Fertilization and Agricultural Production

Nutrient uptake in intensive cropping systems : Knowledge of nutrient removal under intensive cropping systems is important for developing future nutrient management strategies. Estimates of nutrient uptake for a number of intensive cropping systems in India in Table 6 show that N removal can reach 328 kg ha^{-1} $year^{-1}$ in rice-wheat-green gram rotation, P removal can reach 150 P_2O_5 kg ha^{-1} $year^{-1}$ and K removal up to 389 kg K_2O ha^{-1} $year^{-1}$ in (rice-wheat-cowpea fodder) and annual NPK uptake of 438 to 814 kg ha^{-1} under high intensity cropping (i.e., two to three crops per year). Production of 8 to12 t grain ha^{-1} is associated with N uptake of 139 to 328 kg ha^{-1}, P uptake of 70 to120 kg P_2O_5 ha^{-1} and K uptake of 202 to 389 kg K_2O ha^{-1}. These figures serve as a guideline for fertilizer recommendation.

Balanced fertilization is the key to increased plant use efficiency of applied nutrients. A balanced fertilization programme does more than simply replace the amount of any nutrient removed by the crop. It ensures that fertilizers are applied in adequate amounts, and correct ratios for optimum plant growth. And, it ensures, sustenance of soil and crop productivity.

Table 6. Nutrient uptake in high-intensity and inter-cropped systems in India

Cropping System	*Yield, t/ha*	*Nutrient uptake, kg/ha/year*			
		N	*P_2O_5*	*K_2O*	*Total*
Rice-wheat	*8.8*	*235*	*92*	*336*	*663*
Maize-wheat	*7.7*	*220*	*87*	*247*	*554*
Pigeonpea-wheat	*4.8*	*219*	*71*	*339*	*629*
Rice-rice	*6.3*	*139*	*88*	*211*	*438*
Soybean-wheat	*7.7*	*260*	*85*	*204*	*549*
Maize-wheat-greengram	*8.2*	*306*	*62*	*278*	*646*
Rice-wheat-greengram	*11.2*	*328*	*69*	*336*	*763*
Maize-potato-wheat	*8.6 + 11.9(t)**	*268*	*96*	*358*	*722*
Rice-wheat-cowpea	*9.6 + 3.9(f)*	*272*	*153*	*389*	*814*
Rice-wheat-maize cowpea	*9.3 + 29(f)*	*305*	*123*	*306*	*734*

*t and f represent tuber and fodder yield, respectively.

Balanced fertilization, used in conjunction with other best management practices (BMPs), is essential for optimum N utilization. It should take into account the crop removal of nutrients, the economics of fertilizers and profitability, farmer's investment ability, agro techniques, soil moisture regime, weed control, plant protection, seed rate, sowing time, soil salinity/alkalinity, physical environment, microbiological condition of the soils, soil status of available nutrients, cropping sequence, *etc.* The BMP production systems will encourage quicker ground cover, more crop residues, greater root growth and more leaf area, all of which will improve N use efficiency and reduce erosion

Applying correct amount of fertilizer is important, because, withholding needed plant nutrients can be just as damaging as excessive application. Poorly nourished crops leave less residue to hold soil in place and build organic matter levels.

Importance of Potassium in Tamil Nadu Agriculture

The amount of potassium removed through crop harvests is quite large (Table 7). In most of the crops potassium removals are much larger than nitrogen.

Table 7. Potassium removals relative to N and P for major crops of Tamil Nadu.

No.	*Crop & Plant*		*Removal in kg/ton produce*			*Ratio in relation to N*		
			N	P_2O_5	K_2O	*N*	P_2O_5	K_2O
1.	*Rice*	*Paddy*	*20.1*	*11.2*	*30.0*	*100*	*44.7*	*149.3*
2.	*Sorghum*	*Grain*	*22.4*	*13.3*	*34.0*	*100*	*59.4*	*151.8*
3.	*Maize*	*Grain*	*26.3*	*13.9*	*35.8*	*100*	*52.8*	*136.1*
6.	*Finger millet*	*Grain*	*29.8*	*11.3*	*39.0*	*100*	*37.9*	*130.8*
7.	*Chickpea*	*Grain*	*46.3*	*8.4*	*49.6*	*100*	*18.1*	*107.1*
8.	*Groundnut*	*Grain*	*58.1*	*19.6*	*30.1*	*100*	*33.7*	*51.8*
9.	*Soybean*	*Grain*	*66.8*	*17.7*	*44.4*	*100*	*26.5*	*66.5*
10.	*Mustard*	*Grain*	*32.8*	*16.4*	*41.8*	*100*	*50.0*	*127.4*
11.	*Castor*	*Grain*	*30.0*	*12.0*	*10.0*	*100*	*40.0*	*33.3*
12.	*Sunflower*	*Grain*	*56.8*	*25.9*	*105.0*	*45.6*	*184.8*	*56.8*
13.	*Cotton*	*Seed*	*44.5*	*28.3*	*74.7*	*100*	*63.6*	*167.8*
14.	*Sugarcane*	*Cane*	*1.7*	*0.2*	*2.0*	*100*	*11.8*	*117.1*
15.	*Potato*	*Tuber*	*3.9*	*1.4*	*4.9*	*100*	*35.9*	*125.6*
16.	*Cassava*	*Tuber*	*7.8*	*1.2*	*5.1*	*100*	*15.4*	*65.4*
17.	*Grapes*	*Fruit*	*4.9*	*1.5*	*5.9*	*100*	*30.6*	*120.4*
18.	*Banana*	*Fruit*	*8.2*	*3.0*	*32.3*	*100*	*36.6*	*393.9*
19.	*Tomato*	*Fruit*	*4.1*	*1.5*	*5.9*	*100*	*36.6*	*393.9*
20.	*Tea*	*Made Tea*	*110.0*	*38.0*	*44.0*	*100*	*34.5*	*40.0*
21.	*Coffee*	*Clean beans*	*37.0*	*6.0*	*47.0*	*100*	*16.2*	*127.0*
22.	*Tobacco*	*Leaf (dm)*	*17.0*	*5.0*	*26.0*	*100*	*29.4*	*152.9*
23.	*Coconut*	*1000 nuts*	*7.1*	*3.5*	*10.7*	*100*	*49.3*	*150.7*
24.	*Cardamom*	*Pods*	*122.0*	*14.0*	*200.0*	*100*	*11.5*	*163.9*
25.	*Cashewnut*	*Nuts*	*88.0*	*25.0*	*42.0*	*100*	*28.4*	*47.7*

Potassium Fertility Status of Soils

The research findings indicate that the Tamil Nadu soils are being mined of potassium over time due to intensive crop cultivation and insufficient K application. Recent soil test reports indicate that large percentage of soil samples are in the category of medium potassium fertility indicating the need of potassium fertilization. Over 60 percent samples rated as low and medium in potassium.

Soil analyses in all 17 districts, 10 districts viz. Kancheepuram, Cuddalore, Salem, Dharmapuri,Erode, Ramanathapuram, Virudhunagar, Tirunelveli, Tuticorin and Kanyakumari are falling under either low or medium categories. This situation is quite alarming. Apparently, there is strong need to improve potassium fertilization to enhance crop production and maintain soil fertility for sustainable high yield agriculture in Tamil Nadu. The districts Vellore, T.V. Malai, Tiruchirapalli and Thanjavur have over 60 percent samples rated high in potassium.

Crop response and profitability to applied potash

As Tamil Nadu is capable of growing variety of high yielding, high value crops, the K removal from crop harvests is bound to be high. For example, Finger millet – cowpea -maize cropping sequence takes up 267 kg potassium from each hectare of land. As crop yields of the state are progressively increasing over the years, the magnitude of responses to applied potash is also showing increasing trend. Researches indicate that potash application is not only beneficial to crops but also highly remunerative to the farmers of Tamil Nadu (Table 8).

Potash application at higher rates in crops of Tamil Nadu is essentially needed to prevent potash depletion and ensure achieving high yields, high produce quality and high farmer's profits.

Fertilizing for High Crop Yields

From thousands of fertilizer experiments conducted on farmers' fields it has now been very well established that the application of balanced NPK dose produced the highest yield of the crops while imbalanced fertilization reduced the yield. Inadequate use of phosphorus and or potassium becomes responsible for significant reduction in crop yields. Data from a number of permanent fertilizer experiments conducted at different locations in the country recently showed that the crop yields even under recommended doses of NPK are low and the super-optimal doses of NPK fertilizers (150% optimum NPK) substantially increased the crops yield over optimum dose. Apparently, there is need to refine the NPK recommendations by increasing the dose to achieve optimum yield.

An elaborate program of monitoring changes in soil fertility should be established which can serve to periodically revise nutrient application rates to achieve maximum fertilizer efficiency, profitability, yield sustainability and high quality so that today's maximum yield could be transformed into tomorrow's average yield.

Table 8. Crop response to applied potash in Tamil Nadu

CROP	$N-P_2O_5-K_2O$ DOSES (kg/ha)	YIELD (kg/ha)	INCREASE IN YIELD DUE TO K	NET RETURNS DUE TO K (Rs./ha)
Rice	200-75-0	4,880		
(kharif)	200-75-100	7,934	3,054	5,835
Rice (rabi)	200-75-0	4,820		
	200-75-100	6,973	2,153	5,672
Tobacco	60-125-0*	2,220		
	60-125-150*	2,530	310	8,592
Cotton	200-150-0	1,840		
varieties	200-150-100	2,930	1,090	26,489
Cotton	200-150-0	2,430		
hybrids	200-150-100	3,810	1,380	33,989
Potato	240-240-0**	32,180		
	240-240-240**	50,290	18,110	47,805

* 50 & 150 kg ha^{-1} Mg and S respectively

** 48 & 80 kg ha^{-1} Mg and S respectively

Sources: PPIC supported research projects at TNAU, 1997-2003

Long-term fertilizer experiments: Learning the right lesson

Findings from long-term fertilizer experiments clearly show how high productivity in an N-driven system will be short-lived and counter-productive regarding narrow food security goals. Continuous use of N in unbalanced fertilizer regimes can never sustain high yields. Adequate P and K, and any other deficient nutrients must be provided to secure food availability, the environment, and farmer income at levels the country requires.

L ong Term Experiments in Tamil Nadu

The first long-term fertilizer experiments were started at Coimbatore during British period in 1909 and remained in operation till 1970. The plots received irrigation till 1937 only and were maintained under rainfed conditions later on. The results of these experiments (Table 9) clearly show similar trends as the present series of Long –Term Fertilizer Experiments (LTFE) (Table 10) (Nambiar 1994). As the level of application of NPK in these experiments was low; N (25 kg), P_2O_5 (67 kg), K_2O (60 kg ha^{-1}) so the highest crop yield levels with NPK were 1613 kg for sorghum, 1720 kg for finger millet and 622 kg for cotton against 591, 549 and 282 kg, respectively in the control (unmanured) (Table 9). The yields with FYM were highest because of very high dose of manures

13 t ha^{-1}, which supplied 3-4 times more nutrients besides producing beneficial effect on physical conditions of soil and its water holding capacity. The yields for sorghum, finger millet and cotton with FYM were 1819, 1664, 622 kg ha^{-1} respectively. *The higher responses to NPK over NP and of NP over N indicated that deficiency of P and K was of higher magnitude but higher yields were obtained only by joint application of all the three major nutrients.* Unfortunately, these experiments were abandoned and we missed valuable information perhaps more important than the classical Rothamsted (UK) experiments.

Table 9. Average yield of crops (kg ha^{-1}) from the old permanent manural experiments over the years (1909-1970) at Coimbatore

Treatment	*Sorghum*	*Fingermillet*	*Cotton*
CM (FYM)	*1819*	*1664*	*622*
NPK	*1613*	*1720*	*466*
NP	*1609*	*1657*	*513*
K	*1329*	*834*	*334*
PK	*934*	*1456*	*376*
NK	*888*	*697*	*344*
CMR	*711*	*800*	*463*
P	*704*	*1000*	*261*
N	*695*	*639*	*308*
Unmanured (control)	*591*	*549*	*282*

N = 25 kg N ha^{-1}; P = 67 kg P_2O_5 ha^{-1}; K = 60 kg K_2O ha^{-1}; CM = Cattle manures (FYM) 13 t ha^{-1}; CMR = Cattle manure (residue)

New Long-Term Fertilizer Experiments at Coimbatore

The new long-term fertilizer experiment (LTFE) was started at Coimbatore at a new site with intensive cropping system of finger millet-maize-cowpea on a medium black soil (vertic Ustochrept) under irrigated condition. In 1987, cowpea was excluded because of the operational difficulties with three crops in the rotation and the experiment is continuing with 2 crops – finger millet- maize rotation. The data are given in Table 10. The doses of fertilizer applied are also shown in the same.

From the mean grain yield data for finger millet , maize and cowpeas for the period 1971-87 (Table 10) it is evident that the increase in yield in all the 3 crops over the untreated control were in the order: NPK + FYM > NPK > NP> N> control. Application of N alone was only slightly better than control but NP and NPK treatments gave nearly 4 times higher yields as compared to control. Though

NPK was slightly better than NP but the differences between NPK and NP were small. These results show that the deficiency of P was most serious but that of K only marginal. The NPK + FYM treatment was best of all and it produced nearly one tonne more grain over the NPK treatment. The most beneficial effect of FYM over NPK treatment could be partly due to large amount of additional nutrients (major, secondary and micronutrients) supplied by it and partly due to its effect on soil structure and improvement of other physical conditions of the soil. However, availability of organic manure in such a heavy amount is a great challenge.

Table 10. Mean grain yield (kg ha^{-1}) of crops under various fertilizer treatments in long term fertilizer experiment at Coimbatore (1971-1987)

Crop	*Mean yield (kg ha^{-1}) 1971-87*				
	Untreated control	*N*	*NP*	*NPK*	*NPK + FYM*
Fingermillet	*687*	*945*	*2640*	*2604*	*3093*
Cowpea	*193*	*258*	*536*	*542*	*625*
Maize	*585*	*703*	*2666*	*2902*	*3388*
Total yield of fingermillet + maize	*1272*	*1648*	*5306*	*5506*	*6481*
Total (finger millet + maize + cowpea) food grains	*1465*	*1906*	*5842*	*6048*	*7106*

Amounts of nutrients applied to different crops				
	N (kg ha^{-1})	**P_2O_5 (kg ha^{-1})**	**K_2O (kg ha^{-1})**	**FYM (kg ha^{-1})**
Fingermillet	90	45	17	10-15
Cowpea	25	50	0	0
Maize	135	67	35	0
Total	250	162	52	10-15

Source: Nambiar (1994)

It is evident that the response ratio is many times higher in treatments with P (Table 11). In fact, even the average responses for the years 1985-87 show that responses to P and K were better than for all the 17 years average. Though the responses to K are small but the balance sheet clearly shows (Table 12) large K depletion as a signal of impending K deficiency. Though the P balance is highly positive but the continuing high magnitude of responses to applied P is a clear indication that the P availability is not adequate to meet the P requirements of this intensive cropping system. The experiment is still continuing but the analysis has been restricted to the period for which relevant soil data were available.

Table 11. Response ratio (kg grain/kg nutrient) to applied nutrients over the years in LTFE

	Mean response ratio over initial 2 years 1985-87			*Mean response ratio over 17 years 1970-87*		
	N	***P_2O_5***	***K_2O***	***N***	***P_2O_5***	***K_2O***
Fingermillet	*2.8*	*46.9*	*9.6*	*2.9*	*37.7*	*-2.1*
Maize	*0.6*	*32.0*	*13.4*	*0.9*	*29.3*	*6.7*
Cowpea	*1.1*	*6.3*	*-*	*2.6*	*5.6*	*-*

Table 12. Balance sheet of N, P and K with optimal NPK application (kg/ ha) in finger millet-maize- cowpea cropping system in LTFE at Coimbatore (1971-85)

	N	***P***	***K***
Applied	*250*	*96*	*44*
Removed	*234*	*51*	*267*
Balance	*16*	*45*	*-223*

These results show that P deficiency is a most serious limiting factor in this soil. It is further clear that K deficiency will also become prominent in due course of time. These observations in no way minimize the importance of N rather it clearly supports the contention that without N and balanced fertilizer use (containing NPK), it is not possible to obtain consistently high yields. Although an average grain yield of 5-6 t ha^{-1} has been obtained over two decades, but it shows that fixation of P and depletion of K may become a limiting factor for sustainable high crop production on these soils. Secondly 5-6 t ha^{-1} is not a very high yield. If we have to obtain a sustainable yield of 10 t ha^{-1} from 2 crop rotations, it would require much higher use of balanced fertilizer NPK and FYM. We also need to continuously monitor the changing scenario of micronutrients and sulphur.

Dynamic nature of balanced fertilization

A wealth of information on the dynamic nature of balanced fertilization in intensive cropping systems has become available from several long-term fertilizer experiments using high yielding varieties (HYVs). These experiments conducted in India solidly demonstrated that a field producing 1,300 kg grain/ha from two crops grown without fertilizer could produce 7,420 kg grain (5.7 times more) under optimum nutrient application (data not shown).

Responses to fertilizers in these experiments were always in the order of NPK>NP>N. Continuous use of N alone produced the greatest yield decline at a majority of sites. Responses to N declined with the passage of time, while responses to P and K improved due to increased soil Pand K deficiency.The data of LTFE from Coimbatore confirm these trends (Table 13).

The disastrous consequences of practicing intensive farming without due attention to balanced fertilization are obvious and clear.

Similar is the experience of dryland agriculture on Vertisols in Taml Nadu. Suresh *et al.* (1999) in an analysis of long-term fertilizer experiments on sorghum *(Sorghum bicolor)* and *cumbu (Pennisetum glacum)* on Vertisol under dry farming conditions at Kovilpatti (TN), which are being run from 1982, reported that besides NP an application of 25 kg zinc sulphate per ha was found necessary to maintain high yields of both these crops over the years. Omission of K in the fertilizer schedule has caused a continuous depletion in

Table 13 Nutrient response ratio (kg grain/kg nutrient) in long-term fertilizer experiments: Example – Coimbatore

Soil and Crops	*Nitrogen 1973-77*	*Nitrogen 1992-96*	*Phosphorus 1973-77*	*Phosphorus 1992-96*	*Potassium 1973-77*	*Potassium 1992-96*
			Coimbatore (Inceptisol)			
Finger millet	*3.1*	*5.4*	*35.3*	*43.9*	*-11.4*	*13.4*
Maize	*1.7*	*-1.3*	*32.7*	*28.6*	*-1.3*	*14.5*

Source: Swarup and Ch. Srinivasa Rao (1999)

Lessons Learnt from Long-term Fertilizer Experiments

- ❖ Intensive cropping with only N input is a short-lived phenomenon
- ❖ Omission of limiting macro- or micro-nutrient leads to its progressive deficiency due to heavy removals.
- ❖ Sites initially well supplied with P and K or S become deficient when continuously cropped using N alone.
- ❖ Fertilizer rates considered as “optimum” still result in nutrient depletion at high productivity levels, and if continued, become “sub-optimal” rates.

available K status over the years. Apparently, the situation in unirrigated conditions is also not much different from the irrigated conditions emphasizing the need for balanced fertilization avoiding deficiency of any yield-limiting factors. These observation make it clear that the situations of soil fertility changes in Alfisols, which are the dominant soils of Tamil Nadu, need a close study.

Suboptimal Status of Optimum Nutrient Recommendations

Evidently, the normally recommended rates of NPK fertilizers are sub-optimal in multiple cropping system. The data of the MYR initiated by the PPIC – India Programme revealed that it is possible to surpass the national demonstration yield level by a considerable margin both in rice-rice system in Tamil Nadu and rice-wheat system in the Punjab and Uttar Pradesh by increased NPK application and adoption of improved production technology. This can mean that excessive depletion of soil fertility would demand nutrient replenishment at higher rate.

Nutrient : Supply and Balance

One factor that is closely and directly correlated to yield increases and total production is nutrient supply. Nutrient source, weather organic or inorganic, is not a major question when it comes to supplying these needed nutrients. Both are simply the transfer of nutrients from one location to another-to a location which is more convenient (or available) for the growing crop to use. Availability of adequate nutrients is the question. Where available, both sources should be used together as increasing amounts of nutrients have to be supplied to increase production.

While it is clear that increasing production relies on greater availability of nutrients, it is also important to understand that nutrient balance becomes that key to sustaining production. This is true for several reasons. First of all, each additional increment of yield becomes more difficult to achieve, thus greater management precision is required. Also, economics and environmental protection are important components of sustainability. Nutrient balance also affects these areas dramatically.

Both correct amounts and correct ratios of applied nutrients are critical to nutrient management and sustainability. Imbalance allows mining of the most deficient nutrients in the soil. Once the critical level is reached, yield falls dramatically…even though large aggregate amounts of nutrients might have been applied.

Again, it is important to note that to assure sustainable production, nutrient balance must be supported by adequate nutrient supplies. The nutrient ratio applied in India may be closer to balanced than the ratio in China. However, amounts applied are so low that soil mining, degradation and food shortages in India are a much greater problem than in China, and the average yields are also much lower, as shown in Table 14.

Table 14.Comparison of nutrient balance and application rates in India and China

Country	*Year*	*Nutrient ratio $N : P_2O_5 : K_2O$*	*Nutrients applied, kg/ha $N - P_2O_5 - K_2O$*	*Cereal yield, tones/ha*
India	*2000-01*	*6.9 : 2.7 : 1*	*98.4*	*2.32*
India	*2001-02*	*6.8 : 0.6 : 1*	*102.2*	*2.32*
China	*2000-01*	*6.5 : 2.5 : 1*	*217.9*	*4.75*
China	*2001-02*	*5.6 : 2.2 : 1*	*225.1*	*4.90*

*150 if "unreported-unofficial" area is included

Whether in China, in India, in Canada or in the U.S., wherever increased yields are a necessity, the only way that balanced fertilization and sustainable high yields will be achieved is through the increased supply of commercial fertilizer nutrients.

Nutrient Balance: Beyond NPK

Nutrient balance discussions are often confined to nitrogen (N), P and K because of their major importance in crop production. Also, they are most often the limiting factors that need to be addressed in solving nutrient deficiencies. Because, however, goes beyond NPK. For instance, in a survey of soils throughout China, 22 percent were deficient in sulfur (S) and 13 percent deficient in magnesium (Mg). Clearly, nutrient balance goes beyond NPK and will not be achieved without adequate availability of commercial fertilizers nutrients.

Site-Specific Nutrient Management for Yield Maximization and Profit in Rice-Based Cropping Systems

Rice-based systems, particularly rice-wheat and rice-rice, cover an estimated area of 16 million hectares (M ha) in India. Since both rice based cropping systems provide staple food grains, their sustained high productivity is essential for national food security. However, productivity in these systems has stagnated for the last one decade and is even declining in certain areas. Causes for this trend include: depletion of native nutrient reserves, emergence of multi-nutrient deficiencies, and the consequential decline in efficacy of applied nutrients. Surveys of different agro-climatic regions indicate that farmers have started applying greater doses of nitrogen (N) than is recommended in order to achieve previously attained yield levels. Such indiscriminate use is likely to further widen the nutrient imbalance in soil-plant systems, increase pest incidence, cost of production, and environmental problems. Long-term experiments indicate that crop productivity can be sustained with balanced fertilization which fully accounts for emerging deficiencies of secondary and micronutrients.

Site-specific nutrient management (SSNM) is an approach that considers crop demand as well as the need to improve soil fertility levels, and which ensures higher nutrient use efficiency, crop productivity, and economic returns to the farmer. In studies recently initiated at Modipuram, it was possible to harvest 8 to 9 t rice/ha with SSNM. Annual productivity of rice or wheat hardly exceeded 6 t/ha in on-going multi-location experiments on yield maximization. Thus, there is great opportunity for improvement. Another advantage of yield maximization through SSNM is the associated land-saving which allows land to be diverted to high value crops and other farm enterprises without decreasing total food production, therefore addressing the frequently discussed issue of diversified farming. This project initiated SSNM at 17 crop research system centres including Coimbatore and Thanjavur centres in Tamil Nadu. The experimental results obtained from these centres are described below:

Experience from Coimbatore

Effect of site specific nutrient management on yield - A significant response to site-specific nutrient management at Coimbatore was observed in *kharif* rice and yield was more than double as compared to the farmer's practice. Although the standard state recommendation includes 12 t/ha FYM along with recommended dose of NPK, the SSNM treatment out yield it by 7.1% (Table15).

Alike *kharif* rice, *rabi* season rice also gave an additional yield of 1.59 to 2.56 t/ha with SSNM practice over state recommendation and farmers practice respectively. Although the nutrient application in treatment 1 and treatment 7 ware same in wheat, the yield was 26% higher in treatment1. Increase in yield under treatment 1 over T7 may be ascribed as residual response of 50 kg S applied to previous *kharif* rice crop. Increase in yield under SSNM treatment was mainly attributed due to increase in number of effective tiller, number of grain/ear, number of spikelet/ear, which get culminated into higher harvest index (Table 15)

Response to P, K and S application - Application of 80 kg P_2O_5/ha significantly increased grain yield of kharif rice and rabi rice with additional yield advantage of 3.30 t/ha in the system's productivity. Of the total annual productivity 85% yield improvement was recorded with *rabi* rice. Increasing rates of K_2O at 60 kg/ha has only beneficial effect on yield and at this rate of application yield obtained were 7.0 and 6.8 t/ha under *kharif* and *rabi* rice crop, respectively. Using of 50 kg S/ha failed to show significant advantage in *Kharif* rice , but the succeeding rabi rice gave an extra yield of 1.41 t/ha due to S residue **(Table 15).**

Table 15. Productivity of *Kharif* and *Rabi* rice as influenced by site- specific nutrient management at Coimbatore

Tr. No.	Kharif rice Major and secondary nutrients (kg/ha)				Rabi rice Major (kg/ha)			Kharif rice		Rabi rice	
	N	P_2O_5	K_2O	S	N	P_2O_5	K_2O	Grain yield (kg/ha)	Straw yield (kg/ha)	Grain yield (kg/ha)	Straw yield (kg/ha)
T_1	150	120	60	50	150	120	60	7003	10143	6812	7209
T_2	150	80	60	50	150	80	60	7305	10009	6812	7125
T_3	150	40	60	50	150	40	60	6257	10203	4750	6034
T_4	150	0	60	50	150	0	60	6793	9926	4022	5550
T_5	150	120	30	50	150	120	30	6048	10047	3700	8534
T_6	150	120	0	50	150	120	0	6716	10454	5687	8100
T_7	150	120	60	0	150	120	60	6861	9954	5400	8119
T_8	State Recommended doses of Nutrients (SR)				SR			6538	9995	5225	7838
T_9	Farmer's Practice (FP)				FP			3182	4764	4250	6375
CD ($p<0.05$)								611	784	379	594

Source: PDCSR-PPIC- India Programme SSNM Research Project, Coimbatore Centre, 2003-04

Experience from Thanjavur

Effect of site-specific nutrient management on yield - In *kharif* rice, application of fertilizer as per SSNM schedule having 150 kg N, 30 kg P_2O_5, 10 kg K_2O, 60 kg S and 30 kg Manganese sulphate (T5) gave highest yield of 9.46 t/ha at Thanjavur (Table16). Yield recorded under state recommendation doses of nutrients (T11) were on par to T5, but it was significantly superior over farmer's practice (T12) (8.35 t/ha). Similar to *kharif* rice, *rabi* season rice crop also responded to SSNM practices but the response to P applied dose was only up to 60 kg/ha. Grain: straw ratio computed for *kharif* rice indicated a narrowed ratio due to SSNM practice (1.17) than state recommended fertilizer practice/farmer practice (1.21 to 1.25). No such definite trend was obtained for grain: straw ratio in *rabi* season rice crop.

Response to P&K application - Application of graded doses of P (0, 30 and 60 kg/ha) had significant response in terms of *kharif* and *rabi* rice yield. The highest yield of 9.2 and 7.34 t/ha, respectively in *kharif* and rabi rice were obtained with 60 kg/ha P_2O_5 application and other nutrients. Compared with no-P plot 60 kg P_2O_5/ha gave 4.5% to 11.0% higher yield. Potassium application indicated that *kharif* rice crop responded up to 100 kg/ha application, while the response was restricted only up to 50 kg/ha dose in *rabi* season crop. At these rates of application both crops jointly gave 1.6 t/ha additional yield over no-K applied plots (Table 16).

Response to secondary and micro-nutrients - Application of S at 20 kg/ha could bring a yield advantage 356 kg/ha in *kharif* rice crop but further increasing doses of S could not show significant influence on rice yield. Residual effect of S showed response up to 60 kg/ha application, and rabi season rice yield was 10% higher than S control. Directly applied Manganese sulphate @ 30 kg/ha could not benefit *kharif* season rice but gave an additional yield of 0.63 t/ha in succeeding *rabi* rice crop (Table 15).

Increasing Nutrient Demands

Both food and therefore fertilizer needs of India are expected to go up consistently in the future without a break. The net cropped area has more or less stabilized at 143 Mha. The population of 1 billion plus is expected to grow by 14-15 millions each year. At present, each hectare of net sown area has to support more than 7 persons. This pressure will only increase in the coming years

Future Nutrient Needs

Keeping in view the conservative population estimate of 1.4 billion by year 2025 and mini-mum calories requirement of food, the country will need to produce at least 300 Mt of food grain and for this purpose it will be necessary to use 30-35 Mt of NPK from various sources. In addition, the experts on horticulture, vegetable, plantation crops, sugarcane, cotton, oilseeds and potato have projected that by the year 2025, the demand for fertilizers for these

Table 16. Productivity of *Kharif* and *Rabi* rice as influence by site- specific nutrient management at Thanjavur

	Kharif rice					Rabi rice			Kharif rice (kg/ha)		Rabi rice (kg/ha)	
	Major and secondary nutrient (kg/ha)				Micronutrients Fertilizer, (kg/ha)	Major Nutrients (kg/ha)			Grain yield	Straw yield	Grain yield	Straw yield
	N	P_2O_5	K_2O	S	Manganese sulphate	N	P_2O_5	K_2O				
T_1	150	30	150	60	30	150	30	150	8754	10711	7050	8807
T_2	150	60	150	60	30	150	60	150	9207	11258	7344	9249
T_3	150	0	150	60	30	150	0	150	8807	10827	6618	7933
T_4	150	30	50	60	30	150	30	50	9007	10816	7008	8481
T_5	150	30	100	60	30	150	30	100	9459	11090	7050	8439
T_6	150	30	0	60	30	150	30	0	8554	10795	6355	7502
T_7	150	30	150	40	30	150	30	150	8870	10574	6671	7933
T_8	150	30	150	20	30	150	30	150	9449	11048	6650	8249
T_9	150	30	150	0	30	150	30	150	9091	11006	6408	8133
T_{10}	150	30	150	60	0	150	30	150	8975	10827	6418	7639
T_{11}	State Recommended doses of Nutrient (SR)					SR			9144	11101	7018	8660
T_{12}	Farmer's Practice (FP)					FP			8354	10448	6418	7639
CD ($p<0.05$)									426	613	452	581

Source: PDCSR-PPIC- India Programme SSNM Research Project, Thanjavur Centre, 2003-04 high value crops, which also have high export potential and claim fertilizer use on priority basis, will rise to 3.0, 2.0, 3.2, 0.9,3.1, 1.5 and 1.0 Mt, respectively (Fig. 3).

This adds to the total nutrients needs by another 14-15 Mt NPK. Thus, from both inorganic and organic sources the country will be required to arrange for the supply of about 40-45 Mt of nutrients by the year 2025.

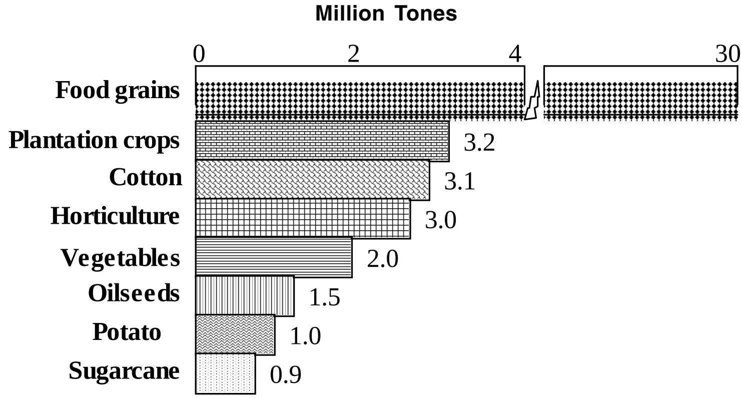

Fig. 3 Projected major nutrient (NPK) needs by 2025

Integrated Nutrient Management

Although IPNS is an age old concept but its importance was not realized earlier due to low nutrient turn over in soil-plant system and almost all the nutrient needs of the then sustenance agriculture were met through organic sources which also supplied secondary and micronutrients besides major nutrients. IPNS has now assumed great importance firstly, because of the present negative nutrient balance and secondly, neither the chemical fertilizers alone nor the organic sources exclusively can achieve the production sustainability of soils as well as crops under highly intensive cropping systems. The interactive advantages of combined use of organics and inorganics have been well documented. The IPNS help to restore and sustain soil fertility and crop productivity. It also helps check the emerging deficiency of nutrient other than N, P and K, favourably, effects the physical, chemical and biological environment of soils and bring economy and efficiency in fertilizers. In the intensive agriculture, importance of integrated management of nutrient resources is being magnified because of the increasing deficiencies of secondary and micronutrients.The plant nutrient imbalance in quest to achieve increasing foodgrain production targets would further aggravate through over exploitation and overstraining of the soil reserves. Soils of India are deficient in a number of essential plant nutrients, the main nutrient deficiencies are those of N, P, K, Zn and S. In certain areas, deficiencies of Fe, B and Mn are also being increasingly important. As the entire nutrient need of the crops can not be met either through chemical fertilizers or through organics, efficient judicious use of all the major sources of plant nutrient viz. soil, mineral, organic and biological in an integrated manner would be essential and inevitable. Considering the present annual production of compost (rural + urban), the average use of organics is around 2 tonnes per ha per year. Taking into account the nutrient content of compost, the contribution from it is around 5 kg NPK. At present, about 4 lakh hectare area is under green manuring. Addition of about 40-50 kg N/ha through green manuring has been reported. Although the contribution of green manure is economically most competitive and ecofriendly, it can not be adopted in those areas where supply of irrigation water is critical and the growth period of green manure crop is non-competitive with normal cropping systems of region. The contribution of green manuring is not likely to be more than 4 lakh tonnes fertilizer N equivalent. The total capacity of biofertilizers production at present is far below the projected demand. As the fertility of the soil gets depleted by growing single and the same crop year after year it is possible to meet 25% of additional N requirement by adopting legume-oilseed, legume-cereal crop rotations in inter or mixed cropping. Grain legumes presently occupy an area of about 24 M ha. Experimental results indicate that the contribution or grain legume to nitrogen need of subsequent crop may be 20-40 kg N/ha when yield of legume was 1.0-1.5 tonnes/ha (about 2 time of national average). The average contribution for the entire country is likely to be 15 kg N/ha or a total of about 3.6 lakh tonnes. Integrated nutrient supply and management based on soil test would be the most practically viable technique which holds the key to sustain crop yield and quality of crops without adversely affecting the environment. From the results of the Long Term Fertilizer Experiments conducted in different parts of the country it has been well established that under high input production system where crop productivity can not be further increased with incremental use of chemical fertilizer alone, addition of organic sources could again increase the yield through increased soil productivity and fertilizer use efficiency.

According to the estimate made by Tandon (1997), 25% nutrients needs of Indian agriculture can be met by utilizing various organic resources. The resources needs to achieve this in future are suggested below:

Resource	Year 2000	Year 2050
FYM (million t)	200	400
Crop residues (million t)	30	50
Urban/rural wastes (million t)	10	50
Green manure are (million t)	25	50

Although there has been marked increase in fertilizer consumption over the years, the gap between removals and additions through fertilizers would remain fairly constant at 10 million tonnes of nutrient per annum. To bridge this gap, importance of integrated nutrient management in Indian agriculture is quite clear.

Although general principles may be the same, technology packages for sustainable management of soil and plant nutrient resources are site-specific and depend on farming systems, farm site, availability of inputs and socio-economic factors, area specific and on-farm synthesis of packages is needed on the basis of components and sub-systems. Agronomic productivity, economic profitability and ecological compatibility of such packages need to be assessed through appropriate research on well defined representative sites.

Recommendations for different agro-ecological situations, taking into account available nutrient resources, farming systems and the choice of improved agro techniques to alleviate soil constraints for plant nutrition need to be generated.

The application of integrated plant nutrition system on a large scale requires some adaptive research, demonstration programme backed by training in good management practices and a policy improvement and infrastructure which stimulates the efficient use of both internal and off-farm inputs.

While the possibilities for integrated nutrient supply are real and attractive, most nutrient packages for high yields required to feed an expanding population from a non-expanding area will continue to be fertilizers driven. This assessment in no way under- estimates the importance of other nutrient sources most of which are gainfully integrated.

Nutrient Management: The Road Ahead

As stated earlier, the potential yields of crops have not yet been realized in India and emphasis is being laid on increasing food grain production by adoption of improved agro-techniques and optimum utilization of production inputs. To sustain the momentum of this objective, a long-term research programme based on higher yields must be instituted to provide the technology for continued higher yields. For developing countries like India, the philosophy of minimum inputs used (particularly fertilizers) can only lead to disastrous results by eventual degradation of the soil, lowering production of crops, destabilization of food supply and finally leading to even more subsistence farming. Maximization of crop yields to achieve increasing food grain production tar-gets would, therefore, be important for India. In quest to achieve yield goals an integrated multidisciplinary systems approach should be developed. The MYR seeks to identify and develop a production system that includes the best of all controllable factors needed to produce the highest possible yield. The MYR on rice-wheat cropping system conducted in India through PPIC support has shown that the production target of 10 t of rice and 6-8 t of wheat can be successfully achieved by adoption of improved varieties, closer crop geometries to sustain higher population stands, and appropriate fertilizer doses. These studies, however, are confined to few locations only. In view of the diverse soil and agro-climatic conditions prevalent in India, the MYR work should be undertaken on more centres involving well defined soils and different cropping systems being followed by the cultivators. A comprehensive constraint analysis should be attempted. The treatments should enable one to evaluate and define yield limiting factors and satellite experiments should be part of the total efforts. Continuing its efforts in the area of research and education, the PPIC–India Programme has carried out a number of projects with major thrust on:

- To create greater awareness for high productivity farming and the fact that it can be sustainable as well
- To convince and persuade various states to take a fresh look at their general fertilizer recommendations and revise them towards more optimal and more balanced levels, as has been achieved on large scale in Uttar Pradesh.

Recent research findings of the PPIC-India Programme have established that India's low crop yields can be enormously increased by balanced and efficient use of fertilizers. The maximum economic yields (MEY) of some important crops have been recorded with increased input of fertilizer nutrients, particularly P and K. Various progress reports and bulletins document with data the PPIC-India Programme's work in India. These can be obtained from us.Some of the results of the PPIC- India Programme sponsored research projects given in Table 17 clearly indicate that crop yields can be economically maximized with site specific nutrient management.

Table 17. Narrowing the Yield Gap: SR vs. SSNM : Tamil Nadu

State/Region	Crop	Recommendation	Treatment dose		Yield (t/ha)
			($N-P_2O_5-K_2O$) + Other nutrients		
Tamil Nadu	Rice HYB	SR	120-38-38	(+5.5 kg Zn)	5.8
		MYR	194-56-50	(+6.5 kg Zn)	7.0
	Hybrid Rice	SR	100-50-50		6.4
		MYR	200-75-100		8.3
	Hybrid Cotton	SR	80-40-40		2.95
		MYR	200-150-100		3.81
	Cassava	SR	60-60-150		40.0
		MYR	90-120-320	(+Ca, S, Zn, B)	51.0
	Peanuts	SR	17-34-54		1.9
		MYR	22-43-68	(+Ca, S, Zn, B)	2.8
	Potato	SR	120-240-120		43.6

		MYR	240-240-240	(+48 kg Mg & 80 kg S)	63.46
	Tobacco	SR	40-100-100		2.43
		MYR	60-125-250	(+100 kg Mg & 150 kg S)	3.46
	Tissue Cultured Banana	SR	340-108-1020		83.3
		MYR	510-162-1530		102.8

SR: Official state recommendation; MYR: Fertiner Recommendations for Yield Maximization Source: TNAU- PPIC- India Programme Sponsored Research Projects Annual Reports

Future research needs

In view of the growing concern for sustainable management of soil fertility, research work on the following areas needs to be addressed:

- Identification of nutrient constraints under major cropping systems on benchmark soils in each of the sub-agro-eco regions of the country.
- Monitoring long-term changes under different agro-ecological systems and building up models for prediction of changes in soil health for national planning and remedial measures.
- Developing techniques for enhancing fertilizer nutrient-use efficiency and reducing environmental pollution.
- Developing techniques for balanced and conjunctive use of various sources of nutrient supply including bio-fertilizers/legumes.
- Evaluation of water, nutrient and tillage interactions in important soil-cropping systems for sustainable high productivity.
- Development of fertility-management strategies for specific problem soils, *viz*. acid soils, saline and alkali soils, waterlogged, arid, hilly and coastal soils.
- Characterization of fertility restorer inputs like available organic/bio-fertilizers, crop residues, city wastes *etc*. and their inventory at least at block level for developing IPNS modules in local /regional perspectives.
- Evaluating quality of organic carbon pool for crop productivity, modelling the turnover of organic matter in long-term experiments and establishing organic carbon threshold values for sustainability.
- Characterization and dynamics of key biotic population (N_2 -fixing organisms, P-solubilizers, mycorrhizae, earth worms) and improving the shelf-life of inoculants and development of efficient techniques for inoculation.
- Development of fertilizer and manure use strategies to reduce nitrate leaching to ground water system.
- Development and refinement of soil-test methods to diagnose nutrient constraints for making reliable recommendations for fertility restorer to achieve sustainable high production.

Fertilizer research agenda must change its focus and orientation. Emphasis should be as much on improving fertilizer use efficiency as on its productivity, profitability and sustainability and eco-friendliness.Models of integrated nutrient management for different well defined agro-ecological zones and cropping systems should be developed to provide guidance for rational and efficient fertilizer use. Networking arrangements are necessary for monitoring and forecasting the changing scenario of nutrient deficiency and toxicity. An elaborate program of monitoring changes in soil fertility should be established which can serve to periodically revise nutrient application rates to achieve maximum fertilizer efficiency, profitability yield sustainability and high quality so that today's maximum yield could be transformed into tomorrow's average yield.

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SITE-SPECIFIC NUTRIENT MANAGEMENT (SSNM) FOR RICE : PROGRESS AND OPPORTUNITIES FOR TAMIL NADU

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INTRODUCTION

Tamil Nadu is a major rice-producing state, and yields of rice in Tamil Nadu are among the highest in India (Nagarajan *et al.,* 2004). At present there is one 'blanket' fertilizer recommendation with fixed rates of NPK for all irrigated rice in Tamil Nadu. Such a recommendation assumes the need of rice for nutrients is constant across soils and among years. The growth and need of rice for supplemental nutrients can, however, be strongly influenced by soils, crop and soil management, and climate — which can vary greatly among fields, villages, and years.

IRRI through collaboration with national agricultural research and extension systems at eight locations in six Asian countries developed and evaluated the concept of site-specific nutrient management (SSNM) for rice in the late 1990s (Dobermann *et al.,* 2002). SSNM, as conceptualized, aimed at dynamic field-specific management of fertilizer N, P, and K to optimize the supply of supplemental nutrients with the plant's demand for nutrients. The plant's need for fertilizer N, P, or K was determined from the gap between the crop demand for sufficient nutrient to achieve a yield target and the supply of the nutrient from indigenous sources, including soil, crop residues, manures, and irrigation water (Dobermann *et al.,* 2004).

The Cauvery Delta Zone (CDZ), which comprises about 11% of the rice production area in Tamil Nadu, was one of the eight locations for the development and evaluation of SSNM in Asia. The CDZ has two contrasting areas — Old Delta characterized by heavy-textured soils with poor drainage, and New Delta containing lighter textured soils with better drainage. About 90% of the rice area in the CDZ is transplanted, and two rice crops are typically grown each year with irrigation when water is sufficient. Scarcity of irrigation water, unbalanced nutrient use including inappropriate timing of N, and pests — including weeds, insects, and diseases — have been identified as constraints limiting production of irrigated rice.

The collaboration of IRRI and TNAU in developing and evaluating SSNM for the CDZ began with a base line survey in 1995 to 1996. On-farm evaluation of SSNM started during 1997 to 1998 and continued for four consecutive seasons up to 2000. This evaluation in 25 farms in the Old Delta at Aduthurai and at 18 farms in the New Delta at Thanjavur revealed increased profit with SSNM as compared to the farmers' fertilizer practice (Nagarajan *et al.,* 2004).

The SSNM approach as developed by 2000 required laboratory analysis of plant samples to determine indigenous nutrient supply through the nutrient omission plot technique, and it relied on the costly chlorophyll meter for determining optimal timing of fertilizer N. From 2001 to 2004, the Reaching Toward Optimal Productivity (RTOP) workgroup of the Irrigated Rice Research Consortium (IRRC) collaborated with TNAU to systematically transform the initial SSNM concept into a simple framework for the dynamic plant-need based management of N, P, and K. On-farm trials were conducted from 2001 to 2003 to refine N and K management practices. SSNM consistently increased grain yield and profit as compared to farmers' fertilizer practice in both the Old and New Delta, and on-farm demonstrations were conducted in 2003 to 2004 to heighten awareness of the SSNM technology among farmers.

Through the activities from 2001 to 2004, SSNM as a concept matured into a simplified SSNM approach for the dynamic plant-need based management of N, P, and K. This SSNM approach enables:

a) Dynamic adjustments in fertilizer N, P, and K management to accommodate field- and season-specific conditions.

b) Effective use of indigenous nutrients originating from sources other than fertilizer.

c) Efficient fertilizer N management through the use of the leaf color chart (LCC), which helps ensure N is applied at the time and in the amount needed by the rice crop.

d) Use of the omission plot technique to determine the requirements for fertilizer P and K.

e) Use of micronutrients based on local recommendations.

The objective of this paper is to describe the current SSNM approach and present an SSNM recommendation for the Cauvery Delta, which takes into consideration the four years of on-farm research following the results reported by Nagarajan et al. (2004).

SSNM approach

The SSNM approach aims to apply nutrients at optimal rates and times in order to achieve high rice yield and high efficiency of nutrient use by the rice, leading to high cash value of the harvest per unit of fertilizer invested. The SSNM approach does not specifically aim to either reduce or increase fertilizer use. Through the development of SSNM during 1994 to 2004, much data were obtained for the relationship between yield of unmilled rice and total N, P, and K in the mature rice crop. The uptake of N, P, and K by a mature rice crop with harvest index of 0.45 to 0.55 can consequently now be estimated from grain yield with sufficient reliability (Witt *et al.,* 1999) that the measurement of N, P, and K in grain and straw is no longer required for the determination of fertilizer N, P, and K rates. Grain yield targets and grain yield in nutrient omission plots can now be directly used in a simplification for estimating fertilizer N, P, and K requirements (Witt *et al.,* 2002; Witt *et al.,* 2004) as follows:

Step 1: Establish an attainable yield target for farmers' fields

The yield target must be reasonably attainable by farmers because it is directly used to calculate fertilizer rates for farmers' fields. A yield target in excess of a yield realistically attainable by farmers would lead to recommendations of more fertilizer than required for high use efficiency and profit. A yield target below a yield realistically attainable by farmers could result in suboptimal yield and profit.

Grain yield from a fully fertilized plot with no nutrient limitations and good management can be used to estimate the yield target. The grain yield attained in the NPK plot or NPK plus micronutrient plot with the omission plot technique can be used as the yield target.

Step 2: Approximate a fertilizer N rate and formulate dynamic N management.

The difference between the yield target and N-limited yield — the yield with no N fertilizer and no limitation of other nutrients — provides an estimate of anticipated crop response to fertilizer N. The N-limited yield can be determined from the yield in N omission plots, receiving no fertilizer N and containing sufficient amounts of other nutrients to ensure they do not limit yield. The measurement of N-limited yield with an N omission plot is not required when N-limited yield can be estimated within ±0.75 t/ha.

The estimated yield response to fertilizer N and a targeted efficiency for fertilizer N use are then used to approximate the total crop requirement for fertilizer N, which can be apportioned among multiple times of application. Within SSNM, fertilizer N use efficiency is defined as the agronomic efficiency for fertilizer N (AE_N), which is the increase in grain yield per unit of applied N. The incremental increase in AE_N decreases with increasing yield. SSNM therefore aims first and foremost for profitable high yield, and then strives to attain this high yield with high AE_N. Considerable information on AE_N in farmers' fields with farmers' fertilizer practices and SSNM have already been obtained through past research. As a generalization, high yields and an AE_N of about 20 to 25 kg grain increase/kg N applied can often be attained with good management in dry seasons in the tropics. The AE_N is typically lower in wet seasons in the tropics, for example about 18 to 20 kg grain increase/kg N applied.

The total amount of required fertilizer N (FN in kg/ha) can be approximated from the anticipated crop response to fertilizer N (i.e., the difference between attainable yield target and N-limited yield) expressed in t/ha and a targeted AE_N, expressed in kg grain increase/kg N applied.

$$FN = \frac{(\text{Attainable yield target} - \text{N-limited yield})\ 1000}{AE_N}$$

The approximated total fertilizer N requirement by the crop is then apportioned among multiple times of application during the growing season to ensure that the supply of N matches the crop need at critical growth stages. Only a moderate amount of N is required by young rice plants within the first 14 days after transplanting (DAT) for transplanted rice or the first 21 days after sowing (DAS) for direct-seeded rice when the plant demand for N is small. The early application of fertilizer N can be reduced or eliminated when high-quality organic materials and composts are applied or the soil N-supplying capacity is high.

Fertilizer N must be dynamically managed to ensure sufficient supply of N to the crop at the critical growth stages of mid-tillering and panicle initiation. Rice plants require adequate N at early and mid-tillering stages to ensure sufficient panicles for high yield. Adequate N at panicle initiation stage ensures sufficient spikelet number per panicle for high yield. Nitrogen absorbed during the ripening phase, in the presence of adequate solar radiation, enhances the grain filling process. In the special case of hybrid rice and large panicle-type rice, it can be necessary to supply supplemental N at heading.

A key ingredient for dynamic N management is a method for the rapid assessment of leaf N content, which is closely related to photosynthetic rate and biomass production and is a sensitive indicator of changes in crop N demand within a growing season (Peng *et al.,* 1996). The chlorophyll meter (for example, Minolta SPAD meter) provides one such rapid and non-destructive method for estimating leaf N content (Balasubramanian *et al.,* 1999), but the high price of the chlorophyll meter prevents its use by individual farmers. The LCC is an inexpensive, simple, alternative tool for monitoring the relative greenness of a rice leaf as an indicator of leaf N status (Bijay-Singh *et al.,* 2002; Shukla *et al.,* 2004; Alam *et al.,* 2005).

The approximated total fertilizer N requirement is typically divided among three or four times of application during the growing season. An N dose for each application can be estimated before the cropping season by dividing the approximated total fertilizer N requirement by the anticipated number of fertilizer applications during a season with average climatic conditions. Two equally effective options are then provided for improved N management using a LCC. In the 'real-time' approach, farmers regularly monitor rice leaves and apply fertilizer N whenever the leaves become more yellowish-green than a critical threshold value indicated on the LCC. In the 'fixed-time/ adjustable-dose' approach, the time for N fertilization is pre-set at critical growth stages, and farmers adjust the dose of N upward or downward based on leaf color (Buresh *et al.,* 2004, 2005).

Step 3: Estimate field-specific nutrient-limited yields for P and K

Nutrient-limited yields are determined by the nutrient omission plot technique. The P-limited yield is determined in a P omission plot receiving no P fertilizer but sufficient supply of other nutrients to ensure they do not limit yield. The K-limited yield is determined in a K omission plot receiving no K fertilizer but sufficient supply of other nutrients (Witt *et al.,* 2002; Dobermann *et al.,* 2004).

Step 4: Determine fertilizer P and K rates

The crop's need for fertilizer P is based on a comparison of the yield target and P-limited yield, whereas the crop's need for fertilizer K is based on a comparison of the yield target and K-limited yield. The SSNM approach recommends sufficient use of fertilizer P and K to both overcome P and K deficiencies and avoid the mining of soil P and K.

Fertilizer P and K requirements, sufficient to overcome deficiencies and maintain soil fertility, are determined with a nutrient decision support system (Witt and Dobermann, 2004), which maintains the scientific principles of the underlying QUEFTS model for rice (Janssen *et al.,* 1990, Witt *et al.,* 1999). Outputs of the nutrient decision support system have been summarized in tables (Witt *et al.,* 2002), whereby fertilizer P_2O_5 and K_2O rates are obtained from an estimate of attainable yield target and either the P- or K-limited yield (Tables 1 and 2). The yield target is determined as described in step 1 above, and the P- and K-limited yields are determined by the nutrient omission plot technique as described in step 3 above.

Table 1. Guidelines for the application of fertilizer P_2O_5 according to yield target and P-limited yield in P omission plots (Witt *et al.,* 2002).

Yield target (t/ha) →	*5*	*6*	*7*	*8*
P-limited yield (t/ha) ↓	*Fertilizer P_2O_5 rate (kg/ha)*			
4	*25*	*40*	*60*	
5	*20*	*30*	*40*	*60*
6		*25*	*35*	*45*
7			*30*	*40*
8				*35*

Table 2. Guidelines for the application of fertilizer K_2O according to yield target, K-limited yield in K omission plots, and rice straw inputs (Witt *et al.,* 2002).

Rice straw inputs	***Yield target (t/ha) →***	***5***	***6***	***7***	***8***
	K-limited yield (t/ha) ↓	*Fertilizer K_2O rate (kg/ha)*			
Low (< 1 t/ha)	*4*	*60*	*90*	*120*	
	5	*45*	*75*	*105*	*135*
	6		*60*	*90*	*120*
	7			*75*	*105*
	8				*90*
Medium (2 to 3 t/ha)	*4*	*35*	*65*	*95*	
	5	*20*	*50*	*80*	*110*
	6		*35*	*65*	*95*
	7			*50*	*80*
	8				*65*

With SSNM, all fertilizer P is applied before 14 DAT or 21 DAS. As a general principle, if the fertilizer K requirement is relatively low (< 30 to 40 kg K_2O/ha) all the K is applied early before 14 DAT or 21 DAS. On sandy soils or when larger amounts of fertilizer K (> 30 to 40 kg K_2O/ha) are required, K can be split applied with about 50% before 14 DAT or 21 DAS and 50% at early panicle initiation.

SSNM recommendation for N in the Cauvery Delta

Background

During the decade of collaboration from 1994 to 2004 between IRRI and TNAU, the N management strategy for rice evolved in response to research findings. Initial evaluations during 1997 to 1998 involved a pre-plant application of N, which depended upon indigenous N supply (INS) as determined from N omission plots; and subsequent use of the chlorophyll meter to adjust doses of fertilizer N at pre-set times during crop growth, based on principles obtained through use of the QUEFTS model. In order to critically match the N supply with crop demand, the pre-plant application of N was subsequently skipped. Because of the high cost involved in using the chlorophyll meter, the LCC was introduced for use in applying N fertilizer. In the evaluation of SSNM through 2001, N was applied at pre-set times and the N doses for applications from tillering onward were adjusted upward or downward based on LCC readings. Then based on the feedback from the farmers, the real-time N management option for using LCC was evaluated, whereby LCC readings were taken at 7 to 10 day intervals from 14 to 21 DAT and urea was then applied whenever the LCC reading fell below a critical value.

Use of the LCC for real-time N management without any other change in crop or fertilizer management increased yield and increased profit as compared to the farmers' fertilizer practice during four cropping seasons from 2001 to 2003. The increased profit averaged 58 US$/ha/season in the Old Delta and 33 US$/ha/season in the New Delta. The benefit of improved N management was largely attributed to increased yield arising from reduced use of early N and increased application of fertilizer N near the critical stage of panicle initiation. The relatively lower profit in the New Delta than Old Delta was apparently due to K limitations on crop growth because the farmers' use of fertilizer K was insufficient for the high yield attainable with real-time N management.

Recommendation with real-time N management

Table 3 presents steps 1 and 2 (as listed above) in the development of a field-specific SSNM recommendation for two locations in the Cauvery Delta based on results of on-farm research. Results of research in farmers' fields indicated that yields in the kuruvai (dry) season for plots with sufficient fertilizer N, P, K, and Zn to eliminate deficiencies of these nutrients typically averaged about 6.2 to 7.2 t/ha in both the Old and New Delta. The attainable target yield was therefore set at 6.5 to 7.0 t/ha. Yields in farmers' fields were often slightly lower in the thaladi (wet) season; therefore the attainable target yield was set at 6.0 to 6.5 t/ha

The N-limited yields as determined with the nutrient omission plot technique were typically lower for the New Delta location, which has lighter textured soils. The N-limited yields in farmers' fields can however vary depending on the management of soils and use of organic materials and manures. A range of values is therefore used to represent the estimated N-limited yield. We then approximate a mean N response of 3 t/ha at both locations in the kuruvai season and 2.5 t/ha at both locations in the thaladi season (Table 3).

Table 3. Approximation of fertilizer N required for rice at two locations in the kuruvai (dry) and thaladi (wet) seasons in the Cauvery Delta, based on estimates of attainable yield targets and N-limited yields in farmers' fields.

Parameter	*Kuruvai*		*Thaladi*	
	Old Delta (Aduthurai)	*New Delta (Thanjavur)*	*Old Delta (Aduthurai)*	*New Delta (Thanjavur)*
Estimate of attainable yield target (t/ha)	*6.5–7.0*	*6.5–7.0*	*6.0–6.5*	*6.0–6.5*
Estimate of N-limited yield (t/ha)	*3.5–4.5*	*3.0–4.0*	*3.5–4.5*	*3.0–4.0*
Approximate N response (t/ha)	*3*	*3*	*2.5*	*2.5*
Targeted agronomic efficiency for applied N (? kg grain/kg N)	*20–23*	*20–23*	*20*	*20*
Approximated fertilizer N requirement (kg N/ha)	*130–150*	*130–150*	*125*	*125*
Estimated number of N applications during the season	*4*	*4*	*4*	*4*
N dose for each application of fertilizer N (kg N/ha)	*35*	*35*	*30*	*30*

On-farm evaluation of SSNM after 2001 in the Cauvery Delta indicated that an AE_N of about 20 to 23 kg grain increase/kg N applied can be attained with good management in the kuruvai season (Table 3). About 130 to 150 kg fertilizer N/ha would be required to achieve these targeted AE_N and the estimated N response of 3 t/ha. The attainable AE_N is often slightly lower in wet than dry seasons. We therefore assume a targeted AE_N of 20 kg grain increase/kg N applied in the thaladi season. The approximated fertilizer N requirement is 125 kg N/ha to achieve the targeted AE_N and the estimated N response of 2.5 t/ha. When approximating fertilizer N requirements, it is often helpful to note that achieving an AE_N of 20 kg/kg corresponds to the use of 50 kg fertilizer N/ha for each 1 t/ha increase in grain yield.

Based on past experiences, fertilizer N applied with real-time N management is split among four applications in a typical season with average climatic conditions. An appropriate N dose for each application of fertilizer N is therefore about 35 kg N/ha in the kuruvai and 30 kg N/ha in the thaladi seasons (Table 3). If N is managed for only three anticipated applications per season with average climatic conditions — for example through the 'fixed-time/adjustable-dose' option or through a real-time option with a more yellowish green critical threshold leaf color for N application — then the N dose for each top dressed application of fertilizer N should be increased to about 40 to 45 kg N/ha. The early application of N within 14 DAT or 21 DAS should however typically not exceed 30 kg N/ha.

The SSNM recommendation with real-time N management is illustrated for the kuruvai season in Figure 1 and for the thaladi season in Figure 2. The first application of N is typically within 14 DAT, although it can be omitted for soils receiving green manures or with high N-supplying capacity. Leaf color is then monitored at about six times between 21 DAT and booting. At each time, the color of the topmost fully expanded leaf from ten or more disease-free hills is compared with the color panels on the LCC. If more than 50% of the leaves are more yellow than a critical threshold color on the LCC, then 35 kg N/ha is applied in the kuruvai season and 30 kg N/ha is applied in the thaladi season.

It is assumed that in a typical season, N will be applied four times. In seasons with above average potential yield, the greater growth and N demand of the crop will result in more rapid yellowing of rice leaves and hence more N applications and hence more fertilizer N use are likely. In seasons with below average potential yield, the rice will require less N and leaves will remain greener longer, resulting in fewer N applications and less fertilizer N use.

The effective use of real-time N management to achieve high yield with high AE_N requires the selection of a critical threshold LCC color, which ensures N application two or three times from early/mid-tillering to booting in an average yielding season. Thresholds for cultivars with inherently yellowish leaves should be more yellowish green than for cultivars with inherently dark green leaves. In Tamil Nadu a six-panel LCC, such as the one produced by Pretech Plast Pvt. Ltd in Bangalore, is used with a critical threshold value of 4 for transplanted rice and 3 for transplanted White Ponni variety and for direct-seeded rice.

SSNM recommendation for P and K in the Cauvery Delta

Background

The existing fertilizer P recommendation for irrigated rice throughout the Cauvery Delta is 50 kg P_2O_5/ha in the kuruvai and 60 kg P_2O_5/ha in the thaladi season. The K recommendation for the entire Cauvery Delta is 50 kg K_2O/ha in the kuruvai and 60 kg K_2O/ha in the thaladi season. Research with farmers for four seasons from 2001 to 2003 revealed the selected farmers used near to the fertilizer P recommendation but less than the K recommendation. The mean fertilizer P use by the selected farmers was comparable at New and Old Delta locations, averaging about 40 kg P_2O_5/ha in the kuruvai and 47 kg P_2O_5/ha in the thaladi. Fertilizer K use by the selected farmers was higher in the New Delta than the Old Delta. In the Old Delta it averaged 25 kg K_2O/ha in the kuruvai and 35 kg K_2O/ha in the thaladi season. In the New Delta, it averaged a comparable 44 kg K_2O/ha for each of the two seasons.

Most K in mature rice plants is present in the straw rather than the grain. The management of rice straw and the portion of the straw retained in the field from the previous crop are consequently important factors influencing the need for fertilizer K. In the Cauvery Delta, rice straw is typically removed from fields, particularly in the thaladi season, and often used for feeding animals.

Through the process of developing and evaluating SSNM in the Cauvery Delta, the nutrient omission plot technique was conducted on numerous farmers' fields at locations in the Old Delta and New Delta. We use grain yield from nutrient omission plots conducted in farmers' fields in the kuruvai season in 1998, 2002, and 2003 (Figures 3 and 4) to illustrate the development of location-specific P and K recommendations (Figures 1 and 2) based on the SSNM approach. One set of omission plots (i.e., fully fertilized NPK plot, P omission plot, and K omission plot) was conducted in each of 11 to 22 farmer's fields in each year at both the Old Delta and New Delta locations. Each farmer's field served as a replication of the omission plot trial, and the total number for the three years was 45 in the Old Delta and 41 in the New Delta.

Figure 3. Yield without fertilizer P and P-limited yield gap — determined with the omission plot technique from the difference between attainable yield with NPK and yield without added P — in the kuruvai season on farmers' fields at locations in the Old and New Cauvery Delta of Tamil Nadu. Error bars show ± the standard deviation of the mean. The number of farmers' fields in each year at each location ranged from 11 to 22.

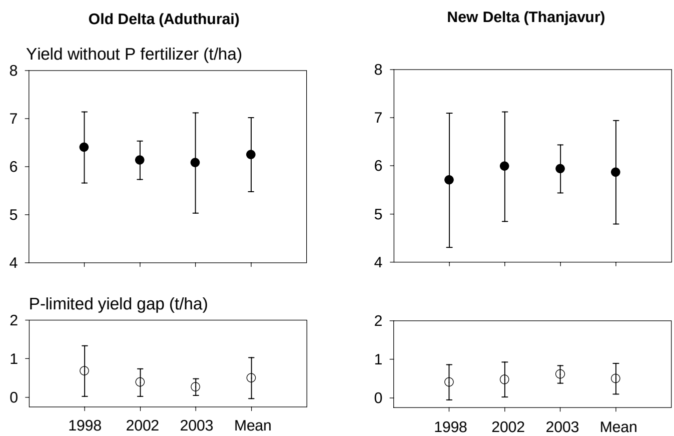
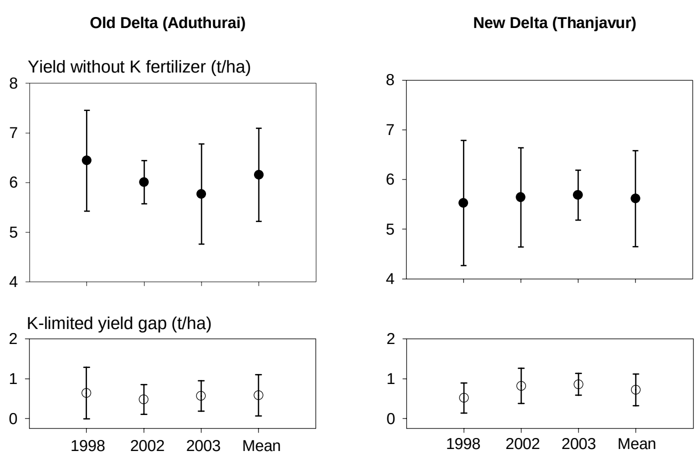


Figure 4. Yield without fertilizer K and K-limited yield gap — determined with the omission plot technique from the difference between attainable yield with NPK and yield without added K — in the kuruvai season on farmers' fields at locations in the Old and New Cauvery Delta of Tamil Nadu. Error bars show ± the standard deviation of the mean. The number of farmers' fields in each year at each location ranged from 11 to 22.



Yields for the three years in fully fertilized NPK plots — which received sufficient N, P, K, and Zn to eliminate constraints of these nutrients — averaged 6.7 t/ha (standard deviation = 0.8 t/ha) in the Old Delta and 6.3 t/ha (standard deviation = 1.0 t/ha) in the New Delta. Yield in the farmers' fields without fertilizer P (i.e., P-limited yield) averaged near 6 t/ha at both locations (Figure 3). The gap between these yields without fertilizer P and yields with full NPK fertilization (referred to as the P-limited yield gap) was consistently < 1 t/ha. It averaged about 0.4 t/ha in the Old Delta and 0.5 t/ha in the New Delta (Table 4).

Table 4. Approximation of fertilizer P_2O_5 and K_2O required for rice in the kuruvai (dry) season at locations in the Old and New Cauvery Delta, based on nutrient omission plots in farmers' fields in 1998, 2002, and 2003.

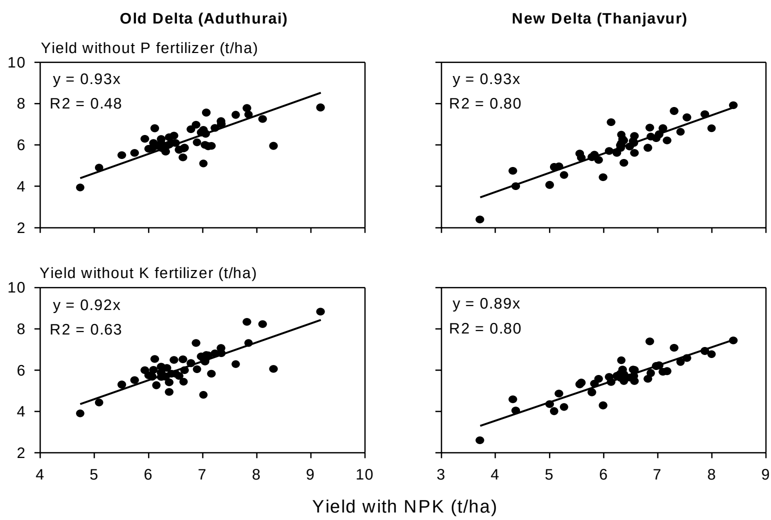
Parameter	*Old Delta (Aduthurai)*	*New Delta (Thanjavur)*
Mean yield with full fertilization of NPK (t/ha)	*6.7*	*6.3*
Mean crop response to fertilizer P (P-limited yield gap in Figure 3) (t/ha)	*0.4*	*0.5*
Mean crop response to fertilizer K (K-limited yield gap in Figure 4) (t/ha)	*0.5*	*0.7*
Attainable yield target (t/ha)	*7.0*	*7.0*
Estimated P-limited yield (based on relationship in Figure 5)	*6.5*	*6.5*
Estimated fertilizer P_2O_5 rate (from Table 1) (kg/ha)	*30–35*	*30–35*
SSNM recommendation for P_2O_5 rate (see also Figure 1) (kg/ha)	*35*	*35*
Existing P_2O_5 recommendation (kg/ha)	*50*	*50*
Estimated K-limited yield (based on relationship in Figure 5)	*6.4*	*6.2*
Estimated fertilizer K_2O rate (from Table 2) (kg/ha)	*60–85*	*65–90*
Performance of K_2O rates (kg/ha)	*60 ? 36* [†]	*94 >> 48* [†]
SSNM recommendation for K_2O rate (see also Figure 1) (kg/ha)	*50*	*80*
Existing K_2O recommendation (kg/ha)	*50*	*50*

[†] Mean grain yield in farmers' fields was only slightly greater (about 0.1 t/ha) for 60 than 36 kg K_2O/ha at the Old Delta location. Grain yield and profit were significantly greater ($P < 0.05$) for 94 than 48 K_2O/ha at the New Delta location.

In the case of K, yields in farmers' fields without fertilizer K (i.e., K-limited yield) averaged near 6 t/ha at the Old Delta location and about 5.5 t/ha at the New Delta location (Figure 4). The gap between these yields without fertilizer K and yields with full NPK fertilization (referred to as the K-limited yield gap) averaged < 1 t/ha and tended to be slightly greater in the New Delta than Old Delta. The K-limited yield gap averaged about 0.5 t/ha in the Old Delta and 0.7 t/ha in the New Delta (Table 4).

Yields for fully fertilized NPK plots, P-omission plots, and K-omission plots can vary among years and farmers' fields — depending upon climate and crop management practices. The P- and K-limited yield gaps within a location (i.e., Old Delta or New Delta) however tended to be relatively stable among years (Figures 3 and 4). Closer analysis revealed a direct relationship between yields for fully fertilized NPK plots and nutrient omission plots (Figure 5). Yield in P- and K-omission plots tended to increase with increased yield in fully fertilized NPK plots, suggesting that yields in P- and K-limited yields were influenced by climate and crop management practices. The relationship between P-limited yield (i.e., yield without fertilizer P, Y_{0P}) and yield with full NPK fertilization (Y_{NPK}) were comparable in the Old Delta and New Delta (Figure 5).

Figure 5. Relationships between yield with full NPK fertilization and yields without fertilizer P and K — as determined with the omission plot technique in 1998, 2002, and 2003— in the kuruvai season on farmers' fields at locations in the Old and New Cauvery Delta of Tamil Nadu.



$Y_{0P} = 0.93\ Y_{NPK}$

The relationships between K-limited yields (i.e., yields without fertilizer K, Y_{0K}) and yield with full NPK fertilization (Y_{NPK}) confirmed a higher response to K in the New Delta than in the Old Delta (Figure 5).

Old Delta: $Y_{0K} = 0.92\ Y_{NPK}$

New Delta: $Y_{0K} = 0.89\ Y_{NPK}$

Recommendation for P and K

The SSNM approach uses P- and K-limited yields and attainable yield targets to develop fertilizer P_2O_5 and K_2O rates (step 4 described above in the SSNM approach). As indicated for the approximation of fertilizer N requirement (Table 3), an attainable yield target for both locations in the kuruvai season is 6.5 to 7.0 t/ha. Omission plot studies during 1998, 2002, and 2003 confirmed 7 t/ha was attainable in farmers' fields when nutrient constraints were eliminated. Yields with full NPK fertilization matched or exceeded 7 t/ha in 36% of the farmers' fields in the Old Delta and 24% of the farmers' fields in the New Delta (Figure 5).

The P-limited yield averaged for all omission plots was about 6 t/ha at both locations (Figure 3). This corresponds to mean yields with full NPK fertilization of 6.7 t/ha in the Old Delta and 6.3 t/ha in the New Delta. Based on the strong direct relationship between P-limited yield and yield with full NPK fertilization (Figure 5), the estimated P-limited yield for a 7 t/ha yield target with full fertilization would be about 6.5 t/ha (i.e., 7 t/ha * 0.93) at both locations (Table 4). The SSNM guidelines shown in Table 1, indicate a fertilizer P_2O_5 rate between 30 and 35 kg/ha would be required when the yield target is 7 t/ha and the P-limited yield is between 6 and 7 t/ha. Modern rice varieties with harvest index of 0.45 to 0.55 contain for each tonne of grain yield about 6 kg P_2O_5 in aboveground biomass (grain and crop residue) at maturity. Assuming a portion of the crop residue is retained in fields and a small amount of animal manure is applied to fields, then the expected export of P_2O_5 from rice fields would be about 5 kg P_2O_5/ha per tonne of grain or 35 kg P_2O_5/ha when grain yield is 7 t/ha. The SSNM-based fertilizer P_2O_5 rate was consequently set at 35 kg/ha for both the Old and New Cauvery Delta (Table 4, Figure 1and 2) to ensure sufficient application of P_2O_5 to replenish P removed with harvested grain and crop residue.

The K-limited yield averaged for all omission plots was about 6 t/ha in the Old Delta and 5.5 t/ha in the New Delta (Figure 4). The corresponding mean yields with full NPK fertilization were slightly <

7 t/ha at both locations (Table 4). Based on the strong direct relationship between K-limited yield and yield with full NPK fertilization (Figure 5), the estimated K-limited yield for a 7 t/ha yield target with full fertilization would be about 6.4 t/ha (i.e., 7 t/ha * 0.92) in the Old Delta and 6.2 t/ha (i.e., 7 t/ha * 0.89) in the New Delta (Table 4). When the yield target is 7 t/ha and the estimated K-limited yield is near 6 t/ha — as for the New Delta — the SSNM guidelines shown in Table 2 indicate a fertilizer K_2O rate of 65 kg/ha when input of residue from the previous rice crop is 2 to 3 t/ha and 90 kg/ha when input of residue from the previous rice crop is < 1 t/ha. The estimated fertilizer K_2O rate for the Old Delta would be slightly less because the crop response to K is less, and the estimated K-limited yield is intermediate between 6 and 7 t/ha (Table 4). Based on SSNM guidelines (Table 2) the estimated fertilizer K_2O rate for the Old Delta is about 60 kg/ha when input of residue from the previous rice crop is 2 to 3 t/ha and about 85 kg/ha when input of residue from the previous rice crop is < 1 t/ha (Table 4).

Evaluation of K recommendation

On-farm trials were conducted on about 25 farmers' fields for two years from 2001 to 2003 to assess the profitability of fertilizer K use at rates estimated through the SSNM approach (Table 4). Two rates of fertilizer K were evaluated with improved N management using the LCC. In the Old Delta the rates were 36 and 60 kg K_2O/ha, and in the New Delta the rates were 48 and 94 kg K_2O/ha. The low rate at each location approximated current K_2O use by farmers, and the high rate approximated a K_2O rate estimated through the principles of the SSNM approach. Profitability of the higher K_2O rate was assessed from the difference in gross return above fertilizer cost (GRF) between the high and low K_2O rates. The GRF was determined from the difference between total value of produced rice and total fertilizer cost.

Use of the higher K rate significantly increased ($P < 0.05$) grain yield and profit in the New Delta but not the Old Delta. Use of 94 rather than 48 kg K_2O/ha in the New Delta increased yield by 0.4 t/ha and increased profit by 39 US$/ha/season. These findings indicate that the existing K_2O recommendation of 50 kg K_2O /ha in the kuruvai season is not sufficient for high profit on light-textured soils in the New Delta when attainable rice yields are increased through improved N management using the LCC. Through this research, the SSNM-based recommendation for K_2O on the light-textured soils at the New Delta has been tentatively set at 80 kg K_2O/ha (Table 4), which is intermediate within the range of K_2O rates estimated from the guidelines in Table 2. The fertilizer K should be split applied to achieve high efficiency (Figure 1and 2).

Use of 60 rather than 36 kg K_2O/ha in the Old Delta had negligible increase on yield (0.1 t/ha) and profit (10 US$/ha/season). Based on these findings, the K_2O recommendation was not increased to 60 kg K_2O/ha, which corresponded to the low end in the range of K_2O rates estimated from SSNM guidelines in Table 2 (Table 4). The SSNM recommendation for fertilizer K was therefore set at the existing K_2O recommendation of 50 kg K_2O/ha in the kuruvai season (Figure 1).

Fig .1 . Fertilizer application for transplanted rice in the Kuruvai season

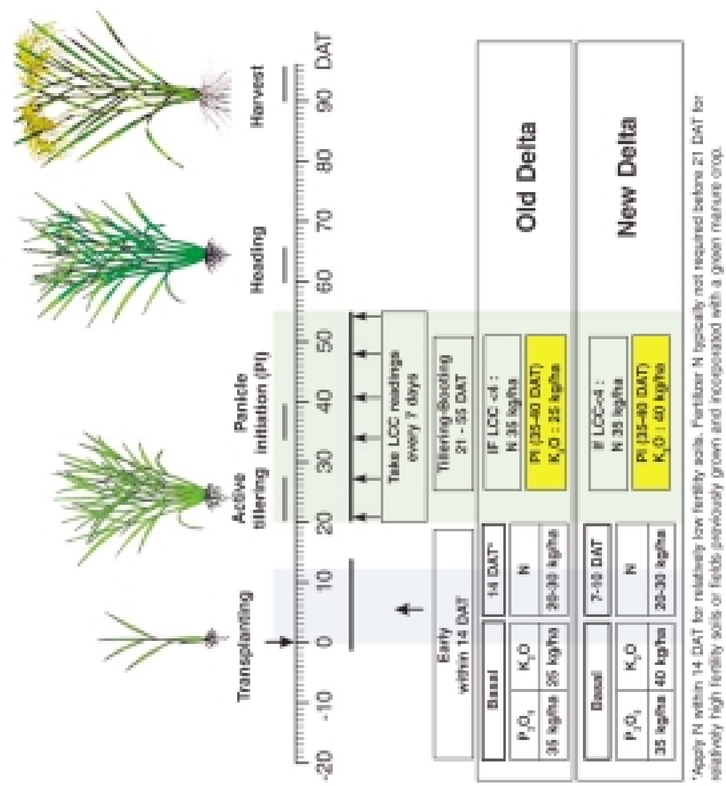
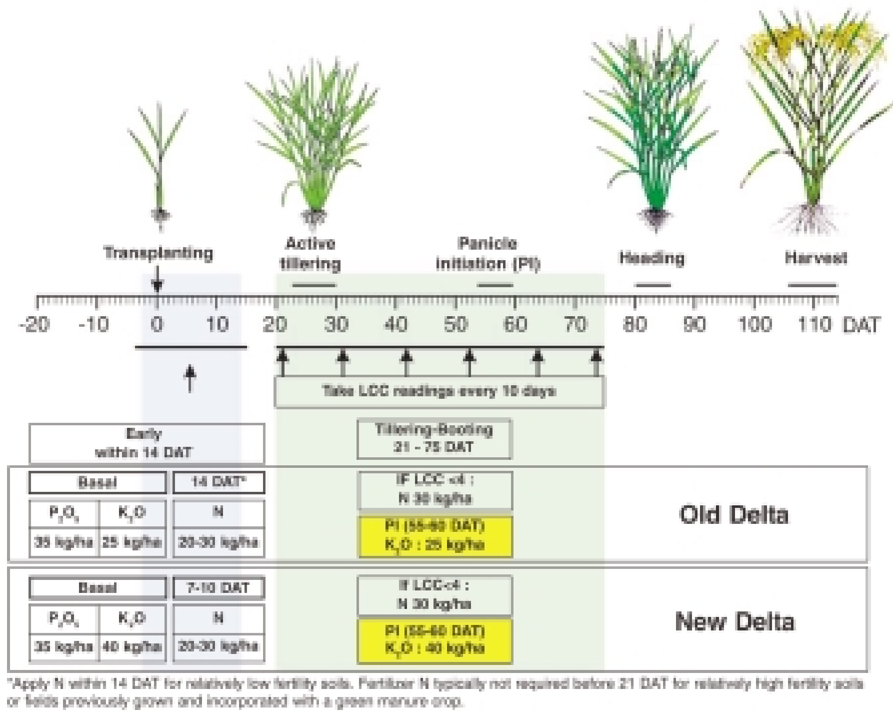


Fig .2 . Fertilizer application for transplanted rice in the thaladi season



Dissemination of SSNM in Tamil Nadu

Collaboration between TNAU and IRRI contributed to a science-based SSNM approach, which was used to develop a locally adapted SSNM recommendation for the New and Old Cauvery Delta Zone (Figures 1 and 2). This SSNM recommendation is ready for wide-scale dissemination and fine-tuning for uptake by rice farmers throughout the Cauvery Delta. At the same time the SSNM approach, as described in this paper, can be extended beyond the Cauvery Delta to develop optimal field-specific management of N, P and K for irrigated rice throughout Tamil Nadu.

Refining and evaluating SSNM-based recommendations

The SSNM approach provides an excellent immediate opportunity for achieving high yield with efficient N management throughout Tamil Nadu. Key ingredients of the SSNM approach for N management, which merit immediate evaluation and dissemination throughout Tamil Nadu, include:

a) Use only a moderate amount of fertilizer N within the first two weeks after transplanting or the first three weeks after direct seeding when the crop demand for N is small. The application of N at this early stage is not based on leaf color because rice plants are too small for accurate reading of leaf color with the LCC.

b) Reduce or eliminate this early application of fertilizer N when green manures and rapidly decomposing organic materials are applied or when the soil N-supplying capacity is high.

c) Combine the early application of fertilizer N, when convenient and appropriate, with application of P and K either as compound (NPK) fertilizers or as single element fertilizers. SSNM provides sufficient flexibility to adjust the timing of the first N application to coincide with the application of P and K within 14 DAT or 21 DAS.

d) Use estimates of probable crop response to fertilizer N and targeted fertilizer N use efficiency (normally 20 to 25 kg grain increase/kg N applied) to approximate the total fertilizer N requirements and a dose of fertilizer N for each top dressing.

e) Apply the approximated fertilizer N dose between tillering and heading (typically two to four times) whenever needed by plants, as determined from leaf color with the LCC.

The SSNM approach provides two equally effective options for N management with the LCC: real-time and fixed-time/adjustable-dose N management. The SSNM recommendation presented in Figures 1 and 2 is for real-time N management. We encourage researchers in Tamil Nadu to formulate an alternative SSNM recommendation with fixed-time/adjustable-dose N management, and then disseminate recommendations with real-time and fixed-time/ adjustable-dose N management as two options from which fertilizer companies, extension, and farmers can select. More information on the fixed-time/adjustable-dose option is provided by Buresh et al. (2004, 2005). Experiences of the Reaching Toward Optimal Productivity (RTOP) workgroup in other countries reveal the fixed-time/adjustable-dose option often integrates better into the recommendations and promotional materials of fertilizer companies; and the fixed-time/adjustable-dose option often gains popularity with farmers as opportunity cost for labor increases because of the two N management options it requires fewer visits by farmers to their fields.

The SSNM recommendation for the Cauvery Delta (Figures 1 and 2) enables adjustments in the timing and dose for the first N application to accommodate field-specific conditions of high INS arising from organic inputs or high soil fertility. Additional research is merited to develop improved predictive understandings of the relationships between INS, use of organic nutrient sources, and the crop need for fertilizer N within 14 DAT or 21 DAS. An outcome of such research would be more robust guidelines for the optimal management of early fertilizer N when organic inputs are used or soils have high INS.

An estimate of N-limited yield is used to calculate an N dose for each top dressing of fertilizer N (Table 3). The calculated N dose in the formulation of fertilizer N management is however only a rough approximation. Calculated N doses are often rounded to increments of fertilizer bags/ha for ease in fertilizer application; and calculated N doses include inherent uncertainty associated with attainable yield target and targeted AE_N as well as N-limited yield (Table 3). We consequently conclude that N-limited yield only needs to be estimated in increments of 1.5 t/ha (within ±0.75 t/ha).

We encourage the use of existing research results and indigenous knowledge to estimate the N-limited yield used in the formulation of N management based on the SSNM approach. The future dissemination and fine-tuning of SSNM in the Cauvery Delta is unlikely to require further use of N omission plots to determine N-limited yield. For irrigated areas outside the Cauvery Delta, it is not necessary to determine N-limited yields with N omission plots before initiating wide-scale evaluation and dissemination of improved N management based on the SSNM approach. Existing research results and indigenous knowledge can provide sufficient information for adequate estimation of N-limited yields for use in formulating improved N management for immediate evaluation and adaptation in farmers' fields.

Research in the Cauvery Delta has clearly demonstrated that improvements in N management can increase yields in farmers' fields. These increases in yield result in increased plant extraction and removal of other nutrients, thereby increasing the need for an adequate supply of other nutrients to achieve the higher yields attainable with improved N management. Based on experiences in the Cauvery Delta, irrigated rice farmers typically apply sufficient fertilizer P to prevent P constraints to achieving high rice yield. Insufficient use of fertilizer K, particularly on lighter textured soils, can however be an important constraint to achieving high yields.

Experiences in the Cauvery Delta indicate that P-limited yield is typically within about 0.5 t/ha of the attainable yield target for irrigated rice fields with a history of receiving e" 30 kg P_2O_5/ha/season. In such cases, a continued seasonal application of fertilizer P is required to replace P removed with harvested grain and residue, thereby ensuring the maintenance of soil P fertility. As indicated earlier, modern rice varieties with a harvest index of 0.45 to 0.55 contain for each tonne of grain yield about 6 kg P_2O_5 in grain plus crop residue at maturity. If all crop residue is removed and no animal manure is applied to fields, then the expected export of P_2O_5 from rice fields for a 7 t/ha rice crop would be about 42 kg P_2O_5/ha. This export of P would be slightly less if some crop residue was retained on the field or some animal manure was applied. Based on the SSNM approach, the application of 35 kg P_2O_5/ha/season to irrigated rice fields with some retention of crop residue or application of manure and a previous history of fertilizer P use should be adequate to attain 7 t/ha (Table 1, Figures 1 and 2).

Results from farmers' fields in the New Delta near Thanjavur indicate the existing recommendation for fertilizer K (50 kg K_2O/ha in the kuruvai and 60 kg K_2O/ha in the thaladi season) is not sufficient to overcome K limitations on light-textured soils in the New Delta when N management is improved to achieve high yields. Based on the economic assessment of two fertilizer K rates in the Old and New Delta, a markedly higher fertilizer K rate is recommended in the New Delta (80 kg K_2O/ha/season) than in the Old Delta (50 kg K_2O/

ha/season), even though the estimated K-limited yields and fertilizer K_2O rates estimated from Table 2 are nearly similar for the two locations (Table 4). This suggests the guidelines for fertilizer K_2O rates as described by Witt et al. (2002) and shown in Table 2 can in some cases require refinements to consider the K-supplying capacity of soil and the relative profitability of contrasting fertilizer K rates.

The higher requirement for fertilizer K at locations in the New Delta than Old Delta suggests lower K-supplying capacity of the light-textured soil in the New Delta. A technique is needed to reliably assess this soil K-supplying capacity and complement the nutrient omission plot technique. Ammonium acetate extractable K does not appear to be a suitable technique for assessing soil K-supplying capacity. The mean ammonium acetate extractable K for soils from locations in the New Delta (0.25 $cmol_c$/kg) was above the critical value of 0.2 $cmol_c$/kg; and K saturation as a percentage of the total CEC was > 2.5, which corresponds to a range in which response to fertilizer K is reportedly unlikely (Dobermann and Fairhurst, 2000). A key ingredient of the SSNM recommendation is the split application of fertilizer K (Figures 1 and 2), which can act to reduce K losses on light-textured soils and increase the availability of K to rice at critical growth stages.

Dissemination and uptake of SSNM in the Cauvery Delta

The SSNM recommendation as illustrated in Figures 1 and 2 together with the option to select either real-time or fixed-time/adjustable dose N management is ready for wide-scale dissemination and fine-tuning in the Cauvery Delta through a partnership of research, extension, fertilizer sector, local government, and farmers. The omission plot technique was vital for the development of P and K recommendations shown in Figures 1 and 2. Activities in the Cauvery Delta can now move beyond a phase of developing P and K recommendations through use of the omission plot technique to a phase with emphasis on enabling farmers to evaluate and adapt the purported improved fertilizer management. A strategy for dissemination in the Cauvery Delta could include the following:

a) Training and orientation on improved N management, which uses only a moderate early application of fertilizer N and then uses the LCC to ensure the top dressing of N matches plant need for N.

b) Providing farmers with an option to manage N by either the real-time or fixed-time/adjustable-dose approach.

c) Recommending about 35 kg P_2O_5/ha in each season for high-yielding modern rice varieties.

d) Encouraging farmers to split apply fertilizer K and integrate increased use of fertilizer K with improved N management.

e) Encouraging farmers to experiment by using the SSNM recommendation in a portion of their rice-production area and comparing its performance with the performance of their fertilizer practice in an adjacent field.

Successful dissemination and uptake of SSNM in the Cauvery Delta will require:

a) Distillation of the SSNM approach and locally adapted SSNM recommendation into easy-to-understand messages and promotional materials for the fertilizer sector, extension, and farmers.

b) Training of lead farmers and field staff from the public and private sector on the SSNM approach and the proposed SSNM recommendation for the Cauvery Delta.

c) Active participation of farmers, including meetings of farmer groups and visits by farmers to fields in which the SSNM recommendation is compared relative to existing farmers' fertilizer practice.

d) Feedback to researchers on the performance of SSNM in farmers' fields, enabling researchers to appropriately fine-tune the SSNM recommendation and better target recommendations on fertilizer K rates to specific soil types and rice-growing areas.

Promotion and uptake of SSNM in Tamil Nadu

The SSNM approach to plant-based nutrient management and the local SSNM recommendation for N management (Figures 1 and 2) with either the real-time or fixed-time/adjustable dose approach can now be extended to rice-growing areas of Tamil Nadu outside the Cauvery Delta. A strategy for developing, evaluating, and promoting locally adapted SSNM recommendations could include the following:

a) Training and orientation on improved N management, which provide farmers with an option to manage N by either the real-time or fixed-time/adjustable-dose approach.

b) Use of the omission plot technique to develop fertilizer P and K rates for contrasting soils and rice-producing areas, which represent large 'domains' for irrigated rice production.

c) On-farm evaluation of two fertilizer K rates in areas with suspected low soil K-supplying capacity, such as light-textured soils with low nonexchangeable K. This evaluation could be comparable to that used in the Cauvery Delta, where the low K rate approximates the rate currently used by farmers and the high K rate approximates a rate estimated from Table 2.

d) On-farm evaluation of two fertilizer P rates in areas with suspected P fixation or other factors restricting P availability. The lower P rate could approximate a rate estimated from Table 2, and the higher P rate could be selected to assess whether there was an economic benefit of additional P use.

e) Partnership of the public and private sector in conducting the nutrient omission plot trials and the evaluation of fertilizer K and P rates.

f) Use results from omission plots and evaluation of K and P fertilizer rates to develop locally adapted recommendations for major rice-growing areas.

SSNM for rice provides a plant-based approach to field-specific management of N, P, and K. It is based on scientific principles developed through nearly a decade of on-farm research throughout Asia. SSNM aims to increase profit for rice farmers by achieving high rice yields with efficient use of nutrients. It consequently does not specifically aim to reduce or increase fertilizer use, but rather ensures nutrient use is sufficient to achieve high yields. Considerable opportunity now exists to incorporate the principles of SSNM into teaching of agricultural students, training for field staff from the public and private sector, and promotional materials on practices for improved rice farming.

Acknowledgment

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RICE FARMING IN ASIA: CURRENT STATUS AND EMERGING CHALLENGES AND OPPORTUNITIES

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INTRODUCTION

In Asia, rice is the staple food for about 60% of the population. It provides from one-third to more than seven-tenths of the daily calorie intake for people in developing Asian countries. Rice is also a key livelihood component of most farmers, the rural landless, and the urban poor. Asian rice-farming households derive about half of their income from rice. An estimated 70% of the world's 1.3 billion poor people reside in Asia and depend on rice for their food. Therefore, efficient and cost-effective rice production is critical to ensure food and nutritional security to the poor and to eradicate poverty in Asia. Without adequate productivity growth, the price of rice is bound to increase and this will make it much more difficult for poor rice consumers to secure their food.

Current status of the rice sector in Asia

About 90% of the global rice is produced and consumed in Asia (Table 1). China, India, Indonesia, Bangladesh, Vietnam, Thailand, Myanmar, and the Philippines are the major rice producers in the region. Indonesia, the Philippines, Malaysia, Japan, and Bangladesh each imported more than half a million tons of rice in 2004. The major rice exporters in the region are Thailand, Vietnam, China, Pakistan, and India (and Australia). The cost of production per metric ton (Mt) of rice varies from US$97 to $160 in developing Asia in comparison with $233 in the United States, $1,091 in South Korea, and $1,624 in Japan (Table 1).

Evolution of rice area, production, yield, and price and their impact on rice farming

From the beginning of the Green Revolution in the mid-1960s to 1999, global rice production increased by almost three fold, while the area planted to rice increased by less than 20% (Figure 1). The higher rice production was achieved by the spectacular increase in mean farm-level rice yield from 2.2 Mt ha^{-1} in 1967 to 3.9 Mt ha^{-1} in 1999 and 4.0 Mt ha^{-1} in 2004. As a result, the inflation-adjust ed real

Table 1. Rice statistics for selected Asian countries in comparison with statistics for the United States, Asia, and the world

Country	Area (million ha) 2004[a]	Production (million Mt) 2004[a]	Yield (Mt ha^{-1}) 2004[a]	Production cost (US$ Mt^{-1}) 2001[b]	Imports (million Mt) 2000[a]	Exports (million Mt) 2000[a]	Additional demand over next 25 y (%)[c]
Bangladesh	11.00	37.91	3.5	130	0.50	--	51
Cambodia	2.30	4.71	2.1	105	0.04	--	--
China	29.42	186.73	6.4	140	0.24	3.07	
India	42.50	124.40	2.9	116	0.01	1.53	46
(Punjab[d])			(5.3[d])	(97[d])			
Indonesia	11.75	53.10	4.5	115	1.36	--	38
Japan	1.65	11.40	6.9	1624	0.66	0.04	--
Korea (Rep. of)	0.99	6.35	6.4	1091	0.17	--	--
Laos	0.82	2.70	3.3	--	0.01	--	--
Malaysia	0.67	2.18	3.3	--	0.61	--	56
Myanmar	6.00	23.00	3.8	--	--	0.14	42
Nepal	1.55	4.30	2.8	107	0.20	--	--
Pakistan	2.21	7.57	3.4	139	--	2.02	--
Philippines	4.00	14.20	3.6	160	0.64	--	65
Sri Lanka	0.76	2.51	3.3	149	0.21	--	--
Thailand	9.80	25.20	2.6	104	--	6.14	--
Vietnam	7.40	35.50	4.8	119[d]	0.005	3.48	45
U.S.A	1.35	10.23	7.6	233[d]	0.30	2.74	--
Asia (total/mean)	134.54	549.46	4.1	--	10.93	16.57	30
World (total/mean)	153.26	608.50	4.0	--	21.78	23.43	25

Data source: [a]IRRI (2005).World Rice Statistics (www.irri.org/science/ricestat/index.asp); [b]FAO (2004); [c]M. Hossain (2002); [d]IRRI sample farm household survey

price of rice in the world market declined by more than 50% (Hossain 2002). During this period, many countries enhanced their food security and saved their scarce foreign exchange by reducing or eliminating imports of rice. At the same time, a few countries started exporting rice to other regions (Table 1). This enormous increase in rice production also saved 186 million ha of marginal land and forest areas that would have been cleared for rice cultivation in the absence of the development of modern rice varieties and production technologies.

However, the declining rice price squeezed farmers' profits. Farmers still continued to profit from rice farming because of (a) the introduction of high-yielding semidwarf rice varieties, good irrigation, mechanization, and better crop management technologies that increased rice yields and reduced the production cost per Mt of rice harvested and (b) the increased annual rice production per unit of land due to the growing of 2 to 3 rice crops per year on the same piece of land, made possible by increased irrigation facilities and the availability of short-duration rice varieties. As a result, the inflation-adjusted domestic producer price of unhusked rice (paddy) remained more or less constant during 1976-2002 (Hossain 2005). A further decline in rice price and a stagnation or decline in yield growth (as seen during 1998-2003) may erode profits for rice farmers and discourage them from further intensification of rice cultivation in Asia.

On the other hand, the demand for rice will increase by a minimum of 1% every year for the next 25 years (Rosegrant *et al.,* 1995, 2001) and this means that an additional 150 million tons of rice must be produced to feed the projected population in 2030. Therefore, further intensification of favorable rainfed and irrigated rice farms is necessary to assure food and nutritional security and to reduce poverty in many Asian countries.

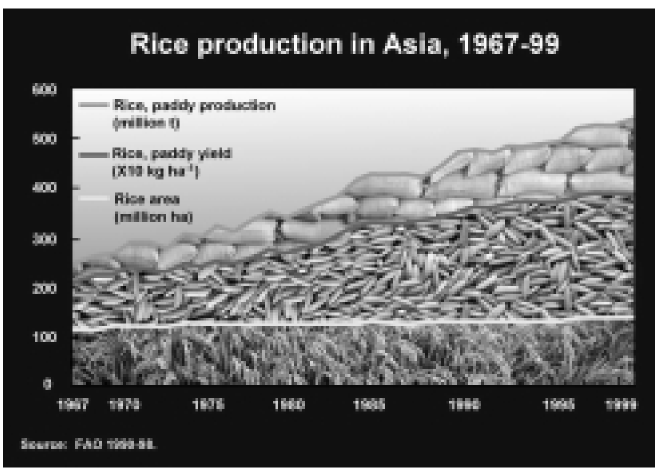

Figure 1. Evolution of rice area, production, and yield during 1967-99 (Source: M. Hossain, IRRI)

Emerging challenges to rice crop intensification

Continuous growth in population, increasing migration of rural people to urban centers, growing biophysical and socioeconomic constraints to rice production, global climate change, increasing environmental concerns, and poor organization and inadequate empowerment of farmers seriously affect the intensification of rice farming in Asia and elsewhere.

Population growth and urbanization and their impact on rice farming

Asia's population is projected to increase from 3.7 billion in 2000 to 4.9 billion in 2030 (Table 2). The annual population growth rate during this period is expected to vary from –0.04% in Japan to 1.5% in Bangladesh and Vietnam, with an average of 1.08% for the region. The proportion of population living in urban centers increased from 22.7% in 1970 to 37.1% in 2000, and it is projected to increase further to 54.5% in 2030 (Table 2), with a rural-urban migration rate of 2.3% per annum. The rates of population growth and urbanization have significant implications for rice farming:

- Continuous population growth and the division of property among children in each generation reduce the farm (and plot) size per rural household.
- More rice consumers in urban areas will depend on fewer rice producers in rural areas.
- There will be less land and water available for rice farming because of increasing demand for these resources for housing, recreation, industry, infrastructure, and other uses.
- Rural-urban migration and growth in rural non-farm enterprises will reduce the availability of rural labor for farming and increase wage rates (Table 3).
- Rural youth in general shun away from farming activities because of their exposure to the urban lifestyle of their counterparts through the media.

Table 2. The United Nations' projected rural, urban, and total population (millions) for Asia, 1970-2030

Particulars	Year 1970	Year 2000	Year 2030
	Population (millions)		
Rural	1657	2313	2222
Urban	486 (22.7%)	1367 (37.1%)	2664 (54.5%)
Total	2143	3680	4886

Source: UN. 2004. World Urbanization Prospects: The 2003 Revision.

Table 3. Long-term trends in wage rates (US$ per day) in selected Asian countries

Country	1961	1971	1981	1991	2000
Bangladesh	0.46	0.44	0.86	1.39	1.27
Philippines	1.39	0.59	1.51	2.16	3.84
Korea, Rep. of	0.82	1.86	10.84	32.59	38.84[a]
Japan	1.22	8.19	24.16	51.93	84.35

[a]1996 figure. *Source: IRRI (2002).World Rice Statistics (www.irri.org/science/ricestat/index.asp)*

Farm-level rice production constraints

Rice farmers face several problems : stagnating yield growth, declining profit (due to rising input costs and low rice price), globalization of trade and the consequent worldwide competition, resource (land, water, and labor) constraints to rice cultivation, crop failures due to adverse weather, high postharvest losses, and growing environmental concerns. Rice research must develop innovative technologies and production practices to tackle these farmers' problems.

Stagnating yield growth : Annual rice yield growth in Asia decreased from 2.7% during 1970-80 to 0.9% in 1990-2002. Mean rice yields on Asian farms oscillated between 3.9 and 4.0 t ha^{-1} during 1998-2003. Modernization of rice farming is critical to maintaining a yield growth of more than 1% per annum for the next 25 years and to making rice farming profitable and attractive to the next generation of rice farmers.

Declining profit : To enhance profit in rice farming, farmers need to use production resources and external inputs efficiently, reduce production losses from pests and diseases and poor postharvest management, and improve grain quality and product diversification to meet changing consumer demand.

Global competitiveness : In a liberalized and open trade arena, farmers in all countries will face severe global competition to market their produce. Those who produce grain at the required quality for various consumer markets at a competitive price will win the race. Researchers and field technicians must provide technical assistance to farmers to enable them to compete successfully in the global market place.

Resource constraints : The supply of land, water, and labor—the critical resources for rice production—are decreasing because of increasing demand for and diversion of these resources to human settlement and expansion of industry, infrastructure, and recreational facilities. In Java alone, 30,000 hectares of agricultural land vanish each year—which could supply rice for 800,000 people. Rice will also have to compete with more profitable crops for field space.

Declining quality and availability as well as increasing competition and cost of fresh water threaten the sustainability of irrigated rice systems in Asia. Tuong and Bowman (2003) estimate that, by 2025, about 2 million ha of Asia's irrigated dry-season rice and 13 million ha of its irrigated wet-season rice will experience "physical water scarcity," and most of the 22 million ha of irrigated dry-season rice in South and Southeast Asia will suffer "economic water scarcity." To tackle this problem of severe water shortage for rice production, we urgently need new methods of irrigation to save water and related crop management technologies to sustain yield (Bouman and Tuong, 2001; Tuong and Bouman, 2003).

High postharvest losses : Asian rice farmers lose 25% to 50% of the total grain value because of poor timing of harvesting and threshing, inadequate moisture control at various stages, and inefficient grain handling and milling. Farmers may be aware of the losses in quantity of grain (10–15%), but not the losses in grain quality (10–35%) that determine the market price for their produce. Farmers often experience breakage of grain, especially in long-grain varieties, caused by inappropriate milling equipment. A majority of farmers allow the rice crop to overripen before harvest and wait for 2 to 5 days between harvest and threshing; these practices increase grain breakage in milling and reduce whole-grain recovery and the price (value) for milled rice.

Climate change and rice production

Climate change is expected to influence future crop yields. Complex interactions between the effects of increased atmospheric CO_2 concentrations (Baker *et al.,* 1990) and trace gases such as ozone (Maggs and Ashmore, 1998), and the effects of temperature increases due to climate change (Rosenzweig and Parry, 1994) are predicted to affect biomass production and crop yields in the future. Increased nighttime temperature associated with global warming is reported to reduce rice yields in the tropics (Peng *et al.,* 2004). Rice grain yield declined by 10% for each 1°C increase in growing-season minimum temperature in the dry season, whereas the effect of maximum temperature on yield was not significant. Breeding rice varieties tolerant of high nighttime temperature is necessary to solve this problem.

Climate change may also increase the frequency of occurrence of drought and flood in different parts of the world, and cause sea levels to rise in coastal regions. Other unpredictable natural disasters such as cyclones, earthquakes, and tsunami-induced giant tidal waves may destroy lives and property, including farm land and water resources in certain areas. Farmers need adequate crop and property insurance protection against such natural calamities.

Farming-related environmental concerns

The application of external inputs increases with the continuous intensification of rice farming (Figure 2). In intensive rice cultivation, farmers use chemicals to obtain bumper rice harvests. Farm chemical misuse, particularly the overuse of pesticides, is due to years of aggressive pesticide advertising, lack of knowledge, and incorrect estimations of crop loss. The chemicals used in Asia, such as methyl parathion, monocrotophos, and metamidophos, are often highly hazardous to human health and are banned in the developed world. In addition, improper use of chemicals in farming will also increase their residues in food products, thereby affecting human health. Despite the promotion of integrated pest management (IPM) strategies, the use of such chemicals continues at high levels worldwide and still troubles the rice industry. Therefore, technologies to reduce chemical use in rice farming are urgently needed.

External N application is critical for intensive rice production because most soils are deficient in N. About 93% of the total N fertilizers allocated for rice are applied to rice fields in Asia (FAO 2001). Rice crops use only about half of the applied N for producing the aboveground biomass (Balasubramanian *et al.,* 2004a; Krupnik *et al.,* 2004). The other half is, to a great extent, dissipated in the wider environment, causing a number of environmental and ecological

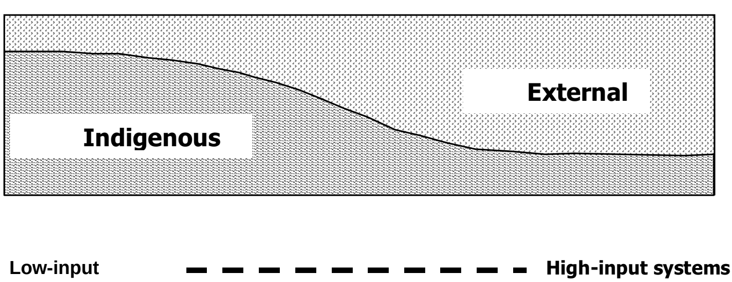

Figure 2. Relative use of indigenous resources vs. external inputs with intensification of rice farming (source: Kam 2003)

side effects. Thus, efficient N use is critical to producing enough food to feed the growing population and avoid large-scale degradation of ecosystems caused by excess N (Tilman *et al.,* 2001).

Other impacts of intensive farming on the environment are land degradation, water depletion/pollution, erosion of biodiversity, and emission of greenhouse gases.

Lack of or ineffective farmer organizations

Rice farmers in Asia are highly scattered in space. They do not organize themselves into effective groups to jointly fight for their rights and entitlements. Farmers are the worst affected group in any country and most of them often suffer in silence.

Opportunities to address emerging challenges to rice production

New technological breakthroughs are needed to further intensify the rice production systems in favorable and irrigated areas in the face of a declining supply of production resources such as land, water, and labor. Another critical area is how to achieve economies of scale in rice farming to effectively mechanize field operations. A third point is how to reach millions of rice farmers with new information and technology when rural youth are moving away from agriculture in search of jobs and a better life in cities. Technology options readily available now (Balasubramanian *et al.,* 2003) or in the research pipeline are discussed below.

Raising the potential yield, nutritional value, and resistance of rice varieties

The potential yield is 10 Mt ha^{-1} for presently available semidwarf indica rice varieties. An additional 10% to 15% increase in rice yield is possible with the development of rice hybrids for the tropics (Virmani 1996; Virmani *et al.,* 1998). New plant type (NPT) varieties and hybrids derived from them are being developed to further increase the potential yield of rice to 12 to 15 Mt ha^{-1} or more (Khush 1995).

Nutrient-dense varieties such as golden rice (for vitamin A) and iron-rich rice are in the research pipeline. They may be available to farmers in about five years. Pest-resistant rice varieties (*Xa21* for bacterial leaf blight, *Bt* for insects) are also being developed to minimize pesticide use in rice farming. Research is ongoing to develop rice varieties tolerant of abiotic stresses such as drought, flood, salinity, etc.

Growing more rice with less water

Water-saving technologies such as saturated soil culture, saturated soil and soil drying, and alternate wetting and drying (AWD) increased water productivity by reducing water input by up to 35% compared with continuous flooding, but grain yield decreased (Borell *et al.,* 1997; Lu *et al.,* 2000; Bouman and Tuong, 2001; Tabbal *et al.,* 2002). AWD is promising because it offers high water productivity coupled with a low penalty on grain yield. In China and the Philippines, AWD is reported to save from 13% to 30% of irrigation water at the field level, with no significant reduction in yield (Cabangon *et al.,* 2001; Belder *et al.,* 2002). In Indonesia, rice yields were maintained or increased under AWD when weeds were controlled effectively (Wardana *et al.,* 2002).

Other water-saving technologies include (a) land leveling to reduce the amount of water needed to keep fields uniformly flooded and at the same time improve weed control, (b) direct dry seeding to save on water used for puddling, and (c) planting on raised beds. Construction of farm ponds and rainwater harvesting and effective management of waste water and saline water for irrigation are other options available for rice production in water-scarce areas or in areas with a poor-quality water supply.

Researchers need to develop adapted rice varieties and appropriate nutrient and pest management strategies to tackle shifts in nutrient needs, weed flora, and pest profiles under situations of limited water use in rice cultivation. Virmani (1996) and Shi *et al.* (2002) have shown that hybrid rice varieties are more adapted to AWD because of their early seedling vigor and vigorous root system that favor efficient use of available water. Breeders at IRRI have identified several elite inbred lines, varieties, and hybrids that are particularly adapted to AWD during the vegetative phase, without any significant loss of yield. IRRI is also working to develop aerobic rice.

Aerobic rice : Rice breeders at IRRI are breeding new aerobic rice varieties by combining upland rice's adaptation to dry soils and the fertilizer responsiveness and high potential yield of irrigated rice varieties (Atlin 2005). The resulting aerobic rice varieties grow in non-flooded soils like maize or wheat and yield as high as 4 to 5 Mt ha^{-1}, using 50% of the water that flooded rice systems use. Farmers have already started cultivating promising aerobic rice varieties in China, Brazil, and the Philippines.

Integrated crop management (ICM) promotes the combined use of adapted rice varieties and location-specific crop management technologies to increase land and water productivity as well as net profit in irrigated rice farming (Balasubramanian *et al.,* 2004b; Chandrasekaran *et al.,* 2004; Thiyagarajan *et al.,* 2002). ICM pilot studies conducted by the Plant Protection Department in South Vietnam indicated that farmers could reduce their seed rate by > 50%, N input by 20–30%, the number of pesticide applications by 30–50%, and crop lodging by 100%, and enhance overall profit by \$93–214 ha^{-1} in direct-seeded rice (Balasubramanian *et al.,* 2002). With a wider adoption of AWD and ICM in Asia, crop yield will be sustained or increased in irrigated rice ecosystems, and the water saved will be available for other more profitable uses and to reduce the risk of salinization/seawater intrusion in downstream areas. Growing healthy crops through ICM will also help reduce pesticide-related health risks to farmers.

The shift from continuous flooding to the aerobic system will cause profound changes in water conservation, soil organic matter turnover, nutrient dynamics, carbon sequestration, soil productivity, weed ecology, and greenhouse gas emissions. Some of these changes can be positive (e.g., water conservation and decreased methane emissions), whereas others can be negative (e.g., release of nitrous oxide from the soil, decline in soil organic matter). Future research must monitor these changes and develop effective water and related resource management interventions that will allow profitable rice cultivation with increased soil aeration while maintaining the productivity, environmental services, and sustainability of rice-based ecosystems.

Site-specific nutrient management (SSNM)

Site-specific nutrient management (SSNM) provides an approach for “feeding” rice crops with nutrients as and when needed. Farmers dynamically adjust the application and management of nutrients to crop needs according to location and season (Buresh *et al.,* 2003; Dobermann *et al.,* 2004). This approach advocates

- the optimal use of existing indigenous nutrient sources, including crop residues and manures, and
- timely fertilizer application to meet the deficit between rice demand for nutrients and the supply of nutrients from soil and organic inputs (Figure 3).

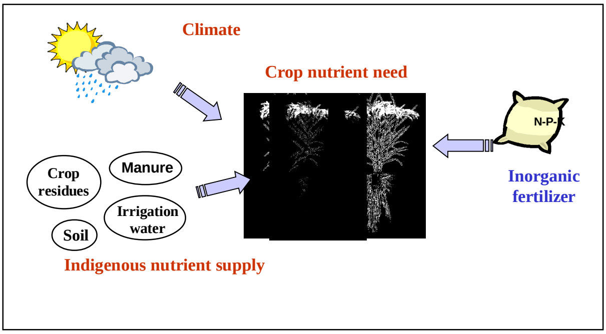

Figure 3. SSNM approach: "Apply fertilizers as and when needed to fill the deficit between crop need and indigenous nutrient supply." (Source: Buresh *et al.,* 2003)

In SSNM, the leaf color chart (LCC) is used to apply N fertilizer as per the crop's need during the growing season (real-time N management) (Balsubramanian 2004; Shukla *et al.,* 2004). Rice leaf color is monitored in the field with LCC from 15 days after transplanting to the booting stage at 7–10-day intervals, and N fertilizer is applied whenever the leaf color falls below a critical value (Figure 4).

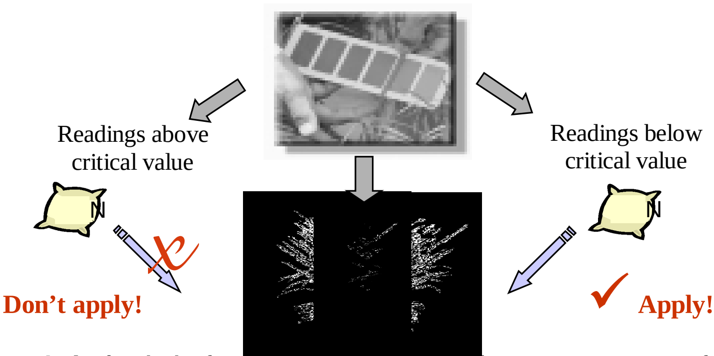

Figure 4. A simple leaf color chart-based decision support system for crop need-based N management in rice

The omission plot technique is used for crop need-based P and K application. A P-omission plot—a plot with no added P but applied with full rate of other nutrients—visually demonstrates to farmers a deficit of P. Similarly, a K-omission plot—a plot with no added K and the full rate of other nutrients—demonstrates a deficit of K (Buresh *et al.,* 2003; Dobermann *et al.,* 2004). The difference in grain yield between a nutrient omission plot and a full NPK plot is used to make

P and K recommendations, using the formula "To produce one metric ton of paddy over the yield of the nutrient omission plot, farmers should apply 15-20 kg P_2O_5 and 30 kg K_2O per ha."

Other nutrients such as S and Zn are applied as per local recommendations at sites deficient in such elements.

The SSNM approach eliminates wastage of fertilizer by preventing excessive rates of application and by not applying fertilizer when the crop does not require nutrient inputs. It also ensures that N, P, and K are applied in the optimal proportions (Buresh *et al.,* 2003).

Additional research is needed to develop integrated nutrient management (INM) strategies for rice grown in non-puddled soil (e.g., bed planting, direct dry seeding, aerobic rice, etc.). The relationship between INM and crop establishment, INM and pest incidence, and INM and water management has to be explored further to develop effective options of integrated crop management and to minimize nutrient losses from the system.

Integrated pest management (IPM)

IPM is a decision-support system for the selection and use of pest control strategies that minimize dependence on chemical pesticides and improve human health and environmental quality. The use of an adapted resistant rice variety, good-quality seed, robust young seedlings, crop need-based nutrient application, and proper water management and weed control will help grow a healthy crop that will minimize the need for pest control by chemicals. Regular field monitoring and taking preventive measures are important steps to prevent a buildup of pests. Maintaining in-field refuges for natural enemies is another way to increase the population of predators more than pests. Community action is needed to control certain pests such as locusts, rice bug, black bug, tungro, and rats. Selected IPM technologies for rice are (a) no early spraying against leaffolders and thrips, (b) pheromone traps for yellow stem borer, (c) an active barrier system for rat control, (d) deployment of pest-resistant varieties, (e) planting of mixed varieties, (f) silica application for blast control, and (g) timely and judicious use of fast-acting bio- or synthetic pesticides.

Mixed planting to enhance diversity and reduce disease incidence: Interplanting of high-yielding hybrid rice varieties that are resistant to blast with susceptible traditional tall glutinous rice varieties has improved total productivity and drastically reduced the use of fungicides to control blast disease in China

(Leung *et al.,* 2003). With low or no incidence of blast in these interplanted crop mixtures, farmers are re-introducing blast-susceptible traditional rice varieties that have high socio-cultural and market value.

Further research is needed on the management of herbicide resistance, development of crop genetic diversification strategies to reduce pest incidence, use of biotechnology to develop rice varieties with multiple resistance, and development of optimum plant nutrition strategies for minimizing pest attack through a better understanding of nutrient ´ pest interactions.

Reducing postharvest losses

Asian rice farmers lose 25% to 50% of the total grain value because of improper handling of rice during and after harvest. To reduce grain losses and to maintain grain quality, rice must be harvested at 95% maturity and threshed immediately after harvest. Simple dryers and sealed storage options are available for drying and storing the grain properly. Sealed storage kills storage pests without pesticides, preserves grain quality, and maintains seed viability. IRRI has developed appropriate and cost-effective tools such as a low-cost moisture meter to monitor grain moisture while processing, super bags for hermetic storage of grain, a rice-milling chart to guide optimum milling of rice, and an indent sheet grader to separate broken rice from the whole kernel. An improvement in harvest and postharvest processing will enhance the market value of rice and thus improve not only farmers' income and livelihood but also enhance profit to millers.

Tackling global climate change

Higher night temperature caused by global warming and other climate-related natural calamities such as flood, drought, tidal waves, cyclones, etc., adversely affect rice production in many countries. The development of rice varieties tolerant of high nighttime temperature during the crop growing period and of saline and alkaline soils is critical. Alternate crops need to be identified and introduced for flood- and drought-prone areas.

Environmental sustainability

Excessive or improper use of fertilizers and pesticides, land degradation, depletion of groundwater, contamination of groundwater with toxic metals such as arsenic, erosion of biodiversity, and emission of greenhouse gases lead to degradation of the environment. The development of alternative technologies to reduce burning of crop residues will help improve air quality in farming areas and at the same time will enhance soil quality. The efficient use of fertilizers and pesticides will reduce the pollution of water sources. The widespread adoption of crop need-based site-specific nutrient management and IPM strategies will not only optimize fertilizer application and reduce pesticide use on crops but will also impact positively on the environment and human health, boost farm profit, and conserve important resources used in the manufacture of fertilizers and pesticides. The increased adoption of direct seeding and alternate wetting and drying irrigation will reduce emissions of greenhouse gases such as methane and nitrous oxide. Enhancing biodiversity through interplanting of resistant and susceptible rice varieties in China has drastically reduced fungicide use in rice farming and helped improve the quality of harvested produce. The integrated use of resource-conserving technologies will enhance the sustainability of production systems and improve the quality of the environment.

Organization of farmers

The voluntary organization of farmers into groups is essential to gain competitive power in input and output markets, effectively coordinate farming operations and allocate community resources (water, grazing land), shape supportive farm policy (crop insurance, minimum support price, etc.), develop own processing and value addition enterprises, and do direct marketing.

Farmer cooperatives

A cooperative organization is effective if managed properly. In most places, farmer cooperatives have failed because of mismanagement, political interference, nepotism, and fraud. The cooperative movement in India celebrated its centenary in 2004 and new efforts are under way to renew cooperative organizations to empower the weaker sections of the community such as women, tribal people, and landless laborers. A national cooperative development corporation coordinates all the cooperatives in the country. To be successful, cooperatives must be formed on a voluntary basis and managed democratically by an elected autonomous professional management team with an independent audit.

Corporate management for farmer groups

Farmers develop an association with a professional leader to guide them. Landholdings are not consolidated, but members must follow strict guidelines in crop scheduling, farming activities, and allocation of common resources. Group facilities such as farm machinery, postharvest processing and storage, and bulk-procured inputs are made available to members. Direct marketing of produce is also organized. Such corporately managed farmer groups exist in India, Indonesia, and Vietnam.

Contract farming

In this case, farmers become contractors of a company. They provide only labor, land, and some capital, but make no major farming/management decisions. The company makes key management decisions, provides all inputs and technical advice and support, supervises all operations to maintain quality, and buys back the produce at an agreed-upon price. Some companies pay the contract price or the market price, whichever is higher at the time of procurement to enhance the long-term relationship with their farmer contractors. Farmers have to follow strict guidelines in farming and maintain product quality as per the agreement. A good example is organic rice farming under contract with a company for technical guidance, input supply, certification, processing, and marketing.

Contract farming provides better linkage among production, processing, and marketing, with farmers, processing companies, and bankers as key stakeholders. Banks provide credit to support and facilitate the win-win arrangement between farmers and companies. There are no middlemen between farmers and companies. All profit goes to the company and some companies may share a part of their profit with farmer contractors to enhance participation and sustainability.

CONCLUSIONS

The impressive research achievements of IRRI and partner research institutions in Asia have led to the development of high-yielding inbred and hybrid rice varieties and innovative production technologies that have assured food security for the galloping population of Asia during the last four decades. Further intensification of rice farming is more difficult because of the emerging challenges of migration of rural youth to cities, declining resources, rising input costs, decreasing profit, degradation of the environment, and poor organization of farmers. Research must find solutions to these challenges in order to ensure food and nutritional security to the one billion more people who will inhabit Asia in the next 25 years.

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MICRONUTRIENTS DEFICIENCIES IN INDIAN CROPS AND THEIR AMELIORATION

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Introduction

Green Revolution has triggered to achieve higher food production and nutritional security in the country. However, intensive cultivation of high yielding varieties, increased use of NPK free from micronutrients, decreased use of organic manures and lack of crop residue recycling created a situation that the inherent pools of most of the micronutrients in soils were gradually exhausted. These resulted in widespread deficiencies of micro- and secondary -nutrients to a level where it became critical for achieving sustainable high crop production (Kanwar and Randhawa 1974, Singh and Abrol 1986).

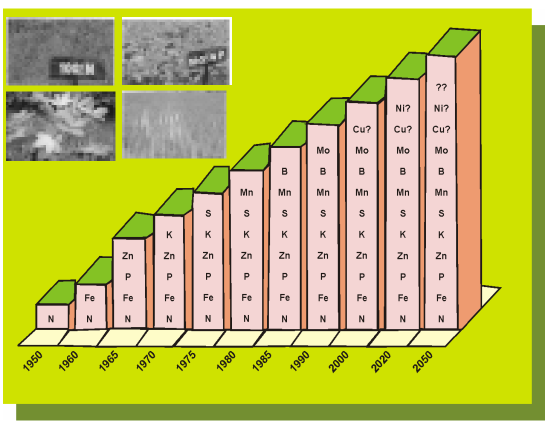


Fig.1: Emergence of nutritional disorders in crops in India

In sixties field scale zinc (Zn) deficiency was first noticed in rice in tarai soils (Nene, 1965), and in wheat on sandy soils (during 1969), then in most of the intensively cultivated area wherever these crops were grown. Later, the deficiencies of Fe became apparent in rice, sugarcane, chickpea, groundnut and that of Mn in wheat in rice-wheat system on sandy soils of Punjab (Takkar and Nayyar, 1979, 1981) and of B in chickpea, rice on highly calcareous soils of Bihar (Singh *et al.,* 1985) in several soils. Since consumption of fertilizer nutrients in the country is likely to increase from 18 and 45 million tonnes to produce nearly 310 million tonnes of food grain for feeding about 1.4 billion people in the year 2050 A.D.Thus mounting pressure of increasing food requirements would further increase the constraints of micronutrient deficiencies and toxicities of trace elements on our limited natural soil resources (Fig.1), hence these issues need more attention.So considering wide spread micronutrients deficiencies and the benefits likely to be accrued and suitable technology technologies developed for effectively combating their deficiencies are summarized below for the benefits of users agencies.

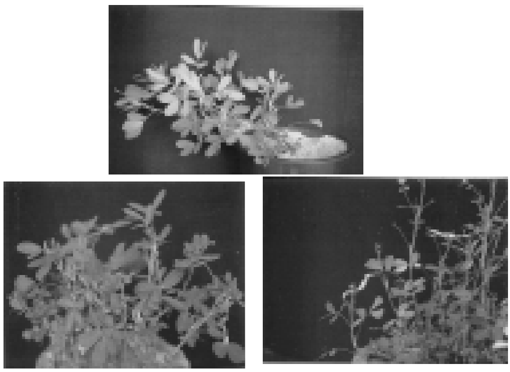
Physiological and biochemical functions of micronutrients in plants

Plant requires seven essential micronutrients to complete their life cycle as they play specific physiological functions in the metabolic activities of plants (Agarwala and Sharma 1979). Micronutrients are required in small amounts but they are very vital in redox process in plant cell for electron transfers and in the synthesis of growth substrates. These are constituents of prosthetic groups in several metallo enzymes and activator of enzymatic reactions. Micronutrient stress influences the pollen viability, sink activity, higher activity of oxidase, hydrolytic catabolic enzymes as well as production and translocation of photosynthates within plant parts. Some micronutrients like molybdenum (Mo) and copper (Cu) are helpful in assimilation and symbiotic nitrogen fixation in root nodules of legume plants. Manganese acts as an activator of enzymes in Krebs Citric Acid Cycle and is involved in activating catalyze reactions such as phosphorylation, decarboxilation and hydrolysis reactions and lignification. Iron is a constituent of large number of metabolic components like cytochrome, heme enzymes, functional metallo proteins such as ferrodoxin and hemoglobin. Boron is involved in the synthesis of growth regulators, sugar borate and their translocation within plant parts, which have striking effect on formation and development of anthers in pollens, which facilitates fertilization and better crop yields.

Diagnosis of Nutritional Disorders in Crops and Soils

Efficient diagnosis is the key for adopting proper amelioration strategies which can be accomplished by looking visual deficiency symptoms, soil and plant analysis and biological response from micronutrient fertilization. Specific deficiency symptoms are characterized and critical level of nutrients have been established in important crops, which are helpful in diagnosing actual nutritional disorder in various crops by various workers (Sharma 1996, Singh 1998, 2000).

Visual symptoms in plants : Deficiency of micronutrient in plant produces specific characteristic symptoms, which can be used as a guide to diagnose micronutrient deficient plants (Fig.2). Visual deficiency symptoms in several plant species and their cultivars have been characterized in refined sand culture (Agarwala and Sharma 1979) and in field conditions (Nayyar et al 1990, Gupta et al 1994, Singh and Saha 1995, 1997), which are being widely used in diagnosing nutritional disorders in important crops.



Groundnut

Fig. 2: Visual symptoms of micronutrient deficiencies in groundnut plants

Plant analysis : There exists a quantitative relationship between tissue micronutrient concentration and growth and yield of the crops, with exception of Fe. Therefore, micronutrient concentration in plants is found quite helpful to isolate deficient crops and soils. Using refined sand culture, threshold value of micronutrients deficiency / toxicities at which $\pm$10% reduction in yield occurs, have been established for Indian crops and their varieties (Table 1).These are being used for precise and successful prediction of their deficiencies in crops (Sharma 1996). The values depend upon the degree of deficiency, plant age and parts sampled, genotype, status of other interacting elements and environmental conditions (Singh and Saha 1995, 1997, Singh 1998).Notwithstanding the inter-species and inter-site differences, concentration of zinc less than 20 mg kg^{-1} suggests the probability of its deficiency in several cereal and oilseed crops.Minor differences in critical concentration have been observed between soil and sand culture. The critical limit of Mn, Cu, B and Mo at which most crops need supplementation may arise if their concentration in plant tissue are less than 20, 4 and 20 mg kg^{-1} and less than 0.1 mg kg^{-1} , respectively.

Table 1. Critical concentration of micronutrients in important crop plants (YL=Young leaves, ML=Middle leaves, L=Leave)

Crop	*Nutrient*	*Age of Plant DAS*	*Plant Part*	*Critical Conc. for mg kg^{-1} for micronutrients*				
				Severe deficiency	*Crop*	*Nutrient*	*Age of Plant DAS*	*PlantPart*
Pigeon pea	*Cu*	*44*	*YL*	*<5.0*	*Pigeon pea*	*Cu*	*44*	*YL*
Pea	*Cu*	*42*	*YL*	*<4.0*	*Pea*	*Cu*	*42*	*YL*
Lentil	*Cu*	*56*	*YL*	*<6.0*	*Lentil*	*Cu*	*56*	*YL*
Wheat	*Cu*	*35*	*YL*	*<4.0*	*Wheat*	*Cu*	*35*	*YL*
Rice	*Cu*	*35*	*YL*	*<2.5*	*5*	*5-40*	*40*	*>100*
Maize	*Cu*	*35*	*YL*	*<2.5*	*4*	*4-20*	*20*	*>100*
Pearl millet	*Cu*	*72*	*YL*	*<2.5*	*8*	*8-14*	*14*	*>20*
Gram	*Cu*	*54*	*YL*	*<3.5*	*10*	*10-15*	*15*	*>18*
Sunflower	*Cu*	*38*	*L*	*<5.0*	*6*	*6-10*	*10*	*>20*
Soybean	*Cu*	*35*	*L*	*<4.0*	*4*	*4-15*	*15*	*>15*
Wheat	*Zn*	*35*	*ML*	*<15*	*20*	*20-100*	*100*	*>20*
Rice	*Zn*	*35*	*ML*	*<15*	*20*	*20-100*	*100*	*>200*
Maize	*Zn*	*35*	*YL*	*<2.5*	*4*	*4-20*	*20*	*>200*
Pearl millet	*Zn*	*44*	*ML*	*<20*	*40*	*40-100*	*100*	*>200*
Pea	*Zn*	*42*	*ML*	*<12*	*20*	*20-80*	*80*	*>300*
Cowpea	*Zn*	*32*	*LB*	*<20*	*45*	*250-150*	*150*	*-*
Black gram	*Zn*	*30*	*ML*	*<12*	*25*	*25-45*	*45*	*-*

Lentil	*Zn*	*55*	*ML*	*<6*	*10*	*10-50*	*50*	*-*
Sunflower	*Zn*	*73*	*L*	*<20*	*40*	*40-100*	*100*	*-*
Groundnut	*Zn*	*55*	*Ml*	*<10*	*15*	*15-60*	*>60*	*-*
Mustard	*B*	*52*	*YL*	*<10*	*25*	*25-70*	*>70*	*-*
Wheat	*B*	*70*	*YL*	*<4*	*35*	*35-60*	*>6*	*-*
Rice	*B*	*50*	*YL*	*<10*	*20*	*20-0*	*>50*	*-*
Pea	*B*	*72*	*YL*	*<3*	*10*	*10-50*	*>50*	*-*
Lentil	*B*	*29*	*L*	*<3*	*10*	*10-50*	*>50*	*-*
Mustard	*B*	*52*	*YL*	*<10*	*25*	*25-70*	*>70*	*>200*
Field bean	*B*	*52*	*L*	*<7*	*10*	*10-36*	*>36*	*>100*
Pigeonpea	*B*	*56*	*L*	*<20*	*40*	*40-200*	*200*	*>200*
Rice	*Mn*	*35*	*ML*	*<25*	*50*	*50-60*	*>60*	*-*
Wheat	*Mn*	*70*	*ML*	*<25*	*55*	*55-75*	*>75*	*-*
Pearl millet	*Mn*	*50*	*ML*	*<10*	*15*	*20-160*	*>160*	*>160*
Gram	*Mn*	*50*	*ML*	*<10*	*17*	*17-20*	*>20*	*-*
Pea	*Mn*	*65*	*Ml*	*<12*	*20*	*22-10*	*>100*	*-*
Lentil	*Mn*	*90*	*ML*	*<35*	*45*	*45-75*	*>75*	*-*
Green gram	*Mn*	*42*	*ML*	*<10*	*16*	*16-25*	*-*	
Mustard	*Mn*	*30*	*ML*	*<10*	*15*	*15-70*	*>70*	*-*
Sunflower	*Mn*	*43*	*Ml*	*<18*	*30*	*30-75*	*>75*	*>200*
Soybean	*Mn*	*54*	*Ml*	*<15*	*35*	*35-120*	*>120*	*-*

Source: Singh (1997) Compiled from annual reports of AICRP Micronutrients

The total Fe is not a good indicator of Fe deficiency and failed to predict the bioavailable iron and responses of crops that are likely to be achieved. Prediction of iron deficiency in plants remained so far a vital subject and active (Fe^{2+}) iron in plants has been shown to differentiate better the Fe-chlorotic plants from the non-chlorotic ones. Recently, Sakal and Singh (1995) established its critical value of active Fe 74 mg kg^{-1} in chick pea , 87 mg kg^{-1} in black gram and 45 mg kg^{-1} in 40-45 days old rice leaves to isolate deficient from sufficient plants. Some studies have shown that activityof ribonuclease or the carbonic anhydrase enzymes proved superior over tissue Zn concentration in predicting its deficiency in field crops. Toxicity of Fe and Mn is reported in rice plants when its concentration goes up 100 to 600 mg kg^{-1} and that of more than 650 mg kg^{-1} in soils.

Soil testing for micronutrient status : By the time micronutrient deficiency appears in growing plants a significant reduction in growth and yield is often noticed. So a reliable test is needed to determine micronutrient requirement of crops prior to planting of crops. Despite some demerits, soil testing is extensively employed to provide such information. Among various soil test methods and extractants evaluated for their suitability, chelating agents have been found relatively more successful in divergent soils. Among various extractants, the chelating agents DTPA (Diphenyl Triamine Penta Acetic Acid) (Lindsay and Norvell, 1978) for the estimation of plant available micronutrient cations, hot water for soluble boron and ammonium oxalate extraction for available Mo, are widely preferred in most of the laboratories. Uniformity in measurements is of paramount importance as extractability of micronutrients (Gupta *et al.,*1994) and precision in colour development during B estimation are temperature dependent (Saha and Singh, 1997), so proper temperature controlled facilities are very much required for reproducible results.

The critical levels of micronutrients determined so far by following Cate and Nelson graphical and statistical methods differ markedly from soil to soil for the same crop and vice versa. The values of Zn for rice ranged between 0.45 and 2.0 mg kg^{-1} in red and black soils, which are considerably higher than the range of 0.38 to 0.90 mg kg^{-1} in alluvial soils. Similarly, the value was relatively low (0.38 mg kg^{-1}) in alluvial soil as compared to 0.67 mg kg^{-1} in red and 1.3 mg kg^{-1} in black soils. Similarly, the value of Zn in calcareous alluvial soil for rice was 0.70 mg kg^{-1} as compared to 0.50 mg kg^{-1} in the non-calcareous soils for maize. In alluvial soils of Punjab the critical value of Mn for wheat was higher (3.0-3.5 mg kg^{-1}) as compared to 2.05 mg kg^{-1} for barley and 2.65 mg kg^{-1} soil for wheat in Ustipsamments/Ustifluvents of Ludhiana (Nayyar *et al.,* 1990).

Similarly, the value for active Fe^{2+} in alluvial soils for chickpea was nearly two times as much as for wheat and sorghum.Critical concentration of HWS-B 0.53 mg kg^{-1} soil was found critical for isolating B deficient calcareous soils for black gram (Sakal and Singh 1995).

In recent years, considering wide heterogeneity occurred in soil properties, soils showed high responses to micronutrient fertilization even in those soils, which are categorized to be high. So it appears that a single critical limit concept was not adequate. Single critical level also called for single fertilizer recommendation. So it created mistrust in the scientific recommendations most often among the farmers. Singh (2004) considering this introduced a multi range critical limits concept to establish critical range concentration for categorizing crops or soils into low, marginal and high nutrient status category by considering both available nutrient status in soil and response slope. The concept facilitated categorizing soils in different range based on actual nutrient concentration level and thus recommending graded dose of fertilizers more judiciously as per levels of soil fertility. The critical ranges of various micronutrients are given in Table 2.

Table 2. Critical levels of DTPA extractable Micronutrient for different soils

State	Soils	Low	Medium	Adequate
		DTPA- Zinc, mg kg^{-1} soil		
Gujarat	Alluvial	< 0.5	0.5-1.0	> 1.0
Gujarat	Swell-shrink black clay	< 0.7	0.7-1.2	> 1.2
Punjab	Alluvial	< 0.6	0.6-1.2	> 1.2
Haryana	Aridisols	< 0.6	0.6-1.2	> 1.2
Andhra Pradesh	Red & Black clayey	< 0.7	0.7-1.2	> 1.2
Madhya Pradesh	Alluvial	< 0.4	0.4-0.8	> 0.8
	Black clayey	< 0.6	0.6-1.2	> 1.2
Tamil Nadu	Red & black clayey	< 1.2	1.2-1.8	> 1.8
Bihar	Alluvial Calcareous	< 0.8	0.8-1.2	> 1.2
	Non Calcareous	< 0.8	0.8-1.2	> 1.2
Uttar Pradesh	Alluvial	< 0.6	0.6-1.2	> 1.2
	Foot hill submontanous	< 1.2	1.2-1.8	> 1.8

		DTPA-Cu, mg kg^{-1} soil		
All state		< 0.2	0.2-0.4	> 0.4
Madhya Pradesh	Alluvial	< 0.2	0.2-0.4	> 0.4
Tamil Nadu	Red & black	< 0.6	0.6-1.2	> 1.2
Bihar	Alluvial calcareous	< 0.5	0.5-1.0	> 1.0
Bihar	Submontaneous alluvial	< 0.5	0.5-1.0	> 1.0
		DTPA-Fe, mg kg^{-1} soil		
Bihar	Calcareous alluvial	< 7.0	7.0-12.0	>12.0
	Non cal. Alluvial	< 4.5	4.5 – 7.5	> 7.5
Gujarat	Alluvial, black clayey	< 5.0	5.0-10.0	>10.0
Tamil Nadu	Calcareous black clay	< 6.0	6.0-8.0	> 8.0
	Non Calcareous black	< 4.5	4.5-7.5	> 7.5
Uttar Pradesh	Alluvial	< 4.5	4.5-7.5	> 7.5
		DTPA-Mn, mg kg^{-1} soil		
Gujarat	Alluvial, black clayey	< 2.0	2.0-4.0	> 4.0
Haryana	Aridisols	< 3.0	3.0-5.0	> 5.0
Punjab	Alluvial loamy sand	< 3.0	3.0-5.0	> 5.0
	Alluvial sandy loam	< 2.0	2.0-4.0	> 4.0
		Hot water soluble B, mg/kg soil		
Bihar	Calcareous alluvial	< 0.25	0.25-0.50	> 0.5
Tamil Nadu	Red and lateritic	< 0.25	0.25-0.50	> 0.5

Source: Singh (2004) Compiled from annual reports of AICRP Micronutrients

Micronutrient Content In Indian Soils

Most of the Indian soils are adequate in total micronutrient cations content but have very less amounts in available pools, which are highly dependent on soil properties and environmental conditions (Singh 1988). Available (DTPA)- micronutrient Zn, Cu, Fe and Mn content in Indian Soils ranged from 0.2- 6.92, 0.2-8.22, 0.8-196 and 0.2-118 mg kg^{-1} soil, respectively. Available B, Mo and Co ranged from 0.8-2.6, 0.07-7.67 and 0.1-5.0 mgkg^{-1} soil, respectively (Sakal et al 1996). Relationship between soil properties and available micronutrients has worked out by several workers. The pH and $CaCO_3$ significantly decreased and organic matter and texture showed positive effects to predict the micronutrient disorders in soils and plants. Micronutrient content of several soil profiles showed a decreasing trend in subsurface layers but pattern of distribution was found inconsistent.(Singh and Abrol 1986).

Micronutrient fertilizer-use-efficiency for various crops is extremely low ranging from 0.5 to 5%, as a result of this only a small portion (1-5%) of micronutrients occurs in bioavailable forms such as exchangeable, complexed, organically bound and amorphous sesquioxide bound zinc fractions (Singh and Abrol 1986). Addition of organic matter increases the organically complexed Zn fraction but decreases hydroxide bound Zn under reduced conditions. Also a most of the applied zinc in soils accumulates in upper 0-10 cm surface layer and its movement to lower layers was negligible in alkaline cultivated soils. Studies on redistribution of the applied zinc to three rice - wheat rotation indicates that transformation of applied zinc increase significantly into amorphous sesquioxide bound Zn > complexed Zn > exchangeable Zn > crystalline sesquioxides bound Zn > residual mineral Zn fractions. The exchangeable and amorphous sesquioxides bound Zn contributed significantly more to Zn uptake by rice compared to other chemical forms (Singh and Abrol 1986).Most of the Fe and Mn in soils exist into water soluble, exchangeable, and easily reducible and mineral forms which remain in equilibrium. Water-soluble Fe accounts very low, but it is an important fraction for plant availability. It has been found 0.6, 7.4, 1.3 and 2.7% of total Zn and 1.4, 23.9, 6.5 and 3.1 % of total Mn in exchangeable, adsorbed, metal bound with organics and occluded forms in four agro-climatic zones of Punjab which is potentially available for growing plants depending upon soil conditions and management practices being adopted.

Micronutrient Deficiency in crops and soils

Among the micronutrient disorders, deficiency of Zn was found to be most widespread in Indian soils. Of the 2,52,000 surface soil and 25,600 plant samples collected from 20 states about 48.5 % soil and 44 % plant samples showed deficiency of zinc The deficiency of other micronutrient elements viz., Fe, Mn, Cu is in the order of 13, 4 and 2 %, respectively (Singh and Saha 1997, Singh 1998). State wise and agro ecological zone wise maps showing Zn, Cu and Mn deficiencies have been prepared for the benefit of various agencies (Fig.3,Map 1-2). Vertisols though have high clay content still show wide spread Zn and Fe deficiency due to their low organic matter content compared to Alfisol. Average percent Fe deficient samples may not reveal the real picture of its deficiency of 12-13% in soils and crops of the country. Its deficiency was found to be the largest 36% in shallow black soils of Karnataka, alluvium derived soils of Bihar followed by 20-27% in Seirozems of Haryana, 6-9% soils swell-shrink soils. Iron chlorosis in groundnut, safflower, sunflower and other crops is serious problem in calcareous soils of AEZ 2 of Saurashtra and Kutchh (Patel et al. 1999).Crops grown on calcareous soil of AEZ 14 showed significant responses to the foliar application of one per cent ferrous sulphate solution (Sakal *et al.,* 1996).

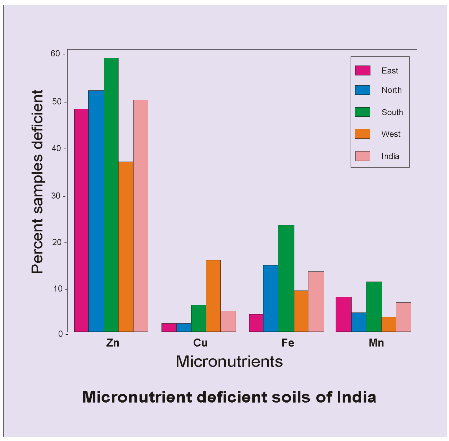
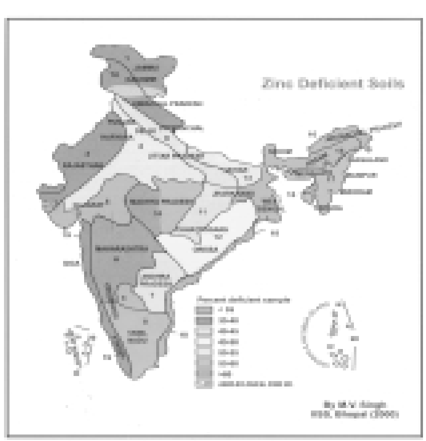
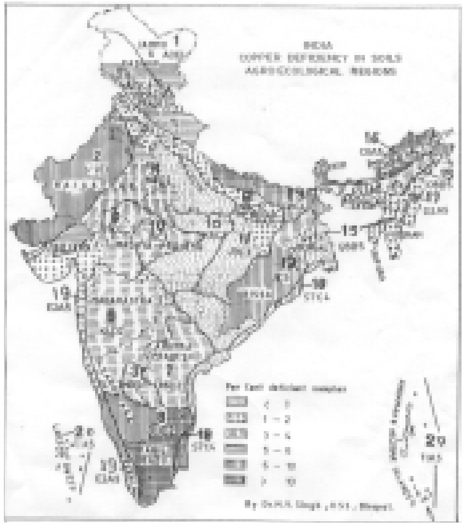


Fig.3 : Extent of Zinc deficiency in different regions of India



Map 1. Extent of zinc deficiency in different agroecological zones of India



Map 2. Extent of copper deficiency in soils of India

Most of the Indian soils are adequate in Cu except some soils of Kerala as compared to Zn, Mn and Fe (Patel and Singh 1995). Only 4% of Indian soils are tested to be deficient in Mn ; its deficiency has been reported wide spread in wheat where rice-wheat system has been followed during 7-8 years in sandy alkaline highly permeable soils of Punjab (Takkar and Nayyar, 1981, Singh and Subba Rao 1995). Deficiency of B ranged from 2-68% with an average of 33% in certain soil types of India (Singh 1998). In 53 benchmark soils , HWS-B content was in the order of Alfisols > Vertisols > Entisols = Inceptisols > Alfisols (Katyal 1982). By and large, boron deficiency is more critical in ensuring high productivity in alkaline calcareous soils, sandy leached soils, limed acid soils and red and yellow and in lateritic soils.

Much information on Mo Deficiency is not available. Its deficiency is not so common in Indian soils. Its deficiency occurs in red and lateritic acidic soils of north and north eastern Himalayan, regions, Santhal Pargna, Kokan and Malabar regions and in hill soils of Srikakulam, Vizag and Vijayanagar districts in Andhra Pradesh. Its deficiency is rarely reported in calcareous alkaline soils, arid and semiarid regions, rather some alkaline soils have excess Mo (Nayyar *et al.,* 1990). Survey of few soils revealed mean deficiency of Mo about 13% in the country. Impeded drainage in saline alkali soils of Kandi area of Punjab increases the availability of soil MoO_4. Forage and other crops grown in such water logged alkali soils accompanied by high organic matter content accumulates excessive Mo which induces Molybdenosis toxicity disease when such forages are fed to animals due to higher mobilization of Mo. Above 27 and 66 percent berseem forage from these soils have toxic and moderate concentration of Mo above 10 mg kg^{-1} (Nayyar *et al.,* 1990).

Frontier Technologies in mapping micronutrient deficiencies : Survey and reassessment indicating individual nutrient deficiency do not give realistic picture unless the deficiency of more than one element is assessed simultaneously in these soils.Till eighties deficiencies of single nutrient like Zn (43%), Fe (9%), Cu (5%) and Mn (4%) were found more predominant as compared to that of multi nutrients Zn+Fe (4%), Zn+ Cu (2.7%), Zn+Mn (1.9%) and Cu+Fe (1.2%) and only 0.2-5.0 per cent samples showed multi-micronutrient deficiencies out of 63575 soil samples data analyzed from six states (Singh,1991). Use of multi-micronutrients other than the desired one caused a significant reduction in wheat yield by 400 - 700 kg ha^{-1} and thus reduced net profit (Gupta *et al.*,1994). Thus, application of straight single micronutrient element fertilizer was found more beneficial in most of the soils.

Recently, soil maps generated from remote sensing data and GPS, instead of random sampling, are found more helpful in identifying reference point, homogeneous soil unit to decide sampling size and monitoring periodic changes in micronutrient status over a period of time .Sharma *et al.,* (2004) using remote sensing technique also found that multi micronutrient deficiencies covered only a small area in several districts of Punjab compared to single nutrient deficiency.

Since the efficient method of correction of Fe and Mn deficiencies is foliar sprays compared to soil application for Zn, B and Cu which further emphasizes the need for using straight fertilizers. So judicious use of multi-micronutrient mixture should be made in specific areas and specific crop where multi nutrient deficiencies are confirmed otherwise their use will not only add to high input cost but leads to less yield benefits and more degradation of soil environment.

Periodic assessment of micronutrient deficiencies in soils : Reassessment of soil micronutrient status revealed that consumption of micronutrient fertilizers at farmers' fields has increased with increasing awareness of micronutrient deficiencies and benefits that are likely to be accrued. The consumption of zinc sulphate, multi nutrient mixtures and liquid fertilizers has increased several folds in various states, thereby the deficiency of zinc has come down to the extent of 15-45 % in soils during past 15-20 years (Singh 1991, Singh and Saha1995).

Multinutrient deficiencies are emerging in alkaline sandy soils of Punjab with introduction of rice -wheat cropping system in areas traditionally under maize, groundnut-wheat sequence. Deficiency of Zn had declined while deficiencies of Fe and Mn have emerged from initial 2-4 % to 20-22 % in several soils (Singh and Saha, 1995) but same trend is not observed in areas of maize–wheat system. However, long term cropping of rice, maize and wheat leads to sign of fatigue and yield gets reduced drastically with a passage of 10-12 cropping cycles of maize-wheat-cowpea in Ustochrepts of Ludhiana and in rice-wheat-cowpea in Hapludolls of Pantnagar due to emerging deficiency of zinc, despite the fact that these soils initially contained adequate available Zn **(Table 3)** (Singh 1997, Singh 2004). Thus intensive cropping, use of high analysis NPK fertilizer generally free from micronutrients and lesser use of organic manures in several high potential areas in several high potential areas in several high potential areas caused greater depletion of soil available micronutrients. This accentuated deficiencies of multi micronutrients like Fe, Mn, B in plants which resulted in lower crop yields, therefore, nutrient indexing programme needs to be taken up on priority for forecasting emerging micro-nutrient deficiencies to sustain higher crop productivity.

Table 3 Mean response of rice and wheat to nutrient and FYM and impact of super imposition of S and Zn on sustainability of rice and wheat yield in Mollisol of Pantnagar (Mean of 2001-2004, 3 yrs)

Response to	*Grain response to added nutrients and FYM over control (t ha^{-1})*		*Effect of super imposition of S and Zn in 150% NPK treatment on grain yield sustainability,(t ha^{-1})*		
	Rice	*Wheat*		*Rice*	*Wheat*
N	*1.64*	*1.78*	*-S*	*3.64*	*3.45*
P	*0.46*	*0.32*	*+S*	*3.85*	*3.58*
K	*0.37*	*0.40*	*-S+Zn*	*4.27*	*3.80*
S	*0.29*	*0.23*	*+S+Zn*	*4.44*	*4.05*
Zn	*0.67*	*0.42*	*+S+Zn +FYM*	*4.78*	*4.45*
FYM	*0.86*	*0.71*			
CD at 5%	*-*	*-*	*CD at 5%*	*0.44*	*0.23*

Iron deficiency, also referred as iron chlorosis, is commonly occurred in more than one-third of the cropping area of India, spread over mostly in the low rainfall zones of the western (Punjab, Haryana, Gujarat, Maharashtra, Rajasthan, Andhra Pradesh and Kamataka) and central (Madhya Pradesh, Uttar Pradesh) parts of the country.

However, this deficiency is more prevalent in groundnut in Saurashtra, Marathwada and part of Rajasthan, Tamil Nadu and Karnataka, causing considerable reductions in yields.

Response of Crops to Micronutrients Application

Once the deficiencies of micronutrients are depicted by soil and plant analysis, its validation through field trials at On-research farm or experiments at cultivator's fields (ECF) is very important so as to confirm the occurrence of micronutrient deficiencies through biological response to applied micronutrients.A large number of ECF trials confirm wide incidences of zinc deficiency in Indian soils and use of zinc was found much more economical (Singh 1991, Sakal *et al.,* 1996). The magnitude of response, however, varied among the crops, varieties, degree of deficiency and crop management practices. Cereals show higher response than other crops (Singh 1991).

Of the large ECF trials conducted on divergent soils, a soil was classified as responsive to zinc fertilization at 5.5 kg Zn ha^{-1} if it produced more than 200 kg ha^{-1} or higher grain response over no zinc treatment. Accordingly, about 62% of the 5166 trials fell in the response range 200 to 1000 kg ha^{-1}.Strikingly 26 % experiments showed more than 500 kg ha^{-1} additional yield due to zinc fertilization and proved highly profitable **(Table 4).** Zinc deficiency assessed as 49% through soil analysis, 44% by plant analysis and 69% through actual biological response (Singh,1998).Overall 50% and 20% of Indian soils showed high and marginal response to zinc, which requires zinc fertilization in the package of practices to sustain higher crop productivity (Singh 1991,1998).

Table 4. Response of crops to zinc application in different states

Crops	*No. of expts.*	*Distribution of ECF expt. (Percentage)*			
		Response range (t/ha)			
		<0.2	*0.2-0.5*	*0.5-1.0*	*>1.0*
		Crop wise			
Wheat	*2391*	*43*	*35*	*16*	*6*
Rice	*2154*	*27*	*39*	*23*	*11*
Groundnut	*58*	*28*	*41*	*28*	*3*
Maize	*231*	*48*	*24*	*21*	*7*
Sorghum	*58*	*64*	*26*	*10*	-
Pearl millet	*180*	*63*	*34*	*2*	*1*
Finger millet	*33*	*73*	*24*	*3*	-
Gram	*03*	*34*	*33*	-	*33*
Cotton	*25*	*60*	*36*	*4*	-

Magnitude of crop responses and benefits from micronutrient application in 2358, 1399, 278 and 17 ECF trials on wheat, rice, maize and barley was 360, 540, 460 and 550 kg ha^{-1}, respectively. In 56 trials on pulses, the mean response ranged from 170-470 kg ha^{-1}. The benefit - cost ratio ranged from Rs.4.to 24 per rupee spent for zinc. In 82 % of the 49 ECF trials, groundnut yield increased by 200 kg ha^{-1}.In 21 frontline demonstrations on cultivators' fields conducted on chickpea, mustard, raya, groundnut and gobhi sarson on zinc deficient soils, the increase in seed yield to the application of 5-10 kg Zn ha^{-1} was 198-485, 425-500, 283-433, 965-1090, 224-395 kg ha^{-1}, respectively corresponding to 18 to 27.5 % and agronomic efficiency of 19-41 kg^{-1}kg zinc added besides its residual effect in soils to the following two to three crops (Singh, 1998)

Average response from soil and/or foliar application of Fe rice, wheat, maize, sorghum, finger millet, lentil, chickpea, soybean, black gram, groundnut, sunflower and sugarcane to soil and/or foliar application of Fe has been reported to be 1370, 890, 450, 570, 300, 410, 320, 350, 340, 160, 550, 6700 kg ha^{-1}, respectively. However, its deficiency in crops is one of the most difficult micro nutrient deficiencies to manage. Application of Mn in 11 ECF trials gave 300 kg ha^{-1} extra wheat yield in Haryana as compared to 500 kg ha^{-1} increase in 692 ECF trials in calcareous soils of Bihar. Nayyar *et al* ., (1996) reported increases in wheat yield by 0.2-2.9 t ha^{-1} with Mn fertilization in sandy soils of Punjab.

Boron deficiency ranged between 17 to 68 per cent. which is confirmed significant response to B added response of cereal, oilseeds, and pulses. Response of rice in 58 trials and of wheat in 36 trials in Bihar was 310 and 370 kg ha^{-1} with 1-2 kg B ha^{-1} (Sakal *et al.,* 1997). Responses of crops in calcareous soils of Bihar and Tamil Nadu to the application of 0.5 -2.0 kg ha^{-1} were 300-750 kg ha^{-1} (28 to 60%) over B unfertilized plots. In red loam soils of Tamil Nadu, Orissa and Andhra Pradesh groundnut showed 35 to 50 % higher yield while chick pea have 150 to 225 kg ha^{-1} to the application of 2 kg B ha^{-1} in coarse textured calcareous soils of Gujarat (Patel *et al.,* 1996).

Crop responses varied widely on different soils depending on Mo status of soils. Grain yield of Sonalika wheat increased by 3 per cent in sandy soils of West Bengal with the use of 0.5 kg Mo ha^{-1}. Response of 340 kg ha^{-1} of rice to Mo was recorded in alluvial sandy loam soil. Subba Rao and Adinarayana (1995) reported that average yield grain yield response of 130-880 kg ha^{-1} of rice and 20 to 680 kg ha^{-1} of wheat to Mo application. Application of 1.5 kg sodium molybdate increased the potato yield by 2.9 t ha^{-1} in black clayey soils, 2 t ha^{-1} potato hill soil, 1.3 ha^{-1} in red and lateritic soils and 1.2 t ha^{-1} in alluvial soils (Grewal and Trehan 1990).Response of green gram, black gram, chickpea, lentil on sandy loam soil, of groundnut in calcareous soils and of mustard on sandy loam to Mo have been recorded. Use of nitrogen fertilizers reduced the response of Mo in legume plants but it showed little effect on non legume plants

Amelioration of Micronutrient Deficiency In Soils And Crops

Several straight, chelated, mixture, blended, solid or liquid, single or multi micronutrient fertilizers have been approved under Fertilizer Control Order (FCO) by the Govt. of India for various states and crops **(Table - 5).**Since these are produced by small sector industries the data on exact quantity of micronutrient fertilizers produced is not available. Takkar *et al.,* (1996) based on sufficiency approach estimated micronutrient fertilizer requirement for Zn 324, Fe 130, Cu 11, B 39 and Mn 22 thousand tonnes by the year 2020.Element wise detail amelioration package is given below.

Table 5 Fertilizer materials approved in fertilizer control order (FCO) in India

Fertilizer materials	*Formula*	*Element/ Forms*	*Contents (%)*
Zinc sulphate heptahydrate	$ZnSO_4.\ 7\ H_2O$	*Zn*	*21.0*
Zinc sulphate monohydrate	$ZnSO_4.\ H_2O$	*Zn*	*33.0*
Manganese sulphate	$MnSO_4.\ 4\ H_2O$	*Mn*	*30.5*
Sodium Molybdate	$Na_2MoO_4.2H_2O$	*Mo*	*22.5*
Ammonium molybdate	$NH_4MoO_{23}.4H_2$	*Mo*	*52.0*
Borax	$Na_2B_4O_7.10\ H_2$	*B*	*10.5*
Solubor	$Na_2B_{10}O_{16}.10H$	*B*	*19.0*
Copper sulphate	$CuSO_4.\ 5H_2O$	*Cu*	*24.0*
Ferrous sulphate	$FeSO_4.7H_2O$	$Fe^{2+} + Fe^{3+}$	*19.5+0.5*
Chelated zinc	*Zn- EDTA*	*Zn*	*12.0*
Chelated iron	*Fe- EDTA*	*Fe*	*12.0*
Zincated urea	*Zn + urea*	*Zn + N*	*2 + 43*
Zincated super phosphate	*Zinc+super*	$Zn + P_2O_5$	*2 + 16*
Teprosyn	*Teprosyn- Zn*	*Zn*	*60*
Granubor (under consideration)	$Na_2B_4O_7.5\ H_2O$	*B*	*14.6*

Zinc

Sources of zinc : Several forms of Zn available in the country have been evaluated for their relative efficiency and effectiveness for correcting their deficiencies in crops or cropping systems. Among various chemical sources, zinc sulphate hepta hydrate ($ZnSO_47H_2O$

referred here as $ZnSO_4$) containing 21-22 % Zn is the major source of Zn in India and has proved most effective as compared to other Zn sources in correcting Zn deficiency in most of the crops diverse soils (Singh and Saha, 1995, Sakal et al 1996). Although Zn-EDTA was found at par to zinc sulphate in calcareous soils of Pusa and Sierozem soil of Hisar but it was found better than zinc sulphate in combating Zn deficiency in rice in loamy sand soils of Punjab (Nayyar et al. 1990). However, its high cost than zinc sulphate made it more uneconomical. The efficiency of sparingly soluble Zn sources such as ZnO, $ZnCO_3$, zinc fritts in high Zn fixing fine textured soils was at par to highly soluble $ZnSO_4.7H_2O$, however, when sparingly soluble and soluble zinc sources were compared in coarse textured soils, it was soluble zinc sources which gave best performance. Thus, zinc sulphate was found the cheapest and one of the efficient source **(Fi g. 4)**

Fig. 4 Correction of zinc deficiency in crops

Micro-macro nutrients blended sources such zinc super and zincated urea was found inferior to zinc sulphate or zinc chelates as they mismatched zinc requirements with the various nutritional requirement of the crop.

Rate of application: Amount of zinc required for alleviating zinc deficiency varied with severity of its deficiency and/or soil type. Data of larger number of field experiments have indicated that in majority of instances Zn deficiency can best be alleviated with application of 11 kg Zn ha^{-1} to wheat and rice; 5.5 kg Zn ha^{-1} to maize, soybean, cotton, pea, sunflower and sugarcane and 2.5 kg Zn ha^{-1} to groundnut, raya, mustard, pigeon pea green gram. chickpea, and ragi. Also the rate of Zn application varied with crop cultivars (Singh and Saha 1995).

In red and yellow soils of Madhya Pradesh, the response of wheat to Zn was obtained up to 5.5 kg ha^{-1} and this on alluvial and black soils of Madhya Pradesh is 11 kg ha^{-1} (Rathore *et al.,* 1995). Double the rate is required for less soluble Zn sources compared to rate of soluble $ZnSO_4$ (Nayyar *et al.,* 1990). In highly calcareous soils of Bihar, application of 10 kg Zn ha^{-1} to first rice crop was enough to succeeding four to five crops for enhancing and sustaining productivity of rice-wheat system (Sakal *et al.,* 1997). The amount of Zn required for crops is double in coarse textured loamy sand soil than in fine textured loam soil of Punjab for wheat (Takkar *et al.,* 1989).

Micronutrient management in problematic soils requires special attention. Crops grown in sodic or calcareous alkaline soils generally show deficiency of Zn or multi-nutrients and thus high responses to zinc fertilization. Besides micronutrients these soils requires a special package of practices (Singh *et al.,* 1987). Higher yields of rice- wheat, berseem, sorghum, mustard and other crops in alkali soils can't be achieved unless the toxicity of Na / deficiency Ca and Zn is corrected simultaneously (Singh and Abrol, 1985). Singh *et al.* (1986) reported that fertilizer zinc requirement of rice, wheat, maize and other crops during reclamation of alkali soils can be substantially reduced by 25-75% if adequate amount of soil amendments are added or level of sodicity is reduced**.** Singh (1988) reported that efficiency of Zn was greater to rice -wheat system when all inputs like Zn, gypsum as well as NPK were applied in optimum and balanced amount compared to unbalanced use of either of the component during reclamation of alkali soils**.**

Time of zinc application : Time of Zn fertilizer application is mainly influenced by zinc content of seed, zinc requirement of crop and severity of zinc deficiency as maximum zinc absorption by plants takes place upto tillering stage, therefore best time of zinc application in field crops is prior to seeding or transplanting. Wheat yield was lower when Zn was top dressed than its basal application (Gupta *et al.,* 1994). Application of zinc in split half at basal and half at tillering stage was found equally effective to full basal application but was superior to top dressing of half at tillering and remaining half at penical stage (Sakal *et al.,* 1997). Thus, basal application of zinc is best but if it is missed, zinc deficiency can be corrected by top dressing of zinc upto 45 days and/or 2-3 foliar sprays of 0.5% zinc sulphate neutralized with lime 25 g L^{-1} with little less yield benefits. In horticultural and plantation crops the foliar feeding of zinc generally excelled to the soil application.

Method of zinc application: Soil application of Zn through broadcast and mixed or its band placement below the seed proved superior to top dressing, side dressing or band placement as well as foliar application of 0.5 to 2.0% $ZnSO_4 7H_2O$ solution. Zinc applied through soaking or coating of seeds in Zn slurry or before transplanting or Zn enrichment seedling resulted in delayed cure of Zn deficiency (Sakal *et al.,* 1997). Dipping of rice seedlings in 2-4% ZnO before transplanting proved equally effective as broadcast application of 11 kg ha^{-1} Zn as $ZnSO_4$ in combating Zn deficiency but root dipping and foliar methods of Zn fertilization in crops could not catch up with the farmers because of certain limitations. Dipping of vegetable seedlings in ZnO suspension (Iyengar and Raja, 1988) and sugarcane sets could not meet its full Zn requirement. However, soaking of sugarcane sets or soaking treatment to potato with $ZnSO_4$ solution proved equally effective as that of foliar sprays or soil application of Zn (Grewal and Trehan, 1979).

Fertilizer zinc management in cropping systems

Zinc leaves marked residual effect and therefore it is not necessary to apply Zn to every crop in the cropping system. In Fatehpur sandy loam alkaline alluvial soil of Punjab, it was found that for first four crops 5.5 kg Zn ha^{-1} and for the next 8 and 12 crops after the repeat application respectively of 2.75 and 5.5 kg Zn ha^{-1} gave the largest response. Under brackish water irrigation in a highly sodic soil (pH 10.4) amended with gypsum @ 50% of the gypsum requirement (GR) the residual effect of 22 kg Zn ha^{-1} could last for four crops of rice- wheat sequence and the fifth crop required repeat application of Zn. In contrast, in an alkali soil (pH 10.45), addition of optimum of zinc and gypsum is necessary **(Table 6)** (Singh *et al .,* 1987).In alkali soil and irrigated with normal water, the yield with continuous application of 2.25 kg Zn ha^{-1} was not different from a single initial application of 18 kg Zn ha^{-1} after the seventh crop, suggesting that its effectiveness had not diminished (Singh and Abrol,1985b). Use of zinc enriched organic manures reduced the zinc requirement of rice in sodic soils.Thus, the use of brackish water or level of sodicity appears to have shortened the residual effectiveness of Zn as compared with the use of normal water irrigation.

Table 6. Rice yield as influenced by gypsum and zinc levels in highly sodic soils

Zinc sulphate added, kg ha^{-1}	*Rice grain yield , t ha^{-1} Gypsum levels added, t ha^{-1}*				
	0	***2.5***	***5***	***10***	***Mean***
0	*0.13*	*0.98*	*2.14*	*2.65*	*1.48*
10	*0.49*	*1.67*	*3.06*	*3.77*	*2.25*
20	*0.58*	*2.00*	*3.14*	*3.85*	*2.39*
30	*0.68*	*1.75*	*2.99*	*3.92*	*2.34*
40	*1.05*	*2.02*	*3.29*	*3.89*	*2.58*
Mean	*0.59*	*1.68*	*2.93*	*3.62*	*-*

LSD (P=0.05) Gypsum=0.36, Zinc=0.28,

Gypsum x zinc = NS Source: Singh et al (1987)

Studies to evaluate the optimum rate and frequency of zinc application to rice- wheat systems revealed that application of 5.5 kg Zn ha^{-1} to every third crop as rice in Ustochrepts of Karnal, Haryana, 10 kg Zn ha^{-1} to every 5th crop in Calciorthents of Pusa, Bihar and application of 11 kg Zn ha^{-1} after six crops in Typic Ustrochrepts of Ludhiana, Punjab were found sufficient and gave maximum response of the system (Singh 2004). Application of 11 kg Zn ha^{-1} to first rice followed by 5.5 kg Zn ha^{-1} to every 5th successive crops gave maximum yield in rice-rice system in light textured black soils of Hyderabad. Field studies on rice-groundnut sequence at Coimbatore revealed that application of 5 kg Zn ha^{-1} with coconut coir pith or FYM at the rate of 1 t ha^{-1} enhanced the productivity of cropping system.

Application of 10 kg Zn ha^{-1} to alternate cotton crop gave the highest yield in zinc deficient arid soils of Haryana. In Punjab, application of 2.8, 5.6 and 11.2 kg Zn ha^{-1} only to Ist cotton crop was sufficient for 2, 4 and 6 crops, respectively for cotton- wheat rotation in loamy sand. Application of 5.6 kg Zn ha^{-1} once to first green gram was found optimum to meet the Zn requirement of three cycles of green gram-wheat rotation in sandy loam (Ustochrepts) of Punjab.Grain sorghum-cotton sequence in BhavaniSagar Project of Tamil Nadu gave significantly higher yield on application of 7.5 kg Zn ha^{-1} to every sorghum or 5 kg Zn ha^{-1} to sorghum plus 2.5 kg Zn ha^{-1} to the following cotton. In medium black soils an application of 15 kg Zn ha^{-1} to first soybean crop only left significant residual effect for enhancing the optimum productivity of three soybean-wheat sequence with a benefit - cost ratio of Rs.13.9 per rupee spent on zinc (Savithri *et al.,* 1996).

Use of organic manure enhance the availability of native and applied zinc through their direct contribution and chelation properties rendering more zinc available to the growing plants. Singh (1994) found that fertilizer Zn requirement of soybean-wheat sequence was met by use 8-16 t ha^{-1} FYM or 6-12 kg Zn ha^{-1} or application 4 t ha^{-1} FYM with 3 kg Zn ha^{-1} in zinc deficient swell-shrink soils (Typic Haplustert) of Madhya Pradesh **(Table 7)** The residual effect of FYM in increasing yield was more compared to overall effect of Zn added to soybean-wheat system. The residual effect of FYM in increasing yield was more compared to overall effect of Zn added to soybean-wheat system. Organic manures 12 t ha^{-1} FYM, 5 t ha^{-1} poultry manure and 2.5 t ha^{-1} of piggery manure were as efficient as 11.2 kg Zn ha^{-1} in meeting the Zn requirements of maize-wheat rotation. Also half or even less rates of these manures proved equally efficient or better when amended with 5.6 kg Zn ha^{-1} for maize-wheat rotation.(Nayyar *et al.*,1990).

Table 7 Integrated effect of FYM and zinc application on seed yield response of soybean over control in medium clayey swell- shrink soils of Bhopal

FYM added t ha^{-1}	*Rate of Zn applied, kg ha^{-1}*				
	0	*3*	*6*	*12*	*Mean*
0	*-*	*63*	*134*	*330*	*132*
4	*206*	*295*	*473*	*598*	*393*
8	*277*	*527*	*651*	*732*	*547*
16	*545*	*868*	*813*	*840*	*766*
Mean	*257*	*438*	*518*	*625*	*-*

CDat5% FYM=0.98, Zn=0.77, FYM x Zn=0.55,

Control Yield =1348 kgha^{-1}, Source: Singh (1994, 1998)

In sodic soil (Vertic Natrustalfs) of Tamil Nadu, maximum yield of rice-cowpea, Zn uptake and highest fertilizer use efficiency (FUE) were achieved when gypsum @ 50%, and dhaincha @ 5 t ha^{-1} were added along with 5.5 kg Zn ha^{-1}. Enrichment of organic matter with inorganic Zn improved the utilization efficiency of fertilizer Zn towards increasing yield of cropping system. In calcareous soils of Bihar, incubation of 2.5 t ha^{-1} of biogas slurry with 2.5 kg Zn ha^{-1} added to rice improved FUE of Zn for rice-wheat system.

Cultivation of Zn-efficient genotypes: Fitting the plants to soil rather than ameliorating the soil with chemical fertilizers to support plants without reduction in yield. In general, susceptibility of the crops and their cultivars to zinc stress is related to their yielding capability. Singh (2004) reported that high yielding short duration varieties are more susceptible to Zn stress compared to long duration low to moderate yielders **(Table 8).**Relative susceptibility of wheat cultivars to Zn stress was in the order to UP-262 = K-8804 > HP-1102 > RW-346 > DL-784-3 > HUW-206 > K-7410 > HP-1633 > Sonalika. So a careful decision is required to select efficient genotypes those are high yielder and less susceptible to micronutrient stress (Singh 2004).

Table 8. Genetic tolerance of mustard genotypes to zinc stress in sandy loam soil

Tolerance category to Zn stress	***Grain yield, kg ha^{-1}***				
	< 1200	***1200-1500***	***1500-2000***	***2000-2500***	***>2500***
Highly zinc Susceptible (> 35% response)			*NDR 389 CS 52 RH 781*	*RH 8113 RLC 9 62 PR 8903, PBM 16*	*DLM 29, DLM 198, RH 785 RLC 949*
Susceptible to Zn stress (25-35% response)		*Kranti TM 31*	*Varuna*	*RH 30 RLM 619, RLM 714*	
Mod.Tolerant (15-25%)			*Rohini RL 1359*		*Pusa-Basant*
Tolerant to Zn stress (5-15%)	*ISN 129*		*PCR 4 Vaibhav*		
Very tolerant to Zn stress (< 05%)		*Vardan PK-8052 RH 8559*	*DLM 23 THM 9012*	*RSM 58*	

Source: Singh (2004)

Iron

Iron deficiency is commonly observed in upland crops like rice, sorghum, sugarcane, maize, groundnut, chickpea and horticultural crops grown in coarse textured uplands, soils low in organic matter, calcareous and alkaline soils world-wide. Most often, iron chlorosis is confused with sulphur and nitrogen deficiency. Chlorosis also resembles to pailing due to multinutrient deficiencies and poor aeration. Matching of visual chlorosis and elemental analysis indicated that more than 60-70% of the chlorotic rabi-summer groundnut plants suffered with interveinal iron cholorosis and rest 25-30% plants showed S-deficiency induced chlorosis. In contrast a reverse trend was observed in rainy season crop(Singh*et al.,* 2004).

Sources of iron: A number of inorganic and other sources have been tested to combat iron chlorosis in plants. Ferrous sulphate, (19-20.5% Fe), ferrous ammonium sulphate (18-22% Fe), Fe-EDTA (9-12% Fe), Fe-EDDHA (10.0% Fe), pyrites (10-22% Fe), biotite, and organic manures (FYM 0.15% Fe), poultry and piggery manure (0.16% Fe), sewage sludge have been used as sources of Fe to correct its deficiency in crops. Since, iron applied to soil through inorganic Fe carriers is susceptible to transformation into unavailable forms, therefore, iron chlorosis in crops is one of the most difficult micronutrients problems to manage. Most often ferrous sulphate, Fe-EDTA and FYM are most commonly used sources in India.

Rates of iron application: The rates of Fe for soil application were found very high (50-150 kg ha^{-1} $FeSO_4.7H_2O$) compared to foliar sprays and soil application therefore were found uneconomical **(Fig 5).** Applications of 5-10 kg ha^{-1} chelates are efficient. But their high cost of chelates as Fe carriers discourages the farmers to use these. Nayyar et al (1990) reported that foliar sprays of unneutralized solution of 0.5-1% ferrous sulphate at 7-10 interval proved quite efficient in correcting iron chlorosis in standing crops. Application of 10-20 kg Fe ha^{-1} either ferrous sulphate or 10 kg Fe ha^{-1} FeEDDHA through broadcast and mixing in topsoil as basal dose is effective. However, in standing crops, foliar spray of 0.5% $FeS0_4$ + 0.02% citric acid aqueous solution of 500-1000 L ha^{-1} at 10-15 days intervals alleviate iron-chlorosis efficiently and economically

Fig. 5 Correction of iron deficiency in crops

Method of iron application: Among various sources, soil application of pyrite and biotite proved inferior to ferrous sulphate in increasing rice yield and Fe uptake in Vertisols (Deore *et al.,* 1994). Fe-EDTA or $FeSO_4$ were equally effective in increasing rice yield when seeds of groundnut and other crops were coated with 2% solution/slurry (Ingle and Sonar, 1982).

Foliar sprays of 0.5-1.0% $FeSO_4$ unneutralized solution of water soluble iron containing salts or 0.1-0.2% iron chelates (FeEDTA) are found more efficient than soil application in correcting Fe-chlorosis in crops. The available iron sources are ferrous sulphate, ferrous ammonium sulphate, ferric citrate, and FeEDTA which can be used for foliar sprays. Iron chelates are more efficient but their use is uncommon due to high cost and nonavailability. Efficiency of ferrous sulphate improves when applied as aqueous solution containing 0.5% iron sulphate with 0.01 % citric acid which increased the groundnut yield by 16-24%. Number of sprays depends upon severity of and growth stage of chlorosis. Generally 2-4 sprays are required preferably in humid weather condition or evening to ameliorate iron chlorosis.

Correction of Iron Deficiency Using Organic Manure: Generally, Fe chlorosis in rice is encountered in upland soils or highly permeable coarse textured soils because of less mobilization of Fe^{2+} as the desired degree of reduction does not occur. The puddling and/or maturing of such soils markedly reduces the extent of Fe-chlorosis in rice. In a three years field experiment on an alkaline Fe-deficient Fatehpur loamy sand, combination of green manure (GM) and the foliar spray of 1% $FeSO_4$ solution produced the largest rice grain yield followed by GM or foliar sprays. Green maturing helped in mobilization of native soil iron into plant available forms during its decomposition (Nayyar *et al.,* 1990).

Other management Options to Iron deficiency: Iron chlorosis generally appears 15 days after emergence of seedlings and continues to occur on the young developing leaves throughout the crop growth period, however, its maximum intensity in the field is noticed during 45-75 days after seeding, the peak vegetative growth period. Increase in soil moisture brings favourable soil environment to transform more Fe in available forms, so, there is automatic recovery of chlorosis with crop growth, but under adverse conditions the newly emerging leaves continue to show severe chlorosis which led to death of leaves and causing even crop failure. The Crops grown in arid conditions or rabi-summer seasons suffer three times more with iron chlorosis compared to kharif or rainy season crops due inadequate soil moisture leading to low soil available iron.

Continuous cropping of oilseed-oilseed or oilseed–pulse based sequence leads to higher multi nutrients deficiencies in both seasons crops as compared to cereal-oilseeds or cereal-legume based sequence. Intercropping of groundnut and maize enhances Fe acquisition compared to monoculture cropping which is mainly attributed to rhizospheric interactions in rhizobox. Since oilseeds are energy rich crops and have high nutrients requirements Iron chlorosis is frequently observed in crops like oilseeds, soybean, groundnut, chickpea, sugarcane. Therefore adoption of proper crop rotation and inter cropping should be practiced to reduce incidences of iron cholorosis in standing crops.

Also balanced fertilization practices reduce pailing of leaves and occurrence of iron chlorosis. Chlorosis occurred in less than 10% plants did not affect the yield much but above this chlorosis level caused significant yield losses 20-41%. Iron chlorosis during 30-70 days after sowing has been identified as the critical period causing maximum yield losses in groundnut. Similarly, efficiency of iron sulphate at 3 kg Fe ha^{-1} applied through fertigation (drip irrigation) in groundnut increased the pod yield of groundnut by 31-36 % over control as compared to 11-21 and 25% with soil and foliar applications, respectively besides improving shelling out-turn, seed mass and kernel boldness and nutrient use efficiency.

Inoculation of nodulating groundnuts with *Bradyrhizobium* strain NC43 and *Pseudomonas* improves iron nutrition by synthesis of chelates (siderophores) that keep iron in soluble form thereby enhanced dry matter and pod yield and ophenanthroline extractable Fe and N contents of the plants.

Cultivation of Fe-efficient genotypes: Fitting the plants to problematic situation is the best way to achieve higher economic benefit rather than adopting costly corrective methods such as application of chemical fertilizers, spraying or through drip irrigation. This helps to cultivate genotypes directly in the targeted areas. Susceptibility of groundnut to iron chlorosis is found very sensitive to genetic control, mainly attributed to rooting behavior and thereby, high efficiency of iron absorption from the soil. Fe-efficient (iron-chlorosis tolerant) genotypes showed 2-3 times more active iron (Ferrous) content, higher uptake of all the nutrients, except Ca, than the Fe-inefficient ones. Spreading groundnut varieties (GAU6-10, Punjab-1, G 6-11) were more tolerant to Fe chlorosis than MH-1, MH-2, GG-2, JL24, PKV68 erect type Spanish and bunching type Valencia genotypes Tolerant varieties are able to mine native iron more effectively by producing certain organic acids called reductants in the rhizosphere leading to low response to soil added iron.On the other hand, showed yellowish canopy most of the time and found more prone to iron-chlorosis. Over all, Fe-efficient as well as high yielding erect Spanish genotypes FeESG-8, FeESG 10-1, FeESG 10-3, and FeESG 10-2 and bunch type FeEVG-17 of Valencia group out yielded over susceptible GG 2, JL 24, SB XI genotypes.

Relative tolerance of sorghum cultivars to Fe stress was in the order of CO-26 > TNS-30 > CO-23 > CSC-541 > TNS-294 > CO-24 > SPV-881 while genotypes SPV-881, CO-4 and TNS-31-1 were found to be highly susceptible. Sorghum cultivar 59-3 was found to be least responsive to Fe and could be successfully grown on Fe deficient soils where other cultivars SL 44, JS 20, and JS 263 failed to produce comparable yield without Fe application. Fe-inefficient genotypes responded to higher rates or requires more number of sprays than the Fe-efficient genotypes having good yield potential. Hence, tolerant cultivars are useful for recommending their cultivation in area prone to iron-chlorosis for high profitability

Manganese

Manganese deficiency occurs sporadic and is not a major problem as indicated by soils and plant analysis. But its deficiency in wheat has emerged and is on the increase since 1979 in Punjab as a result of the adoption of intensive cultivation of rice-wheat system in place of maize-wheat or groundnut-wheat system for a period of 7-10 years on highly permeable coarse-textured alkaline soils (Takkar and Nayyar, 1981).

Sources of manganese : Application of manganese sulphate proved 1.5 and 10 times more efficient than Mn-frits and MnO_2 in increasing grain yield of wheat (Nayyar *et al.,* 1990).

Rate of Manganese application : Soil application of 20-50 kg Mn ha^{-1} is generally recommended to correct the Mn deficiency.Three foliar sprays of 0.5-1.0% manganese sulphate solution about 500 L ha^{-1} for each spray on standing crop requires 7.5-15 kg Mn ha^{-1}. Reversion of soil applied Mn to higher oxide in alkaline soils requires higher rate of Mn application which causes low efficiency than foliar sprays.

Method of manganese application: Both soil and foliar application of Mn caused significant and marked increase in the production of wheat, but the rates of soil applied Mn (40-50 kg ha^{-1}) are uneconomical as compared to 3-4 foliar applications of 0.5-1.0% $MnSO_4$ solution (7.5-15 kg Mn ha^{-1}), initiated before the first irrigation. Soybean gave a significantly higher response of 0.29 to 0.55 t ha^{-1} to foliar application of Mn on three Mn-deficient fields over the yield (1.44-1.81 t ha^{-1}) obtained in Mn control treatment (Nayyar et al. 1995). Also foliar sprays of 0.5% $MnSO_4$ solution produced 1.23 times more wheat grain yield than that of other materials (Sadana et al., 1989). Soaking of potato tubers in 0.05% $MnSO_4$ H_2O aqueous solution for three hours was 2.7 times more efficient than soil application of 20 kg ha^{-1} of $MnSO_4$ and 11% more efficient than two foliar sprays of 0.2% $MnSO_4$ in increasing the tuber yield.

Cultivation of Mn-efficient genotypes: Fitting the plants to problematic situation is the best way to achieve higher economic benefit rather than adopting costly corrective methods such as application of chemical fertilizers, spraying or through drip irrigation

(Fig 6). This helps to cultivate genotypes directly in the targeted areas. Susceptibility of groundnut to iron chlorosis is found very sensitive to genetic control, mainly attributed to rooting behavior and thereby, high efficiency of iron absorption from the soil. Fodder crops susceptibility to Mn stress was Oat > lentil > Lucerne > gobhi sarson > senji > maize fodder crops to the order of berseem > shaftal = metha.

Fig. 6 Tolerance of wheat cultivars to Mn deficiency

A large number of wheat cultivars have been screened in a Mn-deficient loamy sandy soil of Ludhiana for their tolerance to Mn stress and were rated into various categories of tolerance (Nayyar *et al.,* 1990). The magnitude of response to Mn application decreased successively as the rating of the tolerance increased. There was no significant responses in the most tolerant categories. The tolerant cultivar HD 2329, HD 2270, HD 2429, PBW 159, WH 427, HD4594, PBW 151, Raj 3038, WH 416,,HD 2204, HD 2329, Raj 2535 HD 2270, HD 2429, PBW 159, WH 427, HD4594, PBW 151, Raj 3038, WH 416 need only one foliar spray (1.6 kg Mn ha^{-1}) as compared to 2 to 3 sprays (3.2-4.8 kg Mn $ha-^{1}$) to moderate or least tolerant cultivars. HD 2204, HD 2329, Raj 2535The cultivar HD 2329 is widely cultivated by the farmers on the Mn-deficient soils of Punjab, because of high tolerance to Mn stress compared to PBW343, HD 2285 and C 306. Sonalika and WL 2265 genotypes were categorized moderately tolerant and gave similar yield but these need 1-2 sprays compared to HD 2329. Durum wheat genotypes are more susceptible to Mn deficiency compared to aestivum type wheat genotypes (Nayyar *et al.,* 1996, Singh 1998 Kaur and Takkar 1984).

Boron

Spectacular responses of cereals, pulses, oilseeds and cash crops to B application (0.5-2.5 kg ha^{-1}) have largely observed on B different soils of Bihar, Orissa, West Bengal, Assam and Punjab (Sakal and Singh 1995, Sakal *et al.,* 1997)

Sources of boron : In India, two sources of boron viz. borax deca hydrate ($Na_2B_4O_7 10H_2O$,11% B) and solubor ($Na_2B_4O_7.5H_2O$+ $Na_2B_{10}O_{16}$ $10H_2O$, 20% B) are approved as fertilizer sources of B for agricultural use (Table 2). Boron fertilizers are applied to soil or sprayed on foliage on standing crops. Boric acid (H_3BO_3, 17%B) and borax penta hydrate granular ($Na_2B_4O_7 5H_2O$, 14.6%B) are also found efficient for correcting boron deficiencies in crop plants.

Rate of boron application : Amount of boron required for achieving optimum yield varied with nature of crop, season, type of soil. Sakal *et al.,* (1996) reported that mustard, maize, sunflower, onion and lentil gave optimum yields at 1.5 kg ha^{-1} of B application and that of kharif (rainy) crops like rice, groundnut, maize, yam bean and black gram produced the best yield at 2.0-2.5 kg B ha^{-1} rate. In B deficient sandy loam calcareous soils of Bihar the optimum rates for chickpea and winter maize was found to be 2.08 and 1.68 kg B ha^{-1}, respectively **(Fig 7).**

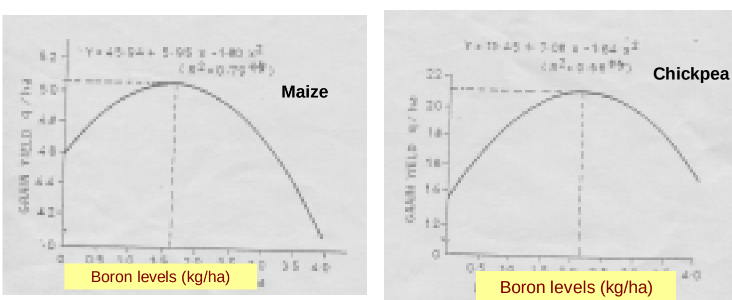


Fig. 7 Effect of boron levels on grain yield of maize and chickpea in calcareous soils

Boron leaves residual effect to the following crops. In a sesamum-chickpea and maize-mustard cropping systems on calcareous soil, 1.5 kg boron ha^{-1} applied to every third crop sustained the best yield of the cropping system **(Table 9).**Total grain response in 3 cropping cycles received was 1.39-3.38 t ha^{-1} for rice-wheat sequence and 0.77 to 2.73 t ha^{-1} for maize-mustard sequence with B:C of Rs.9.43 to 12.86: Re.1.00 (Sakal *et al.,*1996).

Table. 9 : Responses of boron to different crop rotations in calcareous soils

B rates Kg/ha and B use frequency	Total B Added kg ha^{-1}	Rice – wheat (3+3= 6 crops)		Maize – mustard (3+3 = 6 crops)		Sesame - chickpea (3 + 2 = 5 crops)	
		Response kg ha^{-1} in 6 crop	Kg grain kg^{-1} B added	Response kg seed ha^{-1} in 6 crop	Kg seed kg^{-1} B added	Response kg seed ha^{-1} in f5 crops	Kg grain kg^{-1} B added
0.8 C	4.8	3380	704	2650	553	487	122
1.6 A	4.8	4130	860	2700	563	719	180
1.6 C	9.6	2540	265	2530	264	904	94
3.2 C	19.2	2850	891	2910	152	601	38
F.S. 2	1.5	1330	887	1520	1013	555	462

Rate kg^{-1}:Rice, Rs.4.0; Maize Rs.4.50; Wheat Rs.5.50; Mustard Rs.12; Chickpea Rs10, Sesame Rs.20. *Source: Singh (2004)*

Method of boron application: Boron is generally broadcast and mixed prior to sowing of crops or before transplanting. Band placement of 0.5-2.0 kg B ha^{-1} resulted in higher B concentration in cauliflower crops than broadcasting. But band placement leads to some times toxicity in plants when application rate exceeds or improper placement is done. Boron should neither be placed in contact with seed nor should higher rate be used because of potential B toxicity problems. Soil application of 2.0 kg Bha^{-1} was superior to foliar spray (0.2% borax solution) twice or tuber soaking in increasing the potato tuber yield on acid soil (Inceptisol) of Garhwal (Dwivedi and Dwivedi,1992). By and large, soil application of B is a better method of fertilization than foliar and seed soaking. Foliar sprays of 0.25% H_3BO_3 solution in 600L ha^{-1} water twice on standing crops was found inferior than soil application of 0.8-1.6 kg B ha^{-1} in these soils. Regular use of B greater than those recommended rates leads to B toxicity in plants.

Cultivation of boron tolerant genotypes: Cultivar RT-54 and OMT-11-63 of sesame and Pusa bold, RH-30 of mustard genotypes were found tolerant to B stress in calcareous soils (Sakal et al 1996). Thus, tolerant cultivars are recommended in boron deficient for high profitability.

Copper

The deficiency of Cu is found sporadic and response of crops to Cu fertilization has been assessed only at few locations.

Sources of Copper: Copper sulphate ($CuSO_4.5H_2O$, 25% Cu) is a most common, cheap and easily available source of Cu employed for correcting Cu deficiencies in field crops in India. Besides copper sulphate ($CuSO_4.H_2O$, 35% Cu) and cupric oxide (CuO, 75% Cu), use of organic manure or some Cu containing fungicides, Cu chelates (Cu EDTA, 12%Cu) are also used as Cu carriers. Indiscriminate use of Cu containing fungicides like Bordeaux mixture on foliage meets the Cu requirement of crops.

Rates of copper application: Sakal *et al.* (1996) recorded application of 5.0 kg Cu ha^{-1} significantly increased the mean yield response of 440 and 90 kg ha^{-1} of rice and wheat, respectively in Himalayan tarai soils of north Bihar. In Kerela, soaking of rice seed for 24 hrs in 0.25% copper sulphate solution or foliar sprays of 500 g $CuSO_4$ in 100 L water ha^{-1} has been found useful in increasing rice yield. Seed soaking of potato tuber was found least efficient while soil application or foliar sprays were on par, both yielded addition tuber 0.9 to 1.0 t ha^{-1} (Grewal and Trehan 1990). Addition of P fertilizer had positive effect while addition of Zn, Mo and S showed antagonistic effect on its availability and absorption by various crops.

Method of copper applications: Application of copper through broadcast on soil and mixing in surface soil prior to seeding is the most efficient method to correct copper deficiency. However, top dressing of copper on standing crop upto preflowering stage or foliar sprays of 0.5% copper sulphate aqueous solution neutralized with 25 g lime L^{-1} sprayed twice or thrice efficiently corrects the copper deficiency in standing crops. Application of 5 kg Cu ha^{-1} to wheat increased the grain yield over 0.4% foliar sprays. Copper applied in soils leaves residual effect to succeeding crops.

Cultivation of copper efficient genotypes: Among wheat cultivars UP370, UP 262, UP 2001 were found relatively more susceptible to Cu nutrition than WL 711, UP 368 and UP 115.

Molybdenum

Much information on molybdenum deficiency in Indian crops and soils and responses of crops to Mo fertilization is not available. Molybdenum uptake by intensive cropping systems ranges between 12.3 to 32 g ha^{-1}. Continuous submergence, use of organic manures, high soil pH, application of P and S fertilizers increases the availability of Mo but regular use of ammonium sulphate in red lateritic soils decreased its availability due to acidification effect and leaching in soil and antagonism between sulphate and molybdate absorption by plants. In soils containing low available Mo, its deficiency may appear after fertilization due to increased growth and uptake by crop plants. Molybdenum concentration more than 10 mg kg^{-1} dry matter in forages proved toxic to cattle in Punjab (Nayyar *et al.,* 1990). Among various forage crops maize, sorghum, teosinate were rated to be low Mo accumulator plant species.

Sources of Molybdenum : Ammonium molybdate $(NH_4)_6MoO_{22}4H_2O$, 54%Mo) and sodium molybdate $Na_2MoO_42H_2O$, 22% Mo) and molybdenum trioxide (MoO_3 66%Mo) are the common sources of Mo Still only ammonium molybdate is the approved as fertilizer in India. Molybdenum is also added as contaminants through various fertilizers like potassium sulphate and urea 5-6 mg kg^{-1} and phosphatic fertilizers by 250-550 mg kg^{-1}. In addition to these organic manures also carry Mo by 21 mg kg^{-1} FYM, 34 mg kg^{-1} in piggery manure and 42-65 mg kg^{-1} in poultry manure (Arora *et al.,* 1975). So partial requirement of crops is met through indirect application of these sources.

Liming of acid soils helps in correcting deficiency of Mo. It increases the native Mo availability as well as helps in enhancing residual effect of added Mo to succeeding crops. Phosphate, sulphate, molybdenum deficiencies is frequently occur together, therefore, to correct them molybdenized single super phosphate is recommended.

Rates of molybdenum: Singh *et al.* (1979) reported increase in grain of wheat by 130 to 880 kg ha^{-1} in rice and 20-680 kg ha^{-1} for wheat to 0.50 kg ha^{-1} sodium molybdate in soil through broadcast. Wheat variety Sonalika exhibited 38% response in grain yield of wheat with the application of 0.5 kg sodium molybdate in Mo deficient acidic soils of Assam (Ali and Manoranjan 1989). Application of Mo found beneficial in higher nodulation and nitrogen fixation by soybean and other legumes in red soils of Tamil Nadu. Application of 1.5 kg sodium molybdate increased the potato yield by 2.9 t ha^{-1} in black clayey soil, 2 t ha^{-1} potato hill soil, 1.3 ha^{-1} in red and lateritic soils and 1.2 t ha^{-1}in alluvial soils (Grewal and Trehan 1990). Response of green gram, black gram, chickpea, lentil on sandy loam soil, of groundnut to 0.5-1.0 kg ha^{-1} sodium molybdate in calcareous soils and of mustard on sandy loam to Mo have been recorded.

Method of molybdenum application: Deficiency of Mo in crops can be corrected by both soil application and sprays. Foliar sprays of 0.05% to 0.1% sodium molybdate solution thrice increased the pod yield of green gram by 130 kg ha^{-1} in black sandy loam of Tamil Nadu though 2 kg sodium molybdate applied to soil proved non efficient. Seed treatment of 70-140 g ha^{-1} significantly increased the soybean and groundnut yield.

Seed treatment with Teprosyn containing 54% Mo at the rate of 2-3 mL kg^{-1} seed of groundnut and soybean before sowing was found as effective in increasing seed yield as that of applying 500 g ha^{-1} ammonium molybdate in soil (Singh 2003). Presoaking of potato tubers in 0.01% ammonium molybdate solution increased the tuber by 2.9 t ha^{-1} in swell-shrink clayey soil, 2.0 t ha^{-1} in hill soil, 1.3 t ha^{-1} in red and lateritic and 0.2 t ha^{-1} in alluvial soils (Grewal and Trehan 1990). Nayyar *et al.,* (1990) reported that 30 g sodium molybdate per kg seed treatment of soybean improved the yield, quality, oil content. Black gram responded to Mo seed treatment to the 1.5 g sodium molybdate per kilogram of seed in red Mo deficient soils.

Time of Application: Basal application of Mo to groundnut increased the pod yield significantly in calcareous soils of Bihar. Similarly soil application of 800 g ha^{-1} of sodium molybdate with 120 kg S ha^{-1} also increased the pod yield of groundnut in Alfisol of Andhra Pradesh. Basal soil application of 0.50 kg ha^{-1} Mo along with single super phosphate or spraying of 0.1% Mo solution on foliage of crops increased the mustard yield in acid soil. Application of Mo have shown to increase not only the yield of French bean but also improved the marketable yield of beet root and cauliflower.

Role of micronutrients on crop quality

Impact of Development and Its Adoption of Technology

A good information on basic and strategic aspects of micronutrient management related micronutrients dynamics and transformations; their chemical pools, adsorption desorption, depletion, build-up and nutrient balance; soil organic & inorganic amendments and their impact on increasing use efficiency of native and applied micronutrients fertilizers have been generated. Information on standardization, development or refinement of new techniques for diagnosing nutritional disorders,mechanisms of absorption, translocation, uptake, metabolic and enzymatic changes operating at interaction sites have been found very useful helpful in developing suitable technology for correcting nutritional disorders in soils and plants and boosting soil productivity.

Simple, precise, and reliable diagnostic techniques and soil and plant analytical methods have been evaluated or modified. Monographs showing colour visual symptoms for recognizing micronutrient deficiencies have been published for the users. Critical range suitable for specific soil and plant to diagnose deficiency, sufficiency and toxicities for major soils, crops and assess degree of deficiency has been identified and published,. These are being used by different laboratories.

Areas showing zinc, copper, manganese deficiencies have been delineated and soil maps have been published. Areas affected with deficiencies are being delineated in detail and deficiemcy is being confirmed through biological responses. About 6000 ECF and on- research farm trials and 85 frontline demonstrations have been conducted to disseminate the benefit of research results at the farmer's fields. Boron , Cu and Mo deficiencies are being confirmed through systematic field experimentation and to know the reasons of mismatching between soil and plant analysis in certain locations.

Suitable corrective measures such as optimum rate, method, source and time of application for most of the cereals, oilseeds and some of the pulse crops and cropping systems have been developed which helped in developing sound technology for different agro-ecological regions, major soil groups and cropping systems. Several straight, chelated, mixture, blended, solid or liquid, single or multi micronutrient fertilizers have been approved under Fertilizer Control Order (FCO) by the Govt. of India for various states and crops. Based on sufficiency approach estimated requirement for Zn 324, Fe 130, Cu 11, B 39 and Mn 22 thousand tonnes by the year 2020.

Iron deficiency in field crops is a wide spread problem which is causing a significant reduction in yield. If iron chlorosis is expected then apply sufficient quantity of organic manure for its prevention. Apply 10-20 kg Fe ha^{-1} either ferrous sulphate or 10kg Fe ha^{-1} FeEDDHA through broadcast and mixing in topsoil as basal dose. However, in standing crops, foliar spray of 0.5% $FeS0_4$ + 0.02% citric acid aqueous solution of 500-1000 L ha^{-1} at 10-15 days intervals alleviate iron-chlorosis efficiently and economically. Broadcast pyrites on moist surface for 7-10 days prior to seeding or mixing in soil. Ensure proper soil moisture, aeration and apply iron-fertilizers through fertigation.

Addition of micronutrients not only increased the yield but also appreciably increase the energy value, total lipids, crude protein, carbohydrate contents, several enzymes and amino acids, glucoside and their contents of Zn, Fe, B, Mn, Mo and Cu in cereals, oilseeds, pulses, vegetable crops. Supply of Cu and S reduced the Mo toxicity in forages grown on sodic soil and as such improved the quality of forages.

Human and animals fed on food and forages produced in Zn deficient soils had low Zn content in their blood serum. Large number of blood serum samples taken for men and women in Andhra Pradesh, sheep in Gujarat showed zinc deficiency in blood plasma **(Table 10).** In Punjab, metabolic and diabetic patients showed the low value of zinc particularly in diabetic ulcer patients.

Table. 10 Impact of zinc deficiency on human health

Category	No. of people surveyed	Mean Zinc Status (ppm)			
		Soil	Plant	Blood Male	Serums Female
		Ranga Reddy district			
Deficient	18	0.37	18.2	0.49	0.52
Sufficient	44	0.69	26.7	0.55	0.65
		East Godavari district			
Deficient	16	0.45	13.6	0.84	0.97
Sufficient	44	1.12	25.9	1.08	1.06

Presently more than 100,000 tonne of zinc sulphate is used annually in different states besides large quantity of micronutrient mixtures used in Southern parts of India, especially on horticultural and vegetable crops.

Critical Research Gaps And Future Strategies

Deficiencies of various micronutrients are emerging in certain areas which were not observed initially, to say, deficiency of Fe and Mn in rice-wheat system in highly permeable soils of Punjab, deficiency of B in highly calcareous and acid soils of Bihar, Gujarat and red and lateritic soils of Orissa etc.Thus, nutrient indexing programme needs to be strengthened on priority on well defined soil-crop-management, agroeco-regions on fixed benchmark sites.

Emphasis on balanced and integrated nutrient management involving low doses of organic materials, their enrichments is very required to sustain fertility and ensure high yields. For sustainable high productivity of agriculture remedial techniques involving ‘off farm’ and ‘on farm’ inputs need to be given greater impetus .

Since deficiency of micronutrients are increasing, in areas having high potential to future agriculture. Therefore, creation of more centres in NEH region, West Bengal, Rajasthan and Karnatka are extremely essential. Deficiency of multi micronutrients is not so wide spread. So deficiencies of micronutrients are emerging wide spread due to their greater depletion under intensive cultivation. So forecasting of the emerging nutrients deficiencies / toxicities, in given soil-crop-management system, agro-ecological region is extremely essential through careful monitoring the permanent benchmark sites through farmers participatory research Suitable models for forecasting emerging micronutrients deficiencies, their transformation and residual availability and soil pollution needs to be developed.

Information on responses of micronutrients like, Cu, Fe, Mn and B need to be generated that has been found through mismatch of plant or soil analysis. Front line demonstrations, ECF trails need to be conducted to benefits of micronutrient use to the farmers.

Screening of crops and their cultivars for their tolerance to micronutrients viz., Fe and Mn deficiencies and other nutrients as well as tolerant to heavy metal and trace metal toxicities in polluted areas needs to be taken up on priority. More information on interaction between micronutrients and tillage / irrigation is required to improve availability of micronutrients by manipulating soil physical environment.

Increase micronutrient deficiencies causes poor quality of agricultural produce. Monitoring the effect of micronutrients deficiency in soil-plant-animal and human chain needs special priorities.

To create more awareness more publications of bulletins, leaflets, and pamphlets in simple language, through media, mass extension education, and more front line demonstrations at farmer's fields to show benefits of micronutrients technology is required.

Efforts to ensure availability of good quality micronutrient fertilizers, their easy accessibility at low cost at farmers sites through government agencies or fertilizer industries network required very much attention.

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THE EMERGENCE OF ICT AS A TOOL TO HELP FARMERS : REALITY OR MYTH?

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Farmers in Asia regularly list knowledge, credit and good prices as major limitations to improving their livelihoods. The emergence of Information and Communication Technology (ICT) raised tremendous expectations in terms of meeting information/knowledge needs. Despite the promise of ICT, however, there have been few examples of successful ICT application in agriculture. One exception is the Rice Knowledge Bank (RKB) (www.knowledgebank.irri.org). The RKB is now the world's leading ICT repository of rice-based training and technology information. Since its launch in 2002, it has received over 6 million hits, and site use continues to grow. This paper outlines how the RKB is designed to deliver focused, credible, value-added and demand-driven information. Further, the paper highlights that success in the use of ICT depends on partnerships that link information access to information application.

Knowledge — a major need for farmers

"Credit, price and access to knowledge." are the factors most commonly cited by farmers as their major limitations. IRRI saw a great opportunity to address these knowledge needs by harnessing the great power and promise of ICT.

Can ICT really help farmers?

IRRI asked itself the question, "if we develop an ICT-based resource, will farmers really be able to access such knowledge and truly benefit?" Statistics for personal computer (PC) access across Asia (Table 1) suggest that presently there is little hope that farmers would be able to use computers to meet their needs. However, we believe that the reality is more promising. While farmers themselves typically do not have access to computers, research and delivery partners (who educate farmers to produce better crops at a lower cost) often *do* have access. Further, the proliferation of internet cafes throughout Asia suggests ICT will increasingly be available as a tool to help farmers directly access their information needs.

Table 1. The number of computers, mobile phones and TVs for selected Asian countries (ranked by personal computers/1000 people – 2001)

Country	*PCs/1000*		*Mobile phones/1000*		*TVs/1000*	
	1995	*2001*	*1995*	*2002*	*1995*	*2001*
Japan	*120*	*389*	*93*	*588*	*681*	*731*
Korea (sth)	*108*	*257*	*36*	*621*	*322*	*363*
Malaysia	*37*	*126*	*50*	*314*	*169*	*201*
Thailand	*14.1*	*27.8*	*23*	*123*	*198*	*300*
Philippines	*9.6*	*21.7*	*7*	*150*	*105*	*173*
China	*2.3*	*19*	*3*	*110*	*243*	*312*
Sri Lanka	*1.1*	*9.3*	*3*	*36*	*78*	*117*
Vietnam	*1.4*	*11.7*	*0*	*15*	*163*	*186*
Indonesia	*5.0*	*11*	*1*	*31*	*113*	*153*
India	*1.3*	*5.8*	*0*	*6*	*61*	*83*
Nepal	*1.2*	*3.5*	*..*	*1*	*3*	*8*
Pakistan	*3.5*	*4.1*	*0*	*6*	*51*	*148*
Bangladesh	*..*	*1.9*	*0*	*4*	*7*	*17*
Lao PDR	*..*	*3*	*0*	*5*	*10*	*52*
Cambodia	*0.5*	*1.5*	*1*	*17*	*8*	*8*
Myanmar	*..*	*1.1*	*0*	*0*	*7*	*8*

Source: World Bank 2005.

Potential access, however, is of little use. The issue is what is the reality of ICT access? IRRI research in the region has identified cause for optimism in this respect. Recent studies have indicated that almost all major NGOs and government research and extension partner have PCs with CD drives in their offices. Further, many offices have at least some machines with internet connectivity. The conclusion is that ICT tools *are* widely available to the organizations that work with farmers.

The development of the Rice Knowledge Bank

To harness the power of ICT, IRRI developed the RKB (www.knowledgebank.irri.org). This resource is the world's first digital extension service with a wealth of information on rice-related training and extension. The RKB has been independently reviewed and has received critical acclaim as a tool to distill, store and provide information for rice science and extension (e.g., BBC Earth Report, HANDS ON - THE PADDY CHRONICLES, September 2004; the *Further readings about the RKB* section, below, provides more reviews). Such success was not accidental. IRRI's strategy for the development of the RKB recognized that creating a digital repository was only a start. A large number of "shovel-ware" repositories — sites where anything and everything related to an area were placed – already existed. IRRI saw that if the RKB was to be used effectively by farmers and their intermediaries, it was critical that its content be focused, credible, demand driven and value added.

The Rice Knowledge Bank (www.knowledgebank.irri.org) is IRRI's example of practical ICT application

RiceDoctor is one of two Decision Support Tools included in the Rice Knowledge Bank.

Focused

The power and capacity of the internet to all often tempts people to include too much information — working off the principle that, "if a little is good, then more is better." Clearly some tools such as google are designed to effectively deal with such issues. With more than 40 years of science and research, IRRI was well placed to pursue a mass site strategy. However, there is a niche for more targeted sites and early on, the RKB developers recognized the importance of ensuring that the site remain focused; that it contained only knowledge relevant to extension, research, training and support. Such an approach would allow easy site navigation (for internet browsers). Further a focused approach allows target users to quickly identify knowledge that is directly relevant to them; doing so without being lost in the large amounts of interesting but often irrelevant information.

The identification of the target audience was another key aspect in the successful development of the RKB. Since the rice farmers of Asia were considered unlikely to gain access to ICT, the RKB was designed to target the farmer intermediaries — those research and development workers who have ICT access and who need information to help farmers. Targeting these people is especially effective because many are already educated, ICT-literate and are experienced in training farmers.

Credible

A "Google" search of the internet using the keyword "rice" results in an astounding 30 million "hits". The questions become "Which of these can you believe? Which are useful? How could you possibly have time to review them all?". IRRI uses a rigorous sign-off on new content by the relevant IRRI scientists staff to ensure accuracy of material. With these mechanisms in place, and drawing on IRRI's 40 years of proven research competence, users can be confident about the quality and relevance of the knowledge in the RKB.

Value added

The RKB is value-added in two ways. Firstly, the knowledge is available either online, on CD-ROM or in print. Information is therefore available in whatever form is best suited to the needs of the target users. This approach is called single-source publishing.

Secondly, the RKB content is not just a series of computer files on-line. Rather, the RKB presents information in forms that make the knowledge more accessible and more directly usable. Examples of this include:

- **Common navigation format** Once into the RKB, the process of site navigation is similar. The RKB draws on best practices in the private sector to present information in an easy-to-use, fully indexed, book form.
- **Decision support tools** (e.g., TropRice and Rice Doctor) lead users through a simple process to identify and solve their particular problems.
- **Information sheets:** are expanded summaries of topics. These are summarized reference sheets for experts.
- **Fact sheets:** summarize the key points of topics and present them in one or two pages. These sheets aim to provide enough information for practitioners to implement practices.

- **Farmer Technology sheets:** present information on a technology in very simple and clear ways. Extension officers can use these directly with farmers.
- **Reference guides** on field-related information are concise and easy-to-read. The RKB does not include the original scientific papers.
- **e-Learning courses** capture a selection of key training topics in a form that users can access when and where they want and at a time of their own choosing.

Demand driven

Success depends on providing content that is driven by user needs. IRRI ensures priority content by using it's extensive in-country networks. These networks continually identify country needs and provide feedback on the relevance and ease of use of the RKB. In addition, the RKB site has extensive, up-to-date usage statistics. These statistics are analyzed to track the most searched-for topics and key words to help refine needs.

Three demand-driven innovations include the development of the Fact Sheet and Farmer Technology Sheet series and the development of country-specific sites. The country sites present locally relevant knowledge provided by local users in each country. This information is often in local language.

Used — the ultimate definition of success

The ultimate success of the RKB is defined by both access to and application of its information.

A number of anecdotal examples highlight the RKB is being used as designed. One example involves a cramped internet cafe in northeastern Thailand. Dr. Ragat Nag, Director General of the Mekong Department of the Asian Development Bank, noticed an enthusiastic group of youngsters showing their parents how to use a computer. Intrigued,

Dr. Nag found that the kids were showing their parents Rice Doctor, the diagnostic program developed by IRRI to help rice farmers manage rice pests and diseases. The children were accessing the site, searching for information on topics requested by their parents and then translating the relevant pages into Thai for their parents.

Although the above story was encouraging, IRRI realizes that that rice farmers rarely have such direct access to knowledge. As indicated earlier, the farmer intermediaries are the primary target users of the RKB.

There is little doubt about the success of access to the RKB. The site has registered over 6 million hits since its inauguration in 2002 and the number of users continues to grow. At present, the RKB averages over 1,000 visits per day at an average of 12.40 minutes per visit. This on-line time equates to around 10,000 person-days of "training" per year. Some suggest that this form of training is even more effective than traditional face-to-face methods, as the participants get information on exactly what they want when they need it. While these RKB use numbers are encouraging, the key is that the accessed information is applied. As a result, the RKB project continues to look for better ways to ensure application. While user feedback tells us that such application is happening, it is in the area of field application that we hope to see continued growth.

Future of the RKB – increasing the linkage of ICT with field application

Increasingly, IRRI sees the potential to link ICT to practical field application. For example, in Sri Lanka, the Department of Agriculture has established Cyber-Extension Centers. These pilot sites, based in their Agrarian Service Centers, are providing exciting action research opportunities to evaluate the pros and cons of ICT. To date, results are extremely promising. But the key to success lies in the development of a consistent and relevant approach to identifying problems (Table 2), accessing information and applying that information in the field.

As a note, these access and use statistics do not include internal IRRI traffic or use of the many thousands of RKB CDs already distributed in partner countries.

Table 2. The framework for establishing ICT centers for meeting farmers' needs

Meeting needs
• Identify target farming areas with potential for impact. • Identify key partners locally active in research and development. • Work with farmers and intermediaries to identify primary problems and determine major information needs.
Farmers
• Needs and Opportunities Analysis - identify problems, causes, frequency, extent of problems. • Distinguish problems based on form of resolution required — e.g., political, agronomic, handled by other institutions. • Options — identify priority problems and viable options, and their potential chance of success or their feasibilities.

Intermediaries
• Identify the technology and training methodology and delivery needs of partners who are committed to working with IRRI and driving the project.
Support Materials
• Identify available materials to meet the above needs. Material can come from either the RKB or from local sources. (Ensure the credibility of the information.)
• Identify any information gaps and work with appropriate people to develop materials to fill those gaps.
• Improve existing materials — if needed.
• Translate material — if required.
• Upload materials — as appropriate to the national site.
Training
• Run courses for farmers and/or intermediaries.
• Use RKB materials in training and extension.
• Evaluate and improve materials.
• Develop the cyber-extension centers as drop in centers.
Establish Field Demonstrations
• Work with committed partners to demonstrate technologies that address farmers' problems in the area.
Monitor and evaluate progress
• Collect feedback on material for improvement. Materials are those ICT materials developed on both technology and delivery. Further feedback is required on the effectiveness of the participatory technology delivery models.

A recent field trip to Sri Lanka by IRRI staff highlighted the linkage that the Department of Agriculture extension staff are making between farmers' needs — information accessed from the RKB — and solutions with farmers in their fields. Field activities (including Farmers' field days) clearly demonstrated the enthusiasm of the farmer to work more closely with the extension officers. In a similar empowerment example, the extension workers repeatedly discussed their excitement at having access to a tool (the RKB) that empowered them to help farmers in ways they had never imagined. They especially appreciated both the information on the technologies and the information on methodologies for more effectively working with farmers.

Learning from doing

IRRI has similar initiatives in other countries and continues to grow in these areas. The success of the project in Indonesia is proving valuable lessons. In partnership with the Indonesian national partners, the IRRI RKB team has developed a well-focused site to present high demand materials in easily-understood and accessible forms. The project highlights the importance of tightly linking information access with the national efforts to deliver the information to farmers.

Key lessons

Partner commitment and ownership: In both Sri Lanka and Indonesia, there is a national commitment to, and ownership of, the drive to increase production. Partners join and lead the project with clear goals in mind.

RKB site focus: The Indonesian example highlights that smaller can be better. A well-targeted site with high-demand materials delivers the information the partners want.

Farmer participation: Farmers are responding to their increasing role of being part of the delivery process. Rather than being "talked at", they are increasingly involved throughout the technology transfer process. The result is that farmers are more confident that their needs are truly being met.

Linking RKB with an area development initiative: The RKB's usefulness can be realized if is linked with an existing local development initiative being managed by local government units and/or NGOs and/or other stakeholders. The RKB has shown that it can help deliver technical options to farmers more efficiently and with added value.

The RKB vision and the future

"IRRI's Rice Knowledge Bank is the world's leading provider of rice-related training and technology information, used by farmers and people who help them to improve the livelihoods of rice-dependent communities."

In association with increased linkage with motivated and active partners, the areas for RKB expansion and/or improvement include:

- Including or linking to information on other crops and related practical development needs
- Further development of the Country sites – with more high priority material included in local language

- Including summaries of key Policy requirements for successful upscaling and development
- Knowledge Management interface – improving the ease-of-navigation of website

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Notes

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EMERGING NEED FOR BETTER EXTRAPOLATION OF PESTICIDE FATE DATA FROM TEMPERATE TO TROPICAL REGIONS[1]

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INTRODUCTION

The use of pesticides is essential to combat pests in modern agriculture. However, the potential adverse impact of pesticide use on ecosystem and human health continues to be a cause of concern. To minimise any such effects, sound understanding of environmental fate and behaviour of pesticides under local soil and environmental conditions is essential. Indeed, in last 20-30 years, a substantial body of research on the fate and behaviour of pesticides has been developed. This, however, originates predominantly from the temperate soils of Europe and North America. Despite the fact that large number and volumes of pesticides are used in tropical countries, the environmental fate of pesticides (especially modern pesticides) in the tropics remains poorly understood (Racke, 2003).

The combinations of chemical properties as well as site-specific soil and environmental conditions deter-mine the environmental fate and behaviour of a pesticide. Soil and environmental conditions vary markedly with geographical locations. Soil properties such as soil pH, abundance and nature of clay minerals, sesquioxides and soil organic matter can be vastly different in soils of different agroclimatic regions. For example, many soils of semi-a-rid tropical countries (e.g. parts of India, Pakistan China and Australia) are alkaline (pH > 8.0), whereas highly weathered soils of the tropics (Malaysia and Australia) and those in high rainfall areas are acidic (pH 5.5–6.5). Many soils of the a-rid zone and tropical countries are low in SOM content, whereas the volcanic soils, such as in New Zealand and Japan, are rich in allophone clay and contain much higher organic matter contents (averaging 10–12 %). Clearly, many soils in the tropical region are very different from the soils of Europe and North America, on which the pesticide environmental fate databases have originated from (Wauchope *et al .,*1992; Hornsby *et al.,* 1996).

Due to lack of availability of local environmental fate, the regulatory agencies and resource managers in several tropical developing countries have no option, but to rely on European and North American databases. The obvious question is, how relevant are these overseas data to local conditions? In an attempt to partly answer this question, we assess the differences in the nature and properties in soil and environmental conditions between different geographic regions, and their potential influence on pesticide sorption in this paper. The focus in this paper is on the effects of soil and environmental conditions associated with tropical and temperate region on sorption of pesticides. Therefore, while other processes such as degradation, transformation, volatilisation and leaching are equally important and are influenced by soil and climatic factors, these have not been addressed here. Racke (2003) provides a comprehensive account of knowledge on the processes and pathways of dissipation of pesticides in tropical ecosystems.

Trends in pesticide use in Australasia Pacific

Let us first examine the pesticide use trends in the developing countries of the Australasia Pacific region in the global context. Over the past three decades, there has been a large increase in the use of pesticides, globally (Figure 1). There has been a steady increase in the worldwide use of pesticides, with a noticeable increase in the relative use of herbicides and a corresponding decrease in the use of fungicides. Pesticide use in the United States has increased 33-fold since 1945 (Pimental *et al.,* 1991), increasing from approximately 1.910^5 to 3.910^5 tons between 1965 and 1985 (Postel, 1988). In the Australia Pacific region, increases in pesticide use have also been noted. In Australia, data on pesticide sales at factory gate suggest that pesticide usage (per annum) increased from A$166

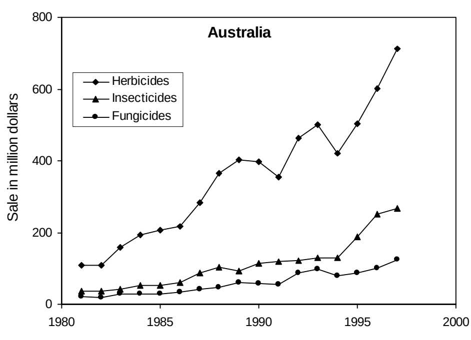

Figure 1. Trends in the world use of pesticides (after Carvalho *et al.,* 1997)

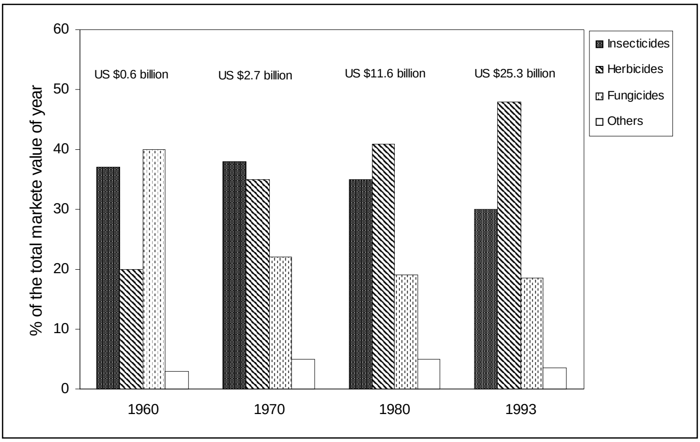

Figure 2. Trend in use of major groups of pesticides in Australia

m in 1981 to A$1107 m in 1997 (Figure 2) with herbicides accounting for 65 per cent followed by insecticides with 24 per cent of total sales in 1997 (Australian Commodity Statistics, 1998). Herbicide use in Australia has facilitated the adoption of minimum tillage practices and the estimates for annual net benefits to Australian agriculture from using these agrochemicals vary from $2500 m (Cribb, 1989) to as high as A$5000 m (Kookana *et al.,* 1998). The figures for the actual weight of active ingredients and individual chemical products, however, are not routinely available.

Accurate statistics of pesticide use in many other developing countries in the tropics is difficult to obtain. Due to higher pest pressures, the use of pesticides in tropical countries is significant. It is difficult to make an accurate estimate of what proportion of global pesticide use occurs in tropical developing countries, but it is probably 10–20 per cent (Logan and Buckley, 1991).

The division into pesticide groups reflects the different pattern of use of pesticides in developed and developing countries. While herbicides dominate in the developed countries, the insecticides are generally the most important class of pesticides used in the developing countries. For example, in USA and Australia, herbicides constitute nearly two thirds of total pesticide use. By contrast, in India, Vietnam and Pakistan insecticides account for 75–85 per cent of the product volume used and weeding still being done by hand (Tennenbaum, 1996).

While many pesticides are common among different countries, some pesticides that have either been banned or severely restricted in developed countries (e.g. BHC, DDT, parathion) are still widely available in several developing countries, due to different regulatory regimes. For the pesticides that are used internationally, extrapolation of data from one region to other can be highly beneficial, if relevant to local conditions. It is therefore useful to examine the similarities and dissimilarities in soil and environmental conditions between temperate and tropical regions.

A comparison of soil properties between tropical and temperate regions

The nature and properties of the soils are driven by several soil-forming factors including, geological parent material, climate (e.g. temperature rainfall), vegetation, relief (e.g. elevation, slope and depth) and time (Buol *et al.,* 1989). Due to wide variations in these factors between tropical and temperate regions, many soils in these regions display correspondingly wide variations in their properties. For example, Brazilian, Australian and the Indian Oxisols are highly weathered, with goethite, gibbsite, hematite and 1:1 clays such as kaolinite, with low organic matter contents and low pH. These soils are subject to relatively high year-round temperatures and occasional high rainfalls (Oliveira *et al.,* 2001). Many soils of the tropics contain variable-charge clay minerals with distinct physical and chemical properties. An estimated 60 per cent of the soils in tropical regions contain variable-charge minerals compared with only 10 per cent of the soils belonging to the temperate regions (Uehara and Gillman, 1981). Such soils exhibit significant anion exchange capacities at ambient pH.

Climatically, tropical temperature regimes are largely warmer and exhibit much less variation from season-to-season compared with temperate zones. In tropical regions, the mean daily incident solar radiation is about twice that of temperate regions. Since the formation and decomposition of soil organic matter are primarily microbially mediated, the temperature at which these processes occur is likely to control the rates of organic matter transformation, provided that other soil conditions such as oxygen, soil water content, clay content, and pH are similar (Swift *et al.,* 1979; Jenkinson, 1988). Thus, the decomposition rate of organic matter in the agricultural soils in tropical regions is therefore considerably faster than in soils from temperate regions. This is supported by the findings of Jenkinson (1988) that soils of tropical regions contain lower organic matter contents than those from the temperate regions. Generally the organic matter in the tropical soils is more decomposed, or humified, than that in the temperate soils. Grisi *et al.* (1998) investigated organic matter and microbial dynamics in soils from tropical (Brazilian) and temperate (UK) conditions, and found that soil organic matter was mineralised more rapidly in the tropical soils.

The large humus accumulation in allophonic soils (many New Zealand soils) containing large amounts of amorphous or crypto-crystalised minerals is well known (Wada, 1985). This is mainly attributed to very stable humus-Al, Fe- complexes which may likely be protected from bacteria and enzymes in micro aggregates rather than by a specific effect of allophane and associated minerals (Wada, 1985; Boudot *et al.,* 1986; Oades *et al.,* 1989). However, other reports (Calderoni and Schnitzer, 1984; Hatcher, 1989) indicate that SOM in allophanic soils is highly decomposed; it may be rich in carboxylic and aromatic groups, giving them very high affinity to Al/ Fe-oxides/hydroxides.

The chemical nature of SOM is influenced by site environmental conditions. Zech *et al.* (1989) investigated eight soil profiles from temperate, subtropical, and tropical regions. Correlating chemical characteristics of SOM (e.g. aromaticity) of bulk soil samples with site factors, they found that temperature and the temperature/ precipitation ratio influence mainly the aromaticity of bulk soil samples. In soil horizons with high pH and low C:N ratios, aromaticity tended to be somewhat higher. This shows that advanced stages of humification are characterised by higher aromatic components of the SOM. About 73 per cent of aromaticity could be explained by the variation of temperature/precipitation ratio and the rest by the variation of soil pH and the C:N ratio (Zech *et al.,* 1989). Studying the humic acids of five Kenyan soils, Arshad and Schnitzer (1989) also found a positive relationship between the temperature/ precipitation ratio and aromaticity. On the other hand, no such influence of chemical factors on the chemistry of humic acids could be identified in sub-humid Kenyan soils (Miltner and Zech, 1994). For more details on the characteristics of tropical soils, refer to an extensive review by Sanchez (1976).

Given the substantial differences in nature and properties of soil and environmental conditions between tropical and temperate regions, it is useful here to discuss their role in determining sorption of pesticides. Racke (2003) in his comprehensive review covered the pesticide dissipation aspects thoroughly and concluded that pesticide losses occur more rapidly under tropical conditions, mainly due to climatic effect than soil type effect. This, however, may not be true in the case of pesticide sorption processes, where the nature of mineral and organic matter may be of greater importance than temperature and moisture. Therefore, a discussion on key factors that govern sorption behaviour of pesticides in soils follows. The impact of soil organic matter in pesticide sorption is then discussed in detail.

Key Factors Governing Pesticide Sorption Behaviour

Sorption is one of the major processes affecting the fate of pesticides in the soil environment. It also plays an important role in regulating the rates and magnitudes of other processes that govern the fate and transport of organic contaminants in soils and sediments. It may cause a decrease in the biological activity of a pesticide and its rate of biological degradation, or it may enhance nonbiological degradation due to surface-catalysed hydrolysis (Stevenson, 1994). The transport of an organic chemical is also significantly affected by sorption onto soil.

The sorption interactions of pesticides have been investigated intensively for the last three decades (Rao and Davidson, 1980; Koskinen and Harper, 1990). A number of soil properties have been reported to influence sorption of pesticides in soil, including organic matter and clay contents, soil pH, soil water content and soil temperature. How the variation of these soil environmental parameters can influence the sorption interactions of pesticides is discussed below.

Type of mineral materials

Clay minerals can make a significant contribution to pesticide sorption, particularly to ionic pesticides and even to non-ionic pesticides if the SOM contents are very low. Weber (1970) reported that s-triazine herbicides were readily sorbed onto various clay minerals including illite, montmorillonite and kaolinite. The clays in highly weathered soils of the tropical regions are dominated by kaolinite (1:1 type of clay minerals possessing low surface area and low negative charge) and have a lower capacity for pesticide sorption than 2:1 type clay minerals like montmorillonite and vermiculite (Bailey and White, 1970). Oxisols (which are rich in non-crystalline to poorly crystalline Al and Fe oxides) have been shown to significantly sorb anionic pesticides, as these can carry net positive charge at ambient pH (Regitano *et al.,* 2000). In contrast, cationic/cationisable pesticides (such as paraquat, diquat and ametryn) show relatively lower sorption in such soils due to lower cation exchange capacities of the soils, despite their high clay contents.

Soil pH

The acidity or basicity of the soil is another factor that influences the sorption, especially of ionisable pesticides (Nicholls, 1988).The soil pH regulates the electrostatic charge of soil colloids (organic matter and oxides) and the chemical dissociation or protonation of pesticide molecules. Basic pesticide molecules become protonated at lower pH and therefore, more strongly sorbed to the soil colloids. Conversely, the acidic pesticides ionise and become anions as pH increases (one or more pH units above the pK_a) and sorption is less (Weber, 1993; Sarmah *et al.,* 1998). Soil pH varies markedly among soils of different regions. The soils in wet tropics are generally acidic, whereas those in arid regions highly alkaline leading to markedly different sorption behaviour. This effect makes direct extrapolation of data between acidic and alkaline soils difficult, especially for ionic or ionisable compounds.

Soil temperature

Soil temperature is an important environmental parameter that is markedly different in tropical and temperate climates. The literature indicates that the effect of temperature on sorption of pesticides to the soil is highly variable. A study conducted by Valverde-Garcia *et al.* (1988) showed that the elevation of temperature favoured sorption of thiram and dimethoate on organic soils. They attributed this enhanced sorption to the increased number of active sites on humus. Khan *et al.* (1996) presented a similar interpretation for sorption of lindane. By contrast, studies on sorption of cyanazine on different homoionic peats by Dios-Cancela *et al.* (1990) showed decreasing sorption with increasing temperature, which was attributed to either a decrease in the attractive forces between the pesticide and the peat or a change in the solubility of the pesticide. In a study on sorption of atrazine on kaolinite and montmorillonite clays, Fruhstorfer *et al.* (1993) postulated that since a rise in temperature causes an increase in the kinetic energy of the molecules with constant electrostatic attraction, this leads to a decrease in sorption of atrazine. Morrill *et al.* (1982) reviewed several studies, which also showed decrease in sorption of organic compounds with increasing temperature.

Soil organic constituents

Organic matter is the most important sorbent in soils for non-ionic pesticides. Strong correlation has been frequently observed between sorption of non-ionic pesticides and SOM content (Karickhoff, *et al.,* 1979). Organic matter can be broadly classified into humic and non-humic, either of which can play a role in pesticide sorption (Morrill *et al.,* 1982). Humified material is often a stronger sorbent for non-ionic pesticides due to the presence of oxygen-containing functional groups such as –COOH, phenolic, aliphatic, enolic, –OH, and C=O, but this is not so for ionic pesticides due to a range of possible sorption mechanisms (Hance, 1988). From the standpoint of interactions of non-ionic pesticides with SOM, significant differences in the chemistry of SOM in soils from different geographical regions are expected. A review on sorption of non-ionic pesticides, with particular reference to the nature of SOM, is therefore presented in the following section.

Soil organic matter and sorption of non-ionic pesticides

Until the late 1970s, the literature widely reported sorption of non-ionic organic compounds from water by soil as an adsorption phenomenon. Lambert (1968) and Swoboda and Thomas (1968) speculated that the role of organic matter was empirically analogous to a solvent medium. However, no evidence was reported to support this hypothesis. Repeated observations of linear isotherms, low heats of sorption, and significant correlations of sorption coefficients with both the SOM content and solute aqueous solubility, lead Chiou *et al.* (1979) to propose that the sorption of nonionic organic compounds to soil and sediment in aqueous systems is due to partition of the compound between water and the organic matter. During the last decade, however, the mechanism of sorption to SOM has received further attention, and evidence that shows the sorption mechanisms in soils involve more than just simple partitioning (Mingelgrin and Gerstl, 1983; Curl and Keoleian, 1984; Xing and Pignatello, 1997).

Since the uptake of a given non-ionic organic compound by soil is strongly dependent on the SOM content (e.g. Means *et al.,* 1980; Xing *et al.,* 1994), sorption or partitioning coefficient (K_p) of a pesticide is expressed per unit mass of organic C in soil, such that:

$$K_{oc} = \frac{K_p}{f_{oc}} = \frac{S_{eq}}{C_{eq}\, f_{oc}} \qquad (1)$$

where K_p is the sorption coefficient; C_{eq} is the equilibrium concentration of the sorbate in the aqueous phase, S_{eq} is the amount sorbed per unit mass of the soil at equilibrium and f_{oc} is the fraction of soil organic C.

It is often assumed that K_{oc} is approximately constant for a given non-ionic compound (Green and Karickhoff, 1990). On that basis, once K_{oc} of the compound is measured, the sorption (K_p) of that compound in any soil or sediment can be estimated from equation (1). The temptation to regard K_{oc} as a constant has been universal and the relationship has become the basis of assessment of pesticide fate and movement in soil.

Several linear equations have been developed to predict K_{oc} for contaminants in soils. These equations are based on the contaminant's octanol-water partition coefficient, K_{ow} or its aqueous solubility (S_w). The coefficients of the equations vary depending on the nature of compounds and number of compounds used in these studies (Ahmad and Kookana, 2002). It becomes attractive to use such empirical relations to estimate sorption coefficients from the molecular properties, especially when sorption data in not available locally. However, in predicting sorption of pesticides in soils using these empirical equations, it is implicit that organic matter in various soils is homogeneous and interacts in the same manner with non-ionic pesticides. Clearly, such uniform behaviour of organic matter among different types of soils is unlikely, given the structural and compositional variability that can exist. Therefore, any such estimation may lead to erroneous estimates of sorption coefficients. Xing *et al.* (1994) reported a pronounced difference between K_{oc} values predicted from K_{ow}, and those measured in the laboratory. The main cause of variation in observed sorption coefficient might be due to the difference in the polar or nonpolar character of organic matter and its structure and configuration, which can affect the sorption of organic compounds.

The assumption of constancy of K_{oc} is invalid in many instances (Minglegrin and Gerstl, 1983). Ahmad *et al.,* (2001b) investigated sorption of carbaryl and phosalone in 48 soils from Australia, Pakistan and UK. They noted that regression of sorption coefficient (K_p) for carbaryl and phosalone pesticides against the total C content of the soils could account for only 53 and 46% of the variance in $K_{p,}$ respectively. The sorption data obtained for carbaryl in soils of various countries has been compared in Figure 3. The K_{oc} values decreased in the order of Pakistani > Australian > New Zealand > British soil. Furthermore, a variation of 17-, 11-, 6- and 2-fold was found in the K_{oc} values of carbaryl in soils of Pakistan, Australia, New Zealand and the UK, respectively. The mean values of K_{oc} in Pakistan and Australian soils were higher than the corresponding values from Europe and North America.

The soils from the UK and New Zealand generally are richer in organic matter. By contrast, the more humified SOM in the warmer climates of Australia and Pakistan, may have been responsible for higher K_{oc} in these soils. The other differences such as the landuse and type of vegetation associated with the SOM in soils may also have contributed to the variation in sorption. In fact, the sorption of pesticides can also vary between soils of the same region possibly due to different affinities of the SOM for the pesticides and interplay of other soil properties. Some data reflecting variability in K_{oc} values for selected non-ionic compounds in soils is presented in Table 1.

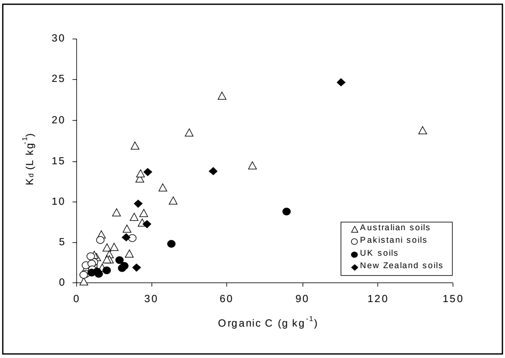

Figure 3. Variations in sorption coefficients for carbaryl, in relation to organic carbon in soils of various countries (after Ahmad and Kookana, 2002)

Table 1. Range of sorption coefficient (K_{oc}) values reported for nonionic pesticides in soils (from Ahmad and Kookana, 2002)

Compound	***K_{oc} (L kg^{-1})$^{\#}$***	***% Organic Carbon***
Carbaryl	*64 - 4318*	*0.3-13.8*
Chlorpyrifos	*2164 - 35170*	*2.1 - 11.4*
DDT	*131541 - 443137*	*2.8 - 6.7*
Disulfoton	*810 - 8723*	*0.3 - 7.9*
EDB	*36 - 160*	*0.9 - 37.4*
Lindane	*736 - 2589*	*2.1 - 35.3*
Napropamide	*190 - 2108*	*0.2 - 4.1*
Parathion	*314 - 15861*	*0.3 - 10.5*
Piperophos	*124 - 13149*	*3.1 - 17.6*
Phorate	*364 - 6862*	*0.3 - 54.7*
Phosalone	*1506-85528*	*0.3-13.8*

#Original values expressed as K_{om}; the factor 1.724 was used to convert to K_{oc}; K_{oc}=1.724 K_{om}

**Lowest organic carbon samples not included*

The SOM may vary from soil to soil in its polarity, elemental omposition, aromaticity, condensation, and degree of diagenetic evolution from a loose polymer to condensed coal-like structures (Garbarini and Lion, 1986; Gauthier *et al.,* 1987; Grathwohl, 1990; Karapanagioti *et al.,* 2000). Therefore, type and age of SOM may affect the sorption of non-ionic pesticides. However, the sorption coefficient K_{oc} ignores these properties that are known to affect the sorption of non-ionic organic compounds (Xing *et al.,* 1994).

Variations in the chemical nature of soil organic matter and pesticide sorption

Due to difficulty in isolating unaltered SOM and characterising its chemical and physical properties (Schnitzer, 1991), the mechanisms involved in the sorption of organic compounds have not been clearly understood (Stevenson, 1994; Almendros, 1995). Also methods of extraction of organic materials from soil may alter its nature, and the observed properties may differ from those of organic matter *in situ*. However, the development of solid-state ^{13}C NMR spectroscopy has provided a useful tool for the examination of SOM by using whole soil samples as well as fractionated samples (Baldock *et al.,* 1992; Preston, 1996; Mathers *et al.,* 2000). Cross-polarising magic-angle spinning (CPMAS) ^{13}C NMR use is advancing the characterisation of soil organic matter and other geologic samples.

Depending on the soil type, the nature of the organic constituents vary considerably (Schnitzer, 1991; Kogel-Knabner, 1993) as the organic matter in soils differs widely in terms of the degree of humification as well as their composition. For example, humic materials of grassland soils are rich in humic acids, whereas fulvic acid dominates in forest soils (Stevenson, 1994).Subsistence farming in the tropics depends heavily on the release of nutrients from more biologically active or labile SOM (Mueller-Harvey *et al.,* 1985). Such SOM includes litter, plant roots, partially decomposed residues or light fraction, water-soluble organic materials, and other non-humic substances (Theng, 1987). In these soils, the type of vegetation from which the SOM originates, affects the chemical composition of soil appreciably; but the other important factor is the degree of decomposition of the SOM. The O-alkyl C tends to decrease with decomposition, while the proportion of alkyl C tends to increase and aromatic C may increase or decrease, depending on the situation (Baldock *et al.,* 1997). Krosshavn *et al.,* (1992) investigated samples with different vegetation sources and others with variation in the degree of humification using soild-state ^{13}C NMR. They found that both the vegetational background and degree of humification substantially influenced chemical structure of the organic matter in these soils. The aromatic fraction of the SOM ranged from 8.5 to 13.7 per cent . According to Inbar *et al.* (1989) aromatic carbon increases with increasing decomposition. Decomposition of SOM leads to gradual changes in the functional groups of the SOM, depending upon various environmental factors including temperature, nutrient status, and soil water content (Lessa *et al.,* 1996).

Ahmad *et al.* (2001c) characterised soils from different regions of Australia and Pakistan. This study revealed clear differences in the chemical nature of organic matter, as seen by ^{13}C CPMAS NMR, in the whole soils from different origins and landuses. Interpretation of the NMR data for structural components (Ahmad *et al.,* unpublished results) to estimate various molecular components of SOM in the soils, also revealed substantial variations in the molecular components of SOM. Sandy soils contained the highest proportions of lignin or lignin-derived materials, followed by forest soils. Many agricultural soils from Australia contained appreciable amounts of charcoal (Skjemstad *et al.,* 1996 1999), whereas three Pakistani soils contained much higher lignin. The soils originated from different regions under different vegetation, landuse, climate, cropping practice and fertiliser applications.

Arai *et al.* (1996) characterised the nature and composition of organic components in two soils (an Alfisol and a Vertisol from semi-a-rid tropics of India) using chemical analysis, photometric and high-resolution solid-state ^{13}C NMR spectroscopies, and ^{14}C dating. They found fulvic acids to be major constituents: about 90 per cent in the Alfisol and 70 per cent in Vertisol, suggesting a faster decomposition of SOM in Alfisol.

While it is useful to relate the chemical nature of SOM to the sorption affinity/capacity for hydrophobic organic compounds (Karapanagioti *et al.,* 2000), so far limited attention has been paid to the relationships between chemical and physical properties of SOM and the behaviour of pesticides in soils (Kozak, 1996). The few available studies on this topic have been restricted to sorption of organic pollutants on commercial and pure humic materials, even though they are not good representative of natural humic substances. Ahmad *et al.* (2001c), however, investigated the relationships between the K_{oc} values of carbaryl and phosalone and the various structural components of soil organic matter in a range of soils from various regions. They found that the aromatic component of the SOM had a significant impact on the sorption of the two pesticides. A strong positive exponential correlation of K_{oc} values with aromaticity (r^2 = 0.94 and 0.95 for carbaryl and phosalone, respectively) was observed, which indicated that aromaticity of soil organic matter is a key structural parameter, which regulates sorption of non-ionic pesticides. Furthermore, molecular nature of SOM predictions from the NMR spectra, and the multiple regression analyses showed that among various molecular components of the SOM, relationships using both lignin and charcoal contents were highly correlated with the K_{oc} values of carbaryl and phosalone (Ahmad, unpublished results). Lignin has also been reported to show high binding affinities for other pollutants (Xing *et al.,* 1994).

From these results, it is very likely that retention of pesticides in burned-over fields and those containing wind-blown carbon particles may be high. This also demonstrates that the extrapolation of data may hold well for groups of closely-related soils in a region, but as the structural and chemical similarity of SOM diminishes, so does the validity of extrapolating data.

In the preceding sections, various factors affecting the behaviour of pesticides in soils of tropical and temperate countries have been considered. A detailed account of pesticide behaviour in soils would involve many other parameters. Nevertheless, the extent of sorption by soil constituents in general, and soil organic matter in particular, is expected to be a primary factor influencing pesticide behaviour. Many soils in tropical regions containing an appreciable amount of variable-charged components and higher pH have many properties that are striking in contrast to those of the soils in temperate regions. These factors need to be taken into account, in addition to the nature of SOM, while sorption data is extrapolated between agroclimatic regions.

Summary and Conclusions

On the basis of above discussion and evidence from selected investigations, it is apparent that the combinations of chemical properties as well as site-specific soil and environmental conditions, that vary substantially with geographical location, determine the environmental fate of a pesticide. Between tropical and temperate regions, soil properties, such as soil organic matter, chemistry of SOM, soil pH, type and content of clay minerals can be significantly different. The discussions in this chapter on the role of the these factors, particularly that of soil organic matter, in influencing the pesticide behaviour in soils from various agroclimatic regions, has demonstrated that markedly different sorption affinities of non-ionic pesticides to tropical and temperate soils are to be expected. It is evident that among various factors regulating behaviour of pesticides in soils, quantity and quality of SOM and climatic conditions are very important. Both of these soil properties vary significantly between different agroclimatic regions. Consequently, it is necessary to be very cautious while extrapolating the pesticide fate data generated in temperate environments to the soils of tropical countries.

Care need to be exercised by the pesticide registration and regulatory authorities of developing countries during the assessment, evaluation and registration of pesticides based on data from other countries. Undoubtedly, pesticides will continue to play a key role in global agriculture and due to the many pesticides in use and the many variations in soil and climatic conditions that exist, it will be difficult to obtain adequate site-specific pesticide data. While we have discussed only one of the key processes that govern pesticide risk in the environment, it hopefully has demonstrated the inadequacy of direct reliance on overseas data for solving local problems. In future, we need to focus on developing novel approaches to adapt and extrapolate overseas data keeping in mind the local peculiarities or uniqueness of soil and environmental conditions. This help harness upstream benefits from pesticide, and in minimising the potential downstream costs associated with their use.

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HERBICIDE RESISTANT CROPS IN INDIA : POTENTIAL AND PROSPECTS

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Despite significant achievements in food grain production since independence, Indian agriculture continues to face serious challenges from ever increasing population. Our population has crossed 1 billion and is expected to be 1.5 billion by 2025 and more than 2 billion by the end of this century. India would need about 300 million tonnes of food grains by 2020 i.e., an increase of about 5 million tonnes per year in the next 20 years. Weeds are a component of our crop production systems. They continually interfere with profitable crop production by competing with crop plants for nutrients, soil moisture and solar radiation. In addition, weeds can harbour insects and disease pests. Noxious weeds and weed seeds can greatly undermine crop quality. The cultivation of dwarf high yielding crop varieties responsive to fertilizers and irrigation and the new intensive cropping systems have aggravated the problem of weeds due to ecological changes. Crop pests (insects, diseases, weeds, etc.) cause about 18% loss in crop production which at current price is equivalent to Rs. 60,000/- crores annually. Weeds unlike other pests are omnipresent and account for at least one-third of this loss.

Weed management in field crops is difficult due to:

i. Complexity of weed flora

ii. Inefficient traditional methods

iii. Complexity of application of different herbicides for different weeds in varying crops.

iv. Laborious, drudgery causing and untimely

v. Adverse environmental and soil conditions

vi. Smaller land holdings

vii. Lack of technical knowledge.

Weed control through manual/mechanical though very effective, has certain limitations such as unavailability of labour during peak period, high labour cost, unfavourable environment particularly in rainy season etc. The reduced availability of labours for agricultural operations is mainly due to modernization, industrialization, decrease in land holding, migration from rural to urban areas, etc. The rural: urban population has changed from 3:1 in 1960 to 3:2 in 2000 and is expected to 3:4 by 2030 (Pingali, 4th ICSC). Biological weed control is considered environmentally benign and less expensive. However, this method is slow, often less effective and can't be used in all situations. The efficacy of bio-control agents under field conditions is highly dependent on environmental conditions. Under such conditions, use of herbicides is advantageous and economical.

The development of safe, effective and relatively inexpensive herbicides coupled with advances in application technology during the past have provided many successful weed management options in crop production. Herbicides being selective, dependable and effective against target weeds gained popularity in the recent years especially under intensive agriculture. In India use of herbicides for weed management is meager as compared to developed nations (Table 1). This is mainly due to low purchasing and risk bearing capacity as well as perception of dry land farmers about weeding. Herbicides offer a better alternative to mechanical weeding. The discovery and use of herbicides have revolutionized the agriculture in many developed countries. Despite the several advantages, many concerns like, food safety; ground water and atmospheric contamination, increased weed resistance to herbicides, destruction to beneficial organisms and concern about endangered species, etc., have also been made with the indiscriminate use of herbicides. Moreover, many herbicides are required to manage complex weed flora in different crops.

Table 1: Pesticide use in India, world and the USA (Sharma and Sharma, 1999)

Pesticide	*% Total pesticide*			
	India		*World*	*USA*
	1988	*1997*	*1994*	*1998*
Herbicide	*5*	*16*	*47*	*55*
Insecticide	*76*	*52*	*29*	*32*
Fungicide	*18*	*30*	*19*	*7*
Others	*5*	*2*	*5*	*6*

Imparting herbicide resistance to normally herbicides susceptible crops to produce herbicide resistant crops (HRCs) has been the most extensively exploited area of plant biotechnology. To date, herbicides have been tailored to be used with particular crops, rather than the crops being bred to tolerate the herbicide (Duke, 1996). Herbicides that control a broad spectrum of weed species often have limited use because they also injure crops (glyphosate, glufosinate). The most desirable herbicides for weed control and crop safety often have other less desirable environmental characteristics (e.g. non-target toxicity, environmental persistence and economic viability). Furthermore, engineering crops for resistance to existing non-selective herbicides may be a more economically viable option for agrochemical industries than the huge costs associated with the discovery, development and commercialization of new herbicides (Reddy, 2001).

Techniques for producing herbicide resistant crops

Herbicide resistance in crops can be achieved by

- Altering the target site so that the herbicide no longer binds,
- Over expressing a target enzyme so that the effect of the herbicides is overcome, or
- Detoxifying the herbicide so that it is no longer lethal to the plant.

Trends in adoption of HRC's

The first use of herbicide resistant crop was in 1994 with the introduction of IMI (Imidazolinone resistant) corn hybrids and STS (Sulfonylurea tolerant) soybean varieties. Resistant genes for several other herbicides or herbicide modes of action have been incorporated in to the genetics of corn, cotton, canola and soybean and are now commercially available. These include glyphosate (Roundup Ready) resistant soybean and corn, glufosinate (Liberty Link) resistant corn and soybean, Bromoxinyl (BXN) resistant cotton, imidazolinone (Clearfield) resistant canola and sethoxydim (Post) resistant corn. During the last nine years (1996 to 2004), global adoption rates for transgenic crops have been unprecedented and reflect grower satisfaction with the products that offer significant benefits ranging from more convenient and flexible crop management, higher productivity or net returns/hectare, and a safer environment through decreased use of conventional pesticides, which collectively contribute to a more sustainable agriculture. The global area of transgenic crops has increased by 47-fold, from 1.7 million hectares in 1996 to 81.0 million hectares in 2004. Of which, 72% (58.6 m. ha) were tolerant to specific herbicide, 19% (15.6 m. ha) were resistant to selected insect damage and 9% (6.8 m. ha) were both herbicide tolerant and insect resistant (James, 2004). Out of the total area under GM crops during 2004, USA, planted 59% of the total area (47.6 m ha) followed by Argentina (16.2 m. ha), Canada (5.4 m. ha), Brazil (5.0 m. ha) and China (3.7 m ha). In 2001, farmers planted biotechnology – derived seed on 46% of global soybean acres, 7% of global corn acres and 20% of global cotton acres. To date, nearly all the planted biotechnology-derived crops have introduced tolerance to selected herbicides for weed control or have introduced protection against pest insects.

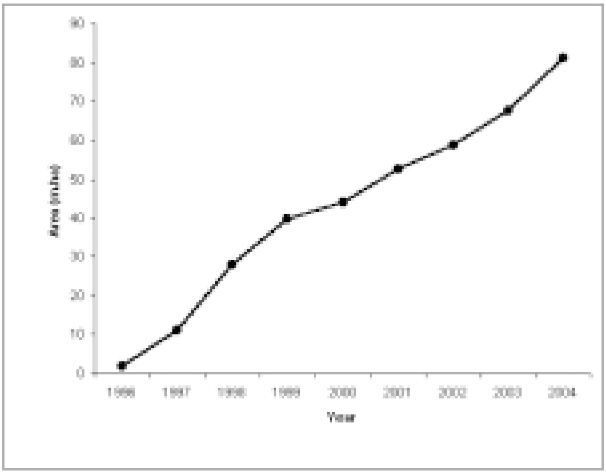

Fig 1. Global area of transgenic crops, 1996 to 2004

Herbicide tolerant soybean was the most dominant transgenic crop grown commercially in nine countries in 2004; listed in order of hectarage, the countries were the USA, Argentina, Brazil, Paraguay, Canada, Uruguay, Romania, South Africa and Mexico. Globally herbicide tolerant soybean occupied 48.4 million hectares, representing 60% of the global transgenic crop area of 81.0 million hectares for all crops. The details of dominant biotech crops are given in Table 2.

Table 2. Global area and % adoption of dominant transgenic crops and traits, 2004 (Manjunath, 2005)

Crops	*HT*	*IR*	*HT+ IR*	*Total transgenic area (m ha)*	*Global area of the crop (m ha)*	*Biotech area as % of global area*
Soybean	*48.4*	-	-	*48.4*	*86*	*56*
Corn	*4.3*	*11.2*	*3.8*	*19.3*	*32*	*28*
Cotton	*1.5*	*4.5*	*3.0*	*9.0*	*23*	*19*
Canola	*4.3*	-	-	*4.3*	*143*	*14*
Total,m ha	*58.5*	*15.7*	*6.8*	*81.0*	*284*	*29*
Trait %	*72.0*	*19.5*	*8.5*	*100.0*		

(HT= Herbicide tolerant; IR= Insect resistant)

Benefits of HRCs

- New strategies and increased flexibility to manage problem weeds.
- Multiple use of herbicides will be prevented.
- Less use of prophylactic soil-applied herbicides.
- Reduced total herbicide usage.
- Use of more environmentally benign herbicides.
- Greater adoption of conservation tillage.
- More practical use of economic thresholds in treatment decisions.
- Lack of herbicide carryover problems.
- An increased margin of safety with which herbicides can be used and subsequent reductions in crop loss due to herbicide injury.
- Reduced risk of crop damage from residual herbicides used in previous rotational crops.

Concerns

- Potential for increased use of herbicides.
- Abandonment of alternative weed control practices other than herbicides.
- Concern that HRCs may become weed problems or resistance may be transferred (through gene flow) to other species.
- Accelerated selection of resistant weed populations from use of higher rates of herbicides.
- Misuse of herbicides, leading to ground water contamination or other environmental problems.
- General public concern about the release of genetically engineered organisms in to the environment.

Potential risks from widespread use of HRCs

Direct effects

- Changes in the genetic diversity of crops (gene pollution)
- Increased HR volunteer crop problems
- Invasion of the HRCs beyond the farm boundary

Escape of transgenes from HRCs

- Introgression to weedy relatives and amplification effects of existing weeds
- Modification of gene pools of crop progenitors in center of origin and diversity

Indirect effect (associated with application of the hebicide)

- Non-selective herbicides wipe out all vegetation except the HRCs
- Impacts on diversity of flora, fauna, microclimate, food chain, wild life etc.
- Development of herbicide resistance in weeds
- Shift in weed flora
- Spray drift reaching non-HR crops grown near by

Problem of volunteer crops

It is believed that long-term use of HRCs, particularly in continuous monocultures, may create crop volunteers that are difficult to control. This has been a major concern in European countries where volunteers of conventionally bred crops are already causing significant control problems (Marshall 1998). Volunteers will be a particular concern with crops like rice, soybean, and mustard that establish readily from seeds lost during harvest. Careful consideration will therefore be needed before multiple herbicide resistance genes are stacked in the same cultivar.

Development of "Super weeds"

It is understood that crops and related wild or weedy plants can and will exchange genes through pollen transfer, if provided with the opportunity, and have been doing so ever since there have been crops and weeds (Harlan, 1982). The identification of spontaneous hybrid forms in a number of crop-weed complexes is well established, including between johnsongrass (*Sorghum halepense*) and sorghum and between wild and cultivated sunflower (Arias and Riesberg, 1994; Arriola and Ellstrand 1996). In India, wild relative of soybean and corn does not exist, as this country is not the center of origin of these crops. Therefore, introducing HR-soybean and corn in India are risk free. However, introducing HR-rice and mustard may be risk-prone as large number of wild relatives like wild rice in rice and wild mustard and many species of *Brassica* exists in our country. Hybridization between cultivated rice and red rice is common and has the potential to increase the adaptability of red rice populations (Langevin et al., 1990).

Endangering biodiversity

It is feared that large scale use of HRCs along with use of non-selective herbicides greatly imparts biodiversity. This may be true in case of the countries like USA, where single crop is grown on a larger area and use of non-selective herbicide would kill all other vegetation except the crop. But practically, despite use of HRCs on a large scale for over 8 years no detrimental effect to biodiversity has been noticed in the USA. However, in India, there is a great diversity and variability in land holding and crop choice; therefore, it is unlikely that biodiversity would be affected significantly. On the contrary the scientists from Broom's Bran Research Station (UK) showed that creative use of GM crops has in fact enriched the biodiversity. Use of HRCs facilitates the adoption of conservation tillage where in soil microbes, earthworms, beneficial insects and bird populations are maintained. GM sugarbeet has recorded a significant increase in spiders, beetles and other insects that provide important food for the nestlings of skylarks, lapwings and partridges.

Social implications

Safety of GM foods to human beings and animals has been a critical issue. A large amount of data is available today which provide a clean chit to GM food. The arguments against GM food have been largely unscientific and on 'assumed' risks rather than 'real' risks. In India the HRCs are not yet been introduced commercially. A section of the people claim that HRCs are not suited or relevant to India. They fear that HRCs replace labour and deny rural women the livelihood as most of the weeding is done by them. This argument is difficult to buy. In the same vein are we talking about banning use of herbicides and agricultural machinery as they also displace labour. In the urban scenario, does this mean we need to ban use of computers in offices and modern gadgets in the kitchen and the washing machine as they do deprive thousands of men and women their livelihood. They forget the fact that manual weeding is laborious, time consuming and drudgery causing. Herbicide provides timely, effective and economical weed control. It provides opportunity to divert labour to take up more productive agricultural enterprises. In WTO regime, it is necessary to reduce the cost of production to compete in International market.

CONCLUSIONS

- The overwhelming adoption of HRCs is primarily due to easy, efficient and often economical control of weeds.

- The movement of HR trait to weed population is a critical issue. Large-scale release of GM crops should be done with great care in regions where genetically compatible wild relatives and weeds exist.
- Long-term impact of HRCs on biodiversity and environment is yet to be fully understood.
- Contamination of non-GM food with GM food in a significant economic and political issue.
- Scientific assessment of relative risks and benefits is needed.
- There is a need for an immediate policy decision on HRCs in India.
- Unscientific and rhetoric arguments against HRCs be opposed.
- Much of the opposition is based on the fear of replacement of labour, which is totally unrelated.
- Go by the belief that every problem has a solution.

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Enhancing Food Safety: Prevention of Preharvest Aflatoxin Contamination

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INTRODUCTION

Aflatoxin contamination is an international food safety problem causing enormous economic losses in several crops, including corn, cotton seed, peanut, and tree nuts. Aflatoxins frequently contaminate agricultural commodities and thus pose serious health hazards to both humans and domestic animals (CAST 2003; Diener *et al.,* 1987; Cleveland *et al.,* 1997,Chen *et al.,* 2002, 2005). More than 50 countries have established or proposed regulations for controlling aflatoxins in foods and feeds, and at least 15 have regulations for levels of other mycotoxins (Haumann 1995). The U.S. Food and Drug Administration has set limits of 20 ppb total aflatoxins for interstate commerce of food and feed, and 0.05 ppb of aflatoxin B1 (Figure 1) for sale of milk. The most practical solution to this problem would be to prevent the contamination process in crops before harvest. One of the easiest technologies to implement by growers would be to utilize crop germplasm that possess greatly enhanced resistance to aflatoxin contamination. A major goal of the research project in our labs is to elucidate the complex natural resistance mechanisms in crops such as corn, peanut and cotton. Understanding the molecular basis of seed-based resistances will lead to identification of biochemical factors correlated with resistance for use in marker-assisted breeding and/or when pertinent resistance genes are identified and cloned, for use in enhancement of resistance in crops through genetic engineering. This strategy is especially pertinent to cotton seed, which does not possess practical levels of natural resistance to aflatoxin producing fungi in its germplasm base. Another goal is to assess resistance-related biochemical products for their stability of expression in native and transgenic crops under environmental conditions (e.g., drought) known to be conducive to aflatoxin contamination.

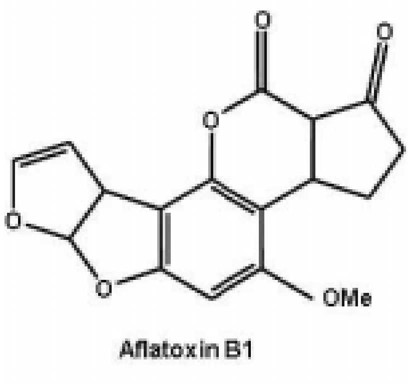

Figure 1. Chemical Structure of Aflatoxin B1

Aspergillus flavus and *A. parasiticu*s, that produce aflatoxin in several crop species including cotton, peanuts, tree nuts and corn, are not true plant pathogens but opportunistic, saprophytic fungi. Plant defense mechanisms against phytopathogens are not specific to these saprophytic fungi. At present, disease management in crop fields is practiced solely through adaptation of suitable cultural practices such as rotation, use of quality seed and fungicides and altering the time of planting (Chen *et al.,* 2005). Breeding for disease-resistant crops, especially perennial crops, is very time consuming and does not lend itself ready to combat the evolution of new virulent fungal races. The steady unraveling of complex interactions between fungal pathogens such as *Aspergilli* and host plants has already paved the way for production of disease resistant crop plants (Cornelissen and Melchers 1993, Bent 1996, Shah 1997, Mourgues *et al.,* 1998).

Transgenic approaches are being undertaken in several industry and academic laboratories to prevent invasion by *Aspergillus* fungi or to prevent biosynthesis of aflatoxin. We summarize here the recent trends in reducing aflatoxin contamination in cultivated crop species by use of natural inhibitors, biocompetitive agents, and biotechnology.

USE OF NATURAL PRODUCT INHIBITORS

There are several plant-derived, natural product inhibitors of aflatoxin synthesis and this subject has been reviewed extensively (Zaika and Buchanan 1987). Inhibitors with unknown mechanisms of action have been discovered (Zeringue and McCormick 1989; Bhatnagar and McCormick, 1988) that could be subject to utilization through direct application to crops in the field. Examples of natural products that may have potential in augmenting host plant resistance against *A. flavus* infection are certain plant derived volatile compounds (Zeringue, 1992). Earlier research efforts in this as well as other labs have shown that certain neem leaf (Bhatnagar and McCormick 1988), cotton leaf-like (Zeringue and McCormick 1990), and corn-leaf (Wilson *et al.,* 1981) volatiles can alter*Aspergillus* growth and consequently, aflatoxin production. In some cases, growth was not significantly affected while aflatoxin biosynthesis was markedly inhibited (Zeringue and McCormick, 1990), whereas in others growth and toxin production were enhanced.Furthermore, some of these compounds also demonstrated the capability to affect the organisms capacity to convert aflatoxin precursors to aflatoxins (Zeringue and Bhatnagar . 1990). The earlier studies, while measuring the effects on fungal growth and aflatoxin production, did not examine the effect of these volatile compounds on fungal development. This characterization is significant in light of earlier observations of Wilson *et al.,* (1981) and Kale *et al.,* (1996) on effects of volatiles on fungal development suggesting that there may be common regulatory elements governing both aflatoxin synthesis and conidiogenesis. In the studies by Greene-McDowelle *et al.,* (1999) and Wright *et al.,* (2000), the mode of action of cotton leaf volatiles on morphological changes that are correlated with effects on fungal growth or aflatoxin production was examined. For this purpose, two alcohols (3- methyl-1-butanol and 1-nonanol) and two terpenes (limonene and camphene) were selected for the study from a list of almost 50 volatiles identified from cotton-leaf (Zeringue and McCormick, 1990); the selected compounds exhibited significant inhibitory effects on either fungal growth or aflatoxin production. This effort was designed as a prelude to better understand fungus *(A. parasiticus*)/cotton plant interactions to elucidate mechanisms that could ultimately lead to the ability to enhance resistance of cotton to fungal invasion by affecting fungal development. Naturally derived aflatoxin inhibitors obtained from the neem tree, *Azadirachta indica* A. Juss., have also been investigated in our laboratory (Zeringue and Bhatnagar, 1996). Our investigation examined the effects of extracts of various neem tree components on aflatoxin biosynthesis by either *A. parasiticus* or *A. flavu*s.

The leaf extract formulations (1 to 40%,v/v), prepared by blending 100 g of leaves in one litre of water, when added to fungal growth medium prior to inoculation did not affect fungal growth but essentially blocked aflatoxin biosynthesis in both *A. flavus* (100%) and *A. parasiticus* (>95%) at concentrations greater than 10 per cent (v/v). Neem seed aqueous extracts were not as effective as the leaf extracts, whereas neem oil had no effect. Injection of the neem leaf extract followed by an *A. flavus* spore suspension (48 hours later) into the pericarp of developing cotton bolls (30-day post-anthesis) did not affect fungal growth in the bolls, but the seeds from the locules exhibited > 98 per cent reduction in aflatoxin production. *In vitro* studies with the fungi suggest that non-volatile neem leaf constituents inhibit aflatoxin biosynthesis in the early stages of the biosynthesis pathway. The neem-mediated inhibition appears to involve regulation of secondary metabolism; because once secondary biosynthesis was initiated the inhibitory effect of the neem leaf constituents was lost. If the inhibitory factor in neem leaf extracts could be effective in field studies, these extracts could be used in controlling the preharvest aflatoxin contamination of food and feed commodities. Such a control measure is, however, best conducted in regions of the world where the supply of fresh neem leaves is adequate.

THE USE OF BIOCOMPETITIVE AGENTS

Microorganisms have often been suggested as agent of control for aflatoxin contamination.The best biocompetitive agent to control *A. flavus* in the field would be non-toxigenic strains of *A. flavus* (Bayman and Cotty 1993; Cotty 1997; Horn and Greene 1995). *A. flavus* does not need to produce aflatoxins as a precondition to infect crops and there appears to be no relationship between the production of high levels of aflatoxins and strain virulence (Cotty 1990). The advantage that non-toxigenic strains of *A. flavus* would have over other potential microbial biocompetitive agents is that non-toxigenic strains are adapted to similar environmental conditions as toxigenic strains, and would be biologically active at the same time (Cotty *et al.,* ,1994). In greenhouse and field experiments, where developing cotton bolls or developing corn ears were wounded and then inoculated with different combinations of toxigenic and non-toxigenic strains, the non-toxigenic strains reduced preharvest aflatoxin contamination by 80-90% (Cotty and Bayman 1993; Cotty 1994). Very significant levels of reduction in aflatoxins were also obtained in peanut when a non-aflatoxin-producing strain of *A. parasiticus* was added to the soil in peanut plots (Dorner *et al.,* ,1992, 1999). Similarly, significant reductions in aflatoxin contamination were also obtained when non-toxigenic strains of *A.*

flavus inhabiting wheat kernels as a substrate were applied to cotton rows in Arizona cotton growing areas with a high incidence of aflatoxin contamination (Bock and Cotty 1999b; Antilla and Cotty 2003). The ability of non-toxigenic strains to interfere with aflatoxin contamination of various crops may, thus, have real practical value.

A. flavus fungi usually become associated with crops in the field during crop development and remain as such during harvest, storage, and processing. Thus, applying non-toxigenic strains into agricultural fields prior to crop development may provide post harvest protection from contamination as well. Non-toxigenic strains applied both prior to harvest and after harvest have been shown to provide protection from aflatoxin contamination of corn, even when toxigenic strains are associated with the crop prior to application.

Biocompetitive strains used in the above-mentioned experiments were native strains;however, the potential exists for the development of biocontrol strains through genetic engineering. Several genes governing aflatoxin biosynthesis have been cloned and have been utilized in gene disruption procedures to introduce precision deletion mutations into the fungal organism. There are probably several fungal factors that determine the ability of an *A. flavus* strains to compete in the ecological system (in the soil, plant, organic debris, etc.). Engineered strains could also be constructed with supplemented traits to optimize infection site occupation and competitiveness, while minimizing host tissue disruption.

Aflatoxin biosynthesis involves at least 23 enzymatic reactions (for a review see Yu *et al.,* 2004a); advances in the molecular biology of the genus *Aspergillus* have led to the characterization of several of the genes encoding the enzymes and to identification of aflatoxin-biosynthetic gene clusters in *A. flavus* and *A. parasiticus* (Figure 2) The uniqueness of aflatoxin biosynthesis is that a polyketide synthase and two fatty acid synthases are required for the formation of the initial anthraquinone and the C-6 side chain, respectively. Subsequent steps in the transformation include reduction, oxidative rearrangement, and anthraquinone ring modification (Bhatnagar *et al.,* 1992; Payne and Brown 1998; Minto and Townsend 1997). A positive regulator, *afl*R, of the aflatoxin pathway is also located on the 70 kb gene cluster (Yu *et al.,* 2004a).

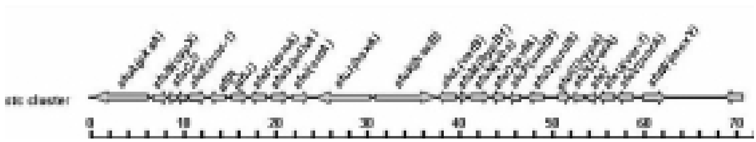

Figure 2. The 70 kb aflatoxin biosynthetic pathway gene cluster (for details refer to Yu *et al.,* 2004a)

Studies on economically important fungi at the genomic scale are an innovative strategy to unravel the mystery of mycotoxin biosynthesis and also to help better understand the biology, evolution, biochemical function, and genetic regulation of the genes in fungal systems (Yu *et al.,* 2004b). Expressed Sequence Tag (EST) technology has allowed rapid identification of the majority, if not all, of the genes expressed in fungal genomes and has lead to a better understanding of function, gene regulation, coordination of gene expression in response to internal and external factors, the relationship between primary and secondary metabolism, plant-fungal interaction and fungal pathogenicity as well as evolutionary biology (Yu *et al.,* 2004c). A microarray, made from the EST sequences, can be used to detect a whole set of genes expressed under specific environmental conditions.This technology allows us to study, simultaneously, a complete set of fungal genes that are responsible for or related to mycotoxin production (OBrian *et al.,* 2003; Pirttilä *et al.,* 2004; Price *et al.,* 2005). The genomics of toxigenic fungi are expected to provide valuable information on turning on or off of toxin production in fungal systems. It will provide vital clues for identifying antifungal gene(s), eliminating pre-harvest mycotoxin contamination of crops, improving high efficiency production of industrial enzymes and accelerating drug development in the near future.

SCREENING FOR RESISTANCE THROUGH TRADITIONAL BREEDING

Corn

Screening corn for resistance to kernel infection by *A. flavus* or for resistance to aflatoxin production is a more difficult task than most disease screening. Successful screening in the past had been hindered (King and Wallin 1983) by the lack of 1) a resistant control; 2) inoculation methods that yield infection/aflatoxin levels high enough to differentiate among genotypes (natural infection is undependable); 3) repeatability across different locations and years; and, 4) rapid and inexpensive methods for assessment of fungal infection and aflatoxin levels.

Several inoculation methods, including the pinbar inoculation technique (for inoculating kernels through husks), the silk inoculation technique, and infesting corn ears with insect larvae infected with *A. flavus* conidia have been tried with varying degrees of success (King and Scott 1982; Turcker *et al.,* 1986). These methods can each be useful individually.However, clarity must exist as to the actual resistance trait to be measured (e.g. husk tightness; silk traits; the kernel pericarp barrier; wounded kernel resistance), before an appropriate technique can be employed. Silk inoculation, however, (possibly more dependent upon the plant's physiological stage and/ or environmental conditions) has proven to be the most inconsistent of the inoculation methods (Payne 1992).

Plating kernels to determine the frequency of kernel infection or examining kernels for emission of a bright greenish-yellow fluorescence (BGYF) are methods that have been used for assessing *A. flavus* infection (King and Wallin 1983). While both methods can indicate the presence of *A. flavus* in seed, neither can provide the kind of accurate quantitative or tissue-localization data useful for effective resistance breeding. Protocols have, however, been developed and used for separation and relatively accurate quantitation of aflatoxin (Shotwell 1983; Wilson *et al.,* 1998).

Most efforts aimed at the identification of resistant corn genotypes, until recently, were successful only to a very limited extent (Widstrom 1987). The hindrances to resistance screening, discussed above, certainly played key roles in this lack of success (Scott and Zummo 1988). However, two resistant inbreds (Mp420 and Mp313E) were discovered and tested in field trials at different locations and released as sources of resistant germplasm (Scott and Zummo 1988; Windham and Williams 1998). The pinbar inoculation technique was one of the methods employed in the initial trials, and contributed towards the separation of resistant from susceptible lines (Scott and Zummo 988). Several other inbreds, demonstrating resistance to aflatoxin contamination in Illinois fields trials (employing a modified pinbar technique) also were discovered (Campbell and White 1995). The most promising sources of resistance among these appear to be Tex6, C12, OH516,M182, and LB31 (White *et al.,* 1999). Another source of resistance germplasm is the corn breeding population, GT-MAS:gk. This population was derived from visibly classified segregating kernels, obtained from a single fungus infected hybrid ear (Widstrom 1987). It tested resistant in trials conducted over a five year period, where a kernel knife inoculationtechnique was employed. Recently, a resistant inbred was released after successful field trials in Mississippi (Williams *et al.,* 1999b).

Discoveries of resistant germplasm may have been facilitated by the use of inoculation techniques capable of repeatedly providing high infection/aflatoxin levels for genotype separation to occur. The identified resistant corn lines do not generally possess commercially acceptable agronomic traits. However, they may be invaluable sources of resistance genes, and as such, provide a basis for the rapid development of host resistance strategies to eliminate aflatoxin contamination.

Other sources of corn germplasm with greater tolerance for high temperatures and humidity have been successfully tested for resistance to aflatoxin production in South Texas (Dunlap 1995). These tropical hybrids all developed tight husks. Also, kernels were shown to resist aflatoxin contamination unless kernel pericarps were breached. These heat tolerant tropical hybrids may offer new choices for producers operating in the southern portion of the United States where aflatoxin contamination is an ongoing problem.

Peanut

Several sources of resistant peanut germplasm have been identified from a core collection representing the entire peanut germplasm collection (Holbrook *et al.,* 1995). Over 95% of this core collection has been preliminarily screened in a single environment; and sixteen genotypes tested over three years in two environments still display low levels of aflatoxin.

A possible link between low linoleic acid content in peanut and low preharvest aflatoxin production has been indicated (Holbrook *et al.,* 1995). Significant correlations have also been observed between leaf temperature and aflatoxin levels and/or visual stress ratings and aflatoxin levels. The preliminary screening of peanut genotypes using either or both of these traits could greatly reduce expenses involved in developing resistant cultivars. Promising germplasm, however, has less than acceptable agronomic characteristics, and is thus being hybridized with those with commercially acceptable features. Resistant lines are also being crossed to pool resistances to aflatoxin production. Thus, some success has been achieved in identifying resistant peanut germplasm, and field studies are being conducted by various researchers to verify this trait.

Methods to improve screening of peanuts for resistance to *A. flavus* have been developed. A system of evaluating peanuts in the field through the manipulation of drought stress was successfully tested (Mehan *et al.,* ,1988). Also, an *in vitro* seed culture system, demonstrating water stress responses in peanuts similar to field responses, and variations in peanut phytoalexins and aflatoxin levels appear potentially useful (Basha *et al.,* ,1994).

Tree Nuts

Among tree nuts, strategies for controlling preharvest aflatoxin formation by breeding for host resistance have been mostly studied in almonds (Gradziel *et al.,* 1995). The approach employed in this effort is to integrate multiple genetic mechanisms for control of *Aspergillus spp.* as well as Navel orangeworm *(Paramyelois transitella* Walk), which appears important for initial fungal infection. Resistance to fungal colonization has been shown to be present in the undamaged seed coat of several advanced breeding selections and is further being pursued through breeding/genetic engineering of resistance to *A. flavus* in kernel tissue and also by developing genotypes that produce low amounts of aflatoxin following fungal infections (Gradziel and Dandekar 1999). Studies have also been conducted with figs and pistachios to identify the mode of infection of the crops by *A. flavu*s. McGranahan *et al.,* (1999) reported that evaluation of 26 walnut cultivars, representing a range of germplasm at USDA, WRRC, has resulted in identification of one variety, Tulare, for its consistent low aflatoxin content, possibly due to its intact seed coat. The value of the intact seed coat in preventing aflatoxin problem was also considered as one of the factors in the low aflatoxin producing variety, Tulare. This variety has been utilized in several crosses with high aflatoxin producing varieties such as Hartley. Upon further analyses, it has been well established by Mahoney and

Mullineux (2004) that precursor(s) of hydrolysable tannins (HT), gallic acid, within the pellicle tissues are responsible for tolerance to A. *flavus* infection in Tulare. Identification of natural sources of resistance to aflatoxin synthesis has helped researchers to evaluate genetics of the trait and to identify genetic component. Once these parameters are clearly understood, strategies could be developed to identify germplasm with agronomically desirable characteristics and resistance to fungal infection(Doster *et al.,* 1995).

Cotton

Cultivated cottons belong to the following four species .The diploid *Gossypium arboreum* and G. *herbaceu*m, often referred to as old world cottons and the tetraploid *Gossypium hirsutum* and G. *barbadens*e. Systematic study of all cotton genotypes to identify lines resistant to *Aspergillus* has not been done so far and there is no known resistant line among cultivated cotton. Thus, genetic engineering offers a novel means of introducing the resistance trait into cultivated species.

DEVELOPMENT OF TESTER STRAINS AND METHODS TO ASSESS RESISTANCE TO *ASPERGILLUS*

Many aspects of regulation of fungal aflatoxin biosynthesis as well as fungal-plant interactions have been examined through the use of fungal strains that have been transformed with reporter gene constructs (reviewed in Cary *et al.,* 2000c; Brown *et al.,* 1995; Du *et al.,* 1999). Reporter genes utilized include the *E. coli uidA* (â -glucuronidase; GUS) gene and the green fluorescent protein (GFP) from the jellyfish, *Aequorea victori*a. With either reporter gene, in vivo expression can be measured qualitatively using a rapid calorimetric assay (GUS) or by fluorescent microscopy (GFP), or quantitatively using fluorometry. Advantages in using GFP-based reporter systems over GUS-based include no destruction of the biological sample, no requirement for added substrates or cofactors for fluorescence measurements, and real-time observation of tissue colonization by the fungus. A number of studies have utilized *A. flavus* and *A. parasiticus* transformed with vectors harboring aflatoxin pathway gene promoter elements driving the expression of GUS to examine regulation of aflatoxin pathway gene expression (Flaherty *et al.,* 1995; Liang *et al.,* 1997; Payne, 1999) and promoter function (Ehrlich *et al.,* 1999; Cary *et al.,* 2000b).Placement of the GUS gene under the control of the *A. parasiticus* aflatoxin biosynthetic gene *ver-1A* promoter showed that GUS activity paralleled AFB1 accumulation suggesting that the rate of transcription plays a role in determining AFB1 production (Liang *et al.,* 1997).These experiments also demonstrated that integration of the *ver-1*A::GUS DNA at the *niaD* (selectable marker gene) locus resulted in 500-fold lower GUS activity than if the DNA integrated adjacent to the *ver-1A* region in the aflatoxin gene cluster. This indicated that local chromatin structure may play a role in determining the level of gene expression in this organism. In an effort to determine if the *aflJ* gene is involved in the regulation of transcription in *A. flavu*s, an atoxigenic strain of *A. flavus* (due to deletion of the entire AF gene cluster) constitutively expressing *aflR* and/or *aflJ* was transformed with either *omt*A::GUS or *ver*-1::GUS plasmid DNA (Payne, 1999). Results showed that *aflR* was required for expression of GUS activity and that the presence of *aflJ* did not increase levels of transcription of either of the GUS constructs. Regions of DNA within the promoter elements of the *A. parasiticus aflR* gene Ehrlich *et al.,* 1999) and *avnA* gene (Cary *et al.,* 2000b) that are required for or modulate aflatoxin gene expression were determined in part through the use of truncated versions of the respective promoters fused with the GUS gene.

Both housekeeping and aflatoxin pathway gene promoters driving the expression of GUS and GFP have been used as a means of following the invasion of aflatoxigenic fungi in plants, identification of resistant verses susceptible germplasm, and the identification of plant metabolites that inhibit fungal growth and/or production of aflatoxin (Brown *et al.,* 1995; Du *et al.,* 1999; Rajasekaran *et al.,* 1999a; Cary *et al.,* 2000d). Inoculation of intact or pin wounded corn kernels with an *A. flavus* strain expressing GUS fused to the *A. flavus* â -tubulin gene promoter (for constitutive expression) was used to observe fungal colonization of seed tissue as well as to determine levels of resistance of seed varieties to fungal invasion (Brown *et al.,* 1995; 1997a). Results showed that the fungus first invaded the embryonic tissue and then colonized the endosperm. A direct correlation between GUS activity (fungal colonization) and aflatoxin production was observed with reported susceptible genotypes demonstrating more GUS staining than reported resistant genotypes. A similar study utilized cytomegalovirus promoter fused to GFP to monitor fungal colonization of both resistant and susceptible lines of corn kernels (Du *et al.,* 1999). In addition, GFP was also translationally fused with the *A. flavus aflR* promoter-ORF. In both cases, more fluorescence was observed over the cut surface of the kernels of reported susceptible genotypes compared to resistant genotypes. These types of studies have also been performed in the field using pinbar wounded ears of resistant or susceptible corn hybrids inoculated with a â -tubulin::GUS *A. flavus* strain (Windham *et al.,* 1998;1999). Results mimicked *in vitro* corn kernel assays with GUS activity observed almost exclusivelyin the embryo of the kernel and in the vascular tissue in the rachis and rachilla regions of the cob. GUS activity was observed more often and at higher levels in reported susceptible varieties. An *A. flavus* strain transformed with GFP fused to an *A. nidulans* glyceraldehyde phosphate dehydrogenase *(gpd*A) gene promoter was used to study the progress of *A.flavus* infection of peanut pods (Ingram *et al.,* 1999). Fluorescence was greater underconditions of low rather than high water availability for both drought susceptible and resistant peanut varieties. The *A. flavus gp*d::GFP strain (Figure 3) was also used to look at levels and localization of infection of cottonseed inoculated with the fungal reporter strain (Rajasekaran *et al.,* 1999a; Cary *et al.,* 2000d). GUS reporter systems have also been used in an effort to identify compounds from plants and other organisms that either induce or inhibit the growth of *A. flavus* and toxin production. Flaherty *et al.,* (1995) using a *ver*-1:: GUS *A. flavus* transformant identified a heat stabile inducer of aflatoxin in extracts of maize kernels colonized by *A. flavu*s. An inhibitor of fungal growth was detected in extracts of black pepper by measuring expression of GUS activity in an *A. flavus* strain transformed with a *nor*-1::GUS construct (Velasquez *et al.,* 1998).

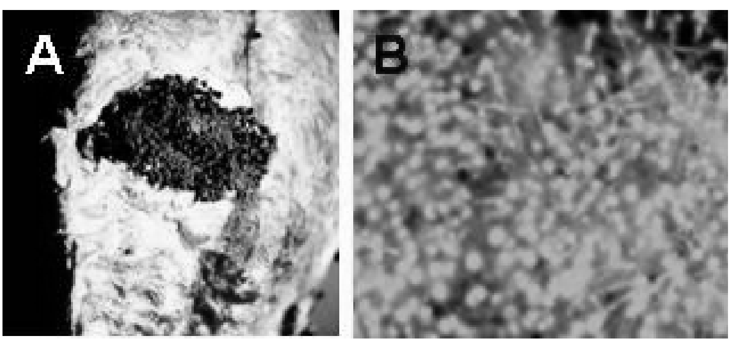

Figure 3. A) Light micrograph of a locule from an immature cotton boll showing growth of *A. flavus* GFP strain at the inoculated site (2.5x). B) Fluorescence of conidia and mycelium of *A. flavus* GFP at 485 nm(5x). Measurement of fluorescence due to *A. flavus* GFP strain is proportional to fungal growth and colonization (Rajasekaran, unpublished).

IMPROVED METHODS TO ASSESS RESISTANCE TO *ASPERGILLUS*

New Screening Methods. A laboratory kernel screening assay (KSA; Figure 4) was developed and used to study resistance to aflatoxin production in GT-MAS:gk kernels (Brown *et al.,* 1993). This assay employs a very simple and inexpensive apparatus such as bioassay trays, petri dishes, vial caps as seed containers, and chromatography paper for holding moisture (Brown *et al.,* 1995). Kernels screened by the KSA are maintained in 100% humidity, at a temperature (31^0 C) favoring *A. flavus* growth and aflatoxin production, and are usually incubated for up to seven days. Aflatoxin data from KSA experiments can be obtained two weeks after experiments are initiated. KSA experiments confirmed GT-MAS: gk resistance to aflatoxin production and demonstrated that it is maintained even when the pericarp barrier, in otherwise viable kernels, is breached (Brown *et al.,* 1993). Penetration through the pericarp barrier was achieved by wounding the kernel with a hypodermic needle down to the endosperm, prior to inoculation. Wounding facilitates differentiation between different resistance mechanisms in operation, and the manipulation of aflatoxin levels in kernels for comparison with other traits (e.g. fungal growth; protein induction). The results of this study indicate the presence of two levels of resistance - at the pericarp and at the subpericarp level. The former was supported by KSA studies which demonstrated a role for pericarp waxes in kernel resistance (Guo et al 1995; 1996a), and highlighted quantitative and qualitative differences in pericarp between GT-MAS:gk and susceptible genotypes (Russin *et al.,* 1997). Current investigations will identify specific chemical compounds associated with pericarp resistance (Gembeh *et al.,* 2000).

The KSA also confirmed sources of resistance among the inbreds tested in Illinois field trials (Brown *et al.,* 1995; Campbell and White 1995). Subsequently, when selected resistant Illinois inbreds (M182, C12, and T115) were examined by the KSA, modified to include an *A. flavus* GUS transformant (a strain genetically engineered with GUS gene driven by a â -tubulin gene promoter for monitoring fungal growth), kernel resistance to fungal infection in non-wounded and wounded kernels was demonstrated both visually and quantitatively, as was a positive relationship between the degree of fungal infection and aflatoxin levels (Brown *et al.,* 1995; 1997b). Thus, it is now possible to accurately assess fungal infection levels and to determine if a correlation exists between infection and aflatoxin levels in the same kernels. *A. flavus* GUS transformants with the reporter gene linked to an aflatoxin biosynthetic pathway gene could also provide a quick and economical way to indirectly measure aflatoxin levels (Payne 1997).

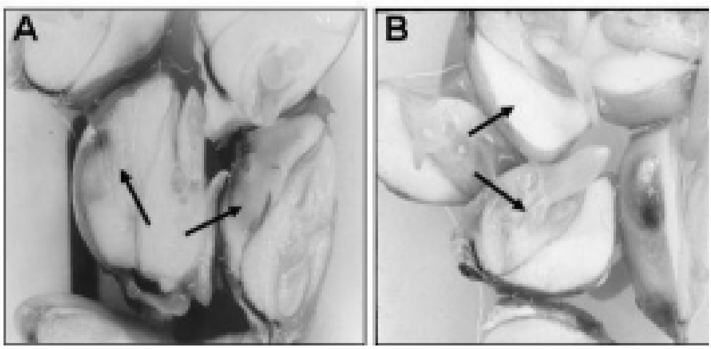

Figure 4. Kernel Screening Assay with *A. flavus* expressing GUS - Blue color indicates presence of fungalinfection of corn kernels seed (A). Resistant kernels do not develop blue color (B)

GUS transformants have also been used to localize and compare fungal growth and aflatoxin biosynthesis between resistant and susceptible corn cobs in field trials, contributing to a better understanding of the infection process, fungal spread, and sites of aflatoxin biosynthesis (Windham *et al.,*1999). *A. flavus* transformants expressing GFP reporter gene constructs can be used to obtain similar results as GUS transformants, and have some advantages over GUS. GFP is less expensive, less labor-intensive, and it can be monitored in living systems (Brown *et al.,* 1997b; Payne 1997).

The kernel screening assay has several advantages to complement traditional breeding techniques (Brown *et al.,* 1995): 1) can be performed and repeated several times throughout the year and outside of the growing season; 2) requires few kernels; 3) can detect/identify different kernel resistance mechanisms expressed; 4) can dispute or confirm field evaluations (e.g. identify escapes); and, 5) demonstrate relationships between laboratory findings and inoculations in the field. Field trials are irreplaceable for confirmation of resistance; however, the KSA may eliminate many preliminary field screenings, and facilitate an in-depth investigation of kernel responses to fungal infection and aflatoxin production.

Molecular genetic strategies. Several of the resistant Illinois inbreds have been incorporated into a breeding program whose major objective is to improve elite mid western corn lines such as B73 and Mol 7. In this program, a generation means analysis mating design was employed to determine the inheritance of resistance of inbreds in crosses with B73 and/or Mol 7 (White *et al.,* 1995a). In the case of several highly resistant inbreds, Tex 6, LB31, C12, and Oh513, genetic dominance was indicated. This study demonstrates that selection for resistance to *Aspergillus* ear rot and aflatoxin production should be effective.Also, the frequency distribution of ear rot ratings and aflatoxin production of F3 families and of backcrosses to the susceptible self families of Mol 7 x Tex 6 and B73 x LB31 point to the possibility of success in the development of resistant inbreds for use in breeding commercial hybrids (White *et al.,* 1995b).

Chromosome regions associated with resistance to *A. flavus* and inhibition of aflatoxin production in corn have been identified through RFLP analysis in three resistant lines (R001, LB31, and Tex 6) in the Illinois breeding program, after mapping populations were developed using B73 and/or Mol 7 elite inbreds (White *et al.,* 1995a). In some cases, chromosomal regions were associated with resistance to *Aspergillus* ear rot and not aflatoxin inhibition, and *vice versa,* whereas other chromosomal regions were found to be associated with both traits. This suggests that these two traits may be at least partially under separate genetic control. Also, it was observed that variation can exist in the chromosomal regions associated with *Aspergillus* ear rot and aflatoxin inhibition in different mapping populations, suggesting the presence of separate genes for resistance in the identified resistant germplasm. RFLP technology may provide the basis for employing a successful strategy of pyramiding different types of resistances into commercially viable germplasm, while avoiding the introduction of undesirable traits.

Identification of biochemical resistance traits. Developing resistance to fungal infection in wounded as well as intact kernels would go a long way toward solving the aflatoxin problem (Payne 1992). Studies demonstrating subpericarp (wounded-kernel) resistance in corn kernels have led to research with the aim of identifying subpericarp resistance mechanisms. When kernels of susceptible genotypes were allowed to imbibe water at 100% humidity at 31^{0}C for 3 days prior to being subjected to the KSA protocol, aflatoxin levels were drastically and significantly reduced compared to unimbibed controls (Guo *et al.,* 1996b). Kernel proteins induced during imbibition may have inhibited growth and/or fungal elaboration of aflatoxins. Examinations of kernel proteins of several genotypes revealed several germination-induced synthesis of ribosome inactivating protein (RIP) and zeamatin in imbibed susceptible kernels with decreased aflatoxin levels (Guo *et al.,* 1997). Both zeamatin and RIP have demonstrated *in vitro* inhibition of *A. flavus* growth (Guo *et al.,*1997). These studies implicate the proteins as potentially involved in kernel resistance to *A. flavus* infection and aflatoxin production.

In a recent study, two kernel proteins were identified from resistant inbred Tex6 which may contribute to resistance to aflatoxin production (Huang *et al.,* 1997). One of the proteins, 29 kDa in size, inhibits *A. flavus* growth, while a second, with a molecular mass greater than 100 kDa, inhibits toxin formation with little effect on fungal growth. In another investigation, an examination of kernel protein profiles of 13 corn genotypes revealed that a 14 kDa trypsin inhibitor (TI) protein is present at relatively high concentrations in seven resistant ones, but is present only in low concentrations in six susceptible ones; This protein exhibits strong bioactivity against the growth of *A. flavus, A. parasiticu*s, and a morphologically diverse group of other fungi (Chen *et al.,* 1998). Trypsin inhibitor antifungal activity may be partially due to its inhibition of fungal alpha-amylase (Chen 1999).Comparisons of kernel protein profiles between susceptible and resistant genotypes may shorten the time it takes to identify resistance-associated proteins. The use of proteomics and large-gel formats can significantly enhance discovery of these proteins (Chen *et al.,*2000), which may, in turn, provide markers for plant breeders, and may facilitate the introduction of resistance, through genetic engineering, into other aflatoxin-susceptible crops. In our laboratory, cotton has been genetically transformed to express the 14 kDa trypsin inhibitor (Rajasekaran *et al.,* 2002). A QTL mapping study is also underway to genetically characterize this proteins contribution to resistance in certain corn genotypes, and to determine its regulation (Brown *et al.,* 1997b).

Studies employing the KSA as well as other studies (Keller *et al.,* 1994) have demonstrated that kernel embryos are preferred as a substrate over endosperm tissue by aflatoxin-producing fungi. Embryo viability has also been shown to be necessary for the expression of kernel resistance (Brown *et al.,*1993). This suggests that resistance, especially in wounded kernels, is a function of kernel ability to limit fungal colonization to a small area after wounding, thus providing kernels with a two-pronged defense. This defense may include: 1) preventing interruption due to whole-kernel expression of an embryo-based resistance mechanism; and 2) denying the fungus easy access to the oil-rich embryonic substrate (Brown *et al.,* 1997b). Whether or not the large levels of aflatoxins found in susceptible kernels are the primary result of fungal metabolic activity on the embryonic substrate, or of later activity in the endosperm, is under investigation in our laboratory.

Using proteomics to identify protein factors associated with kernel resistance. A proteomics approach was recently employed to increase protein resolution and detection sensitivity and, thus, enhance the ability to identify additional resistance associated proteins (RAPs) (Chen *et al.,* 2002a). Endosperm and embryo proteins from several aflatoxin resistant and susceptible genotypes have been compared using large format 2-D gel electrophoresis, and over a dozen such protein spots, either unique or 5-fold upregulated in resistant lines, have been identified, isolated from preparative 2-D gels and analyzed using ESI-MS/MS after in-gel digestion with trypsin (Chen *et al.,* 2002b, 2004). These proteins can be grouped into three categories based on their peptide sequence homology: (1) storage proteins, such as GLB1, GLB2, and late embryogenesis abundant proteins (LEA3, LEA14); (2) stress-responsive proteins, such as aldose reductase (ALD), a glyoxalase I protein (GLX I), and a 16.9 kDa heat shock protein (HSP), and (3) antifungal proteins, which include TI, and pathogenesis-related protein 10 (PR-10).

The indication of stress-related proteins playing a role in host resistance based on the proteomic comparisons agrees with earlier field studies. Increased temperatures and drought, which often occur together, are major factors associated with aflatoxin contamination of corn kernels (Payne 1998). Other studies have found that drought stress imposed during grain filling reduces dry matter accumulation in kernels. This often leads to cracks in the seed and provides an easy entry site to fungi and insects. Possession of unique or of higher levels of hydrophilic storage or stress-related proteins, such as the afore-mentioned, may render resistant lines an advantage over susceptible genotypes in the ability to synthesize proteins and provide protection against fungal invasion under stress conditions.

Breeding for near isogenic inbred lines differing in aflatoxin resistance. Several US maize lines that have demonstrated resistance to *A. flavus* infection and aflatoxin production have been crossed by Dr. Abebe Menkir at International Institute of Tropical Agriculture, Ibadan, Nigeria, with several African lines that demonstrate resistance to ear rot diseases. The African lines, adapted to the savanna and mid-altitude ecological zones of West and Central Africa, had demonstrated moderate to high levels of resistance to *Aspergillus, Botrydiplodia, Diplodia, Fusarium,* and/or *Macropomin*a. Two collections of populations derived from crosses between U.S. and African lines were developed; a tropical collection, each population resulting from 50% U.S. and 50% African contribution;and a temperate collection with populations containing 75% U.S. x 25% African (F1backcrossed to U.S. parent) germplasm. After each selfed generation, through S3, visual selection within and among lines was made using agronomic characteristics and foliar disease resistance. The S4 generation, was the first screened using the KSA (Brown et al.,1995), and five pairs of near isogenic maize lines, differing significantly in aflatoxin accumulation, were identified. These near isogenic lines are ideal materials for identifying factors that associated with kernel aflatoxin resistance and the understanding of host resistance mechanisms in maize.

GENETIC ENGINEERING TO ENHANCE RESISTANCE TO *ASPERGILLUS* AND OTHER FUNGALPATHOGENS

Successful generation of plants genetically engineered to resist fungal invasion and aflatoxin production will depend in large part on development of binary transformation vectors harboring 1) genes encoding efficacious native or foreign antifungal/anti-aflatoxin factors (i.e. proteins/peptides; 2) promoter elements that will provide efficacious levels of expression of the antifungal genes in desired tissues and stage of development; 3) resistance gene markers that will provide a reliable and efficient means of selection for transformed plant tissues. This section will only address potential antifungal genes as many of the proprietary promoters, selectable resistance genes, and transcriptional terminators have been described (ie CaMV 35S promoter, NPT II selectable marker and nopaline synthase terminator) (Potenza 2004).

Proteins capable of inhibiting growth of fungi and bacteria are present in plants, insects,animals, and micro organisms (Punja 2004, Rajasekaran *et al.,* 2002). Transgenic expression of antifungal proteins and peptides to develop disease resistant crops has been demonstrated with some degrees of success in other crops by introducing hydrolytic enzymes such as chitinases, glucanases and lysozymes that are capable of degrading fungal cell walls, RIPs, lectins, relatively small MW polypeptides, osmotins, cell-surface glycoproteins (Herrera-Estrella and Simpson 1995, Graham and Sticklen 1994, Salmeron and Vernooij 1998, Mourgues *et al.,* 1998).

In search of antifungal proteins Jacks etl. (1991) used *in vitro* bioassays with *A. flavus* as the test organism, and documented that addition of a haloperoxidase, myeloperoxidase, greatly enhanced (90-fold) the lethality of H2O2 by catalyzing its conversion to sodium hypochlorite (Jacks *et al.,* 1991). A bacterial chloroperoxidase also greatly reduced the viability of *A. flavus* conidia (Jacks *et al.,* 1998) and the transgenic tobacco plants expressing chloroperoxidase (CPO), isolated from *Pseudomonas pyrrocini*a, showed increased antifungal traits. This particular CPO enzyme neither require a metal ion co-factor nor a heme prosthetic group for activity; as such it proved to be an ideal candidate for genetic transformation of plants. CPO is believed to inhibit fungal growth via the formation of peracetic acid and hypohalites from hydrogen peroxide generated during fungal invasion of plant tissue (Jacks *et al.,* 1998).

Several lines of evidence indicate that products of the lipoxygenase (LOX) pathway in certain plants inhibit *A. flavus* spore germination and mycotoxin production *in vitro* (Burow *et al.,* 1997). The *lox1* genes from soybean and peanut have been cloned and the activities of their products against both *Aspergillus* growth and toxin synthesis determined. The soybean *lox1* gene has been transformed into peanut but attempts to identify lines expressing the gene have been inconclusive (Ozias-Akins *et al.,* 1999).

Antimicrobial peptides appear to be ubiquitous in nature being found in many organisms, from humans to bacteria (Rao 1995, Ganz and Lehrer 1999, Hancock and Chapple 1999,De Lucca 2000). Various plants produce, either preformed or in response to microbial invasion, cysteine-rich antimicrobial peptides such as thionins, defensins, lipid transfer proteins, and hevein- and knottin-type peptides (Broekaert *et al.,* 1997). Examples of antimicrobial peptides of mammalian and insect origin include bovine or human defensins and protegrins (Ganz and Lehrer 1999), magainins from amphibians (Zasloff 1987), and cecropins from the giant silk moth, *Hyalophora cecropia* (Hultmark *et al.,* 1982). The antimicrobial peptides (AMPs) have been shown to be effective against a wide array of microorganisms including mycotoxigenic fungi (De Lucca 2000; Rajasekaran *et al.,* 2001). Antifungal peptides act either by lysing the fungal cell (Ganz and Lehrer 1999, Hancock and Chapple 1999, Shai 1995, Christensen *et al.,* 1988) or by interfering with cell wall synthesis (Debono and Gordee 1994). Transgenic plants expressing naturally-occurring or synthetic peptides have been shown to confer resistance to microbial pathogens in model species such as tobacco. For example, Reynoird *et al.,* (1999) demonstrated improved fire blight resistance in transgenic pear expressing the *attacin E* gene from *H. cecropi*a. Cecropin and cecropin analogs have been expressed in transgenic tobacco *(Nicotiana tabacu*m) with mixed results regarding pathogen resistance. Huang *et al.,* (1997) and Jaynes *et al.,* (1993) demonstrated reduced disease severity in transgenic tobacco expressing cecropin analogs upon infection with the bacterial pathogens, *Pseudomonas syringae* pv. *tabaci and P. solanacearu*m, respectively. However, tobacco plants expressing a native cecropin did not confer resistance to *P. syringae* pv. *tabaci* or *P. solanacearum* presumably due to degradation of the peptide by host proteases (Hightower *et al.,* 1994, Florack *et al.,* 1995). Huang *et al.,* (1997) increased the stability of cecropin B significantly in transgenic tobacco by using a mutant form carrying a single amino acid change. The advent of automated peptide synthesizers and computer-assisted combinatorial peptide chemistry has made it possible to rapidly synthesize, and screen large numbers of peptides for their ability to inhibit the growth of target microbial pathogens (Mayo 2000). These linear, synthetic peptides often can be less than half the size (10-20 amino acids) of their native counterparts and many times more stable and potent without concomitant toxicity to host tissues. One such synthetic peptide, D4E1, has been found to possess broad-spectrum control over several phytopathogens, both fungal and bacterial, including *A. flavus* and *A. parasiticus* (De Lucca *et al.,* 1998, Rajasekaran *et al.,* 2001), and transgenic tobacco plants expressing D4E1 demonstrated increased resistance to *A. flavus* and other phytopathogens (Cary et al 2000a).

The incidence and levels of aflatoxin accumulation in crops susceptible to aflatoxin contamination are due, in part, to wounding of plant tissues by insect pathogens which create avenues of entry for *A. flavu*s. Crops such as cotton, corn, and peanut have been engineered to express *Bacillus thuringiensis* (Bt) genes encoding insecticidal proteins that are toxic to many of the lepidopteran pathogens that feed on these crops. Recent studies on corn have been inconclusive or shown no distinct benefit of Bt- vs. non-Bt corn for the prevention of aflatoxin contamination (Williams *et al.,* 1999a and Wilson *et al.,* 1999). In cotton, studies have shown that aflatoxin contamination is not directly correlated with pink bollworm damage and contamination may occur in the absence of damage (Henneberry *et al.,* 1978; Russell, 1980). Bock and Cotty (1999a) reported that in 1996, transgenic Bt vs. non-Bt cotton seed were similarly contaminated with aflatoxin.

Based on results obtained in our lab and those of others, it has become apparent that complete prevention of aflatoxin contamination will most likely require the introduction of a combination of resistance genes (pyramiding) into the plant rather than a single gene. This will require the development of binary vector constructs for expression of two or more different antifungal genes. Therefore, emphasis must be focused on identification of more candidate antifungal products and the gene(s) that encode them. This can be accomplished through 1) continued identification of non-host plant antifungal proteins/ peptides ; 2) development and testing of synthetic peptides with antifungal activity ; and 3) identification of resistance factors in the host plant using techniques such as genomics/proteomics and molecular mapping of quantitative trait loci (QTLs) as well as conventional biochemical analyses. Additionally, continued molecular dissection of the fungal aflatoxin biosynthetic pathway and elucidation of the mechanisms regulating its expression during growth on the host plant may lead to the identification of genes that encode products capable of interrupting toxin synthesis. Currently we are exploring the possibilities of increased expression of antifungal genes in chloroplasts (DeGray *et al.,*2000). Plastid transformation presents an attractive alternative to nuclear transformation and offers the potential to ameliorate environmental concerns due to pollen escape (Daniell *et al.,* 2002)

The different approaches for developing transgenic disease resistant crops to combat preharvest aflatoxin contamination are discussed below. Examples are drawn from other plants or model plants such as tobacco since the number of publications on transgenic disease resistant crops is rather very limited. Indeed, efficiency of antifungal or antibacterial effects is difficult to evaluate prior to actual transformation of the test plant. Current approaches to developing disease resistant plants through enhancing natural defense mechanisms and/or introduction of antimicrobial proteins or peptides are summarized here.

Cotton

Antifungal activity against *A. flavus* was demonstrated with transgenic cottons expressing the chloroperoxidase gene (Jacks *et al.,* 2002) similar to the results with the transgenic tobacco plants (Rajasekaran *et al.,* 2000). Cotton has also been transformed to express the 14 kDa corn trypsin inhibitor (Rajasekaran *et al.,* 2002) that has been associated with resistance to the mycotoxin causing fungus, *A. flavus* (Chen *et al.,* 1998) and with the gene encoding a synthetic linear peptide, D4E1 (Rajasekaran *et al.,* 1999b; Cary *et al.,* 2000a). Extracts of transgenic tobacco expressing CPO demonstrated inhibition of *A. flavus* growth while *in planta* assays showed reduction in anthracnose symptoms caused by *Colletotrichum destructivum* on inoculated tobacco leaves (Rajasekaran *et al.,* 2000). Similarly, transgenic cotton seedlings, expressing CPO or D4E1, showed resistance to damage by the seedling pathogen, *Thielaviopsis basicola* and significant control *in vitro* and *in situ* of *A. flavus* (Rajasekaran *et al.,* 2003). Performance of these transgenic cottons under field conditions are yet to be determined in the coming years. Another antifungal protein encoding a trypsin inhibitor protein (TI) from an aflatoxin-resistant corn was identified and was demonstrated to inhibit the growth of *A. flavus in vitro* (Chen *et al.,* 1998). Cotton or tobacco plants transformed with a binary vector harboring TI were regenerated but the expression levels were too low to control *A. flavus* but were more than sufficient to control *Verticillium dahliae* (Rajasekaran *et al.,* 2002; Wilkins *et al.,* 2000). Recently Emani *et al.,* (2003) transformed cotton plants with a cDNA clone encoding a 42 kDa endochitinase from the mycoparasitic fungus, *Trichoderma virens*. Homozygous T2 plants of the high endochitinase-expressing cotton lines showed significant resistance against a soil-borne pathogen, *Rhizoctonia solani* and a foliar pathogen, *Alternaria alternata*. Wu et al (1995) introduced a glucose oxidase (GO) gene from *A. niger* to generate large amounts of hydrogen peroxide in transgenic potato plants to augment natural defense mechanisms. The transgenic potato plants showed an increased level of resistance to soft rot caused by *Erwinia carotovora* and to potato late blight caused by *Phytophthora infestans*. In contrast to these observations, a similar attempt with transgenic cottons expressing the *Talaromyces flavus* GO gene resulted in a limited antifungal activity against the root pathogen, *V. dahliae* (Murray *et al.,* 1999). However, these authors also discovered that the expression of GO in cottons resulted in phytotoxicity and reduced yield. Hain *et al.,* (1990) transformed tobacco with a gene encoding stilbene synthase resulting in synthesis of the phytoalexin, resveratrol, and increased resistance to *Botrytis cinerea*. Efforts are also underway in our laboratory to study the effects of stilbene synthase gene in transgenic cotton against *A. flav*us (Hunn *et al.,* 1999) and with other potential antifungal proteins such as thionins and ribosome inhibiting proteins (RIP). It is often speculated that bollworm or insect injury to cotton bolls serve as an entry point for *A. flavus* spores although concrete evidence is not available yet (Zipf and Rajasekaran 2003); yet insect control may be useful in preventing the spore entry into the fatty acid-rich cottonseed. For example, studies have shown that aflatoxin contamination is not directly correlated with pink bollworm damage and contamination may occur in the absence of damage (Henneberry *et al.,* 1978; Russell, 1980; Bock and Cotty, 1999a).

Peanuts

Ozias Akins *et al.,* (2002) field tested transgenic peanut lines expressing *CryIA*(c) as a possible means of inhibiting *A. flavus* inoculation into peanut pods by lesser cornstalk borer (*Elasmopalpus lignosellus*, LCB) since it has been clearly documented that aflatoxin contamination is positively correlated with insect damage (Lynch and Wilson 1991). Her laboratory is also interested in evaluating other antifungal genes such as tomato anionic peroxidase (tap1), synthetic peptide D4E1 to reduce the growth or penetration of invading *A. flavus*. Ozias Akins (1999) is also evaluating the potentials of soybean *lox1* gene in suppressing the aflatoxin biosynthetic pathway. Soybean *lox1* gene encodes an enzyme that catalyses the formation of 13(S) B hydroperoxy linoleic acid (HPODE) that has been shown to suppress the aflatoxin biosynthetic pathway *in vitro* (Burrow *et al.,* 1997; Keller *et al.,* 1999). Recently, Ozias Akins *et al.,* (2003) have shown that transgenic peanut lines expressing the CPO gene (Rajasekaran *et al.,* 2000) showed a 60-70% reduction in A. flavus colony growth. Transformation of peanut with another antifungal peptide, D5C, has also been accomplished (Weissinger *et al.,* 1999). Although the pure D5C showed strong activity against *A. flavus in vitro*, it was shown that the transgenic peanut callus showed poor recovery of plants because of possible phytotoxicity of the peptide. Recently, Weissinger (2004) showed that a synthetic RIP modeled after a corn protein has the potential to control *A. flavus* in peanut seeds.

Tree nuts

McGranahan *et al.,* (1999) reported recently on transformation of walnut with antifungal and/or anti-insect genes. Several transgenic walnut plants carrying the gene for *CryIA*(c) were planted in two locations for evaluation of damage by codling moth larvae and subsequent onset of *A. flavus* infection. A full-length polyphenol oxidase cDNA from walnut embryos of resistant lines has been identified and is being tested for its antifungal or anti-insect activity. Following the recent demonstration by Mahoney and Mullineux (2004) that precursor(s) of hydrolysable tannins (HT), gallic acid present within the pellicle tissues are responsible for inhibiting aflatoxin biosynthesis, Dandekar *et al.,* (2001) have initiated a program to identify and isolate genes responsible for HT/gallic acid biosynthesis with the objective of genetic engineering of susceptible walnut lines (and other crops) which lack or under-express gallic acid in the seedcoat.

Corn

In 1998, growers in Texas, Louisiana and Mississippi sustained losses estimated at about $100 million from corn that could not be utilized because of high aflatoxin concentrations (Anon 1999). Concerted research efforts to combat this problem is lacking because of the reasons that the aflatoxin problem is sporadic and occurs only in pockets of corn growing areas. Transformation procedures for commercial corn lines have been well developed (Zhao *et al.,* 2002) and several antifungal gene candidates are available. However, efforts at present are being directed towards conventional breeding to obtain resistance to aflatoxin contamination from resistant genotypes. Lozovaya *et al.,* (1998) reported that the resistance of a corn hybrid to *A. flavus* infection was correlated with an elevated level of á-1-3-glucanase. Chen *et al.,* (1998) demonstrated a good correlation between high concentrations of a 14-kDa trypsin inhibitor protein present in corn genotypes and resistance to *A. flavus*. They also demonstrated that the trypsin inhibitor protein inhibited the fungal á -amylase thereby reducing the availability of simple sugars for fungal growth (Chen *et al.,* 1999; Woloshuk and Fakhoury 1999). Transgenic tobacco expressing the corn trypsin inhibitor protein showed limited antifungal activity *in vitro* against *V. dahliae* and *A. flavus* (Rajasekaran *et al.,* 1999b). Identification and characterization of resistance-associated proteins (RAP) by comparative proteomics (resistant vs. susceptible corn varieties) are in progress in our laboratories (Brown *et al.,* 2003)

CONCLUSION

Aflatoxin contamination of crop species could be kept under control by using prudent but time consuming and expensive agronomic practices. Alternate methods of controls by using non-toxigenic strains, natural products such as neem extracts should be explored further. However, the best options available to us are through breeding and/or genetic engineering. Breeding for disease-resistant crops is very time consuming and does not lend itself ready to combat the evolution of new virulent fungal races. More over, availability of known genotypes with natural resistance to mycotoxin-producing fungi is a prerequisite for the successful breeding program. While it is possible to identify a few genotypes of corn or peanuts that are naturally resistant to *Aspergillus* we do not know whether these antifungal factors are specific to *A. flavus*. In crops like cotton, there are no known naturally resistant varieties to *Aspergillus*. Availability of transgenic varieties with antifungal traits is extremely valuable as a breeding tool. Use of fungicides or chemicals is costly and can add to the cost of production. Moreover, the growing concerns regarding environmental safety and ground water quality demand less dependence on agrochemicals. Disease resistant transgenic crops would not only control mycotoxin-producing organisms such as *A. flavus*, *A. parasiticus* and *Fusarium* spp. but also several microbial (fungal, bacterial and viral) diseases which cause significant economic losses in crop production. Above all, transgenic crops resistant to aflatoxin producing fungi offer the promise of negating the adverse effects caused by the toxin on immuno-compromised humans and animals. With the large volume of information reported in this review with respect to proteomics of host and genomics and field ecology of the fungus, novel strategies will emerge based on a clear understanding of the aflatoxin contamination process, especially at the molecular level.

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A GENOMIC APPROACH TO TOXICOLOGY IN THE MODEL ANIMAL *CAENORHABDITIS ELEGANS*

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INTRODUCTION

In April 2002, the Swedish National Food Agency (NFA) reported that high concentrations of acrylamide (AA) (30-2300 µg/kg) were produced during the frying or baking of many carbohydrate-rich foodstuffs such as potato products and bread (NFA, 2002; Weiss, 2002; Tareke *et al.,* 2002). Up to then, AA had been of concern as an industrial hazard, causing central and peripheral nervous system damage in vertebrates (Smith and Oehme, 1991) and inducing DNA damage in lab animals (Bull *et al.,* 1984). Because AA has been classified as a Group 2A carcinogen by the International Agency for Research on Cancer or IARC (IARC, 1994) and as a Category 2 carcinogen and Category 2 mutagen by the EU (Food Safety Programme, World Health Organization, 2002), this finding of AA in food constitutes an important public health issue.

Soon after the NFA issued their report, a project called "Basic research for the development of food safety-evaluation systems" was implemented in Chubu University, Japan (Hasegawa *et al.,* 2003; 2004a). Several laboratories in the College of Bioscience and Biotechnology have participated in this project, working in research areas covered by three "-omics" technologies, that is, genomics, proteomics, and effectomics.

In this paper, we introduce some results from our continuing work, in which we are using the free-living soil nematode *Caenorhabditis elegans* as a model organism for toxicological research (Miwa *et al.,* 1980; Miwa and Furusawa, 1982; Miwa *et al.,* 1982, 1983; Tabuse *et al.,* 1989; Sano *et al.,* 1995; Tabuse *et al.,* 1995), by describing studies on the effects of chronic exposure of *C. elegans* to AA at various concentrations that covered those found in common human foodstuffs.

C. elegans has proven to be a powerful biological research tool because of its ease of handling, short lifespan, large brood size, established genetics, and nearly transparent body composed of only about 1000 cells, which marvelously possesses full-fledged metazoan organs such as muscle, hypodermis, nervous system, reproductive system, digestive system, and so on and generates complex and highly regulated behaviours including memory and learning (Riddle *et al.,* 1997). And, now, it is well accepted as a model system for conducting research on human problems. In addition to a large body of genetic and cellular information, genomic information is freely available through a unified Internet web site, *Caenorhabditis elegans* WWW server, http://elegans.swmed.edu/. This site provides an easy link to almost any *C. elegans* lab in the world, whereby it is possible to request, directly from the lab bench computer, such valuable research materials as mutant animals with a wide variety of gene mutations including human gene homologues, transgenic animals loaded with GFP markers, cDNA clones of expressed sequence tags (EST clones), and RNAi feeding libraries of dsRNA expressing *E. coli.*

The work presented here is a part of our efforts to find new biomarkers with which we can monitor biological effects of toxic substances contained in our foods on organisms and to invent a highly sensitive biosensor that should be useful for identifying those toxic substances as well as to search for foods or food supplements that can remove such substances or reduce or counteract their toxic effects.

Acrylamide in foods

The acrylamide (AA) monomer (CH2=CHCONH2; FW, 71.08), industrially produced by the hydration of acrylonitrile (CH2=CHCN), is a colourless and odourless solid substance with a melting point of 84.5^{o}C, easily soluble in water, methanol, ethanol, and acetone. AA polymer, which is nontoxic, has a multitude of uses ranging from a material in papers and fibers, a flocculant in the treatment of sewage, and a soil stabilizer, to electrophoresis gels in research laboratories. AA polymer is depolymerized under certain environmental conditions to become a highly water-soluble toxic monomer (Smith *et al.,* 1996). The AA residue in some farm products, such as beans, corn, potatoes, and sugar beets grown in polyacrylamide-treated soils, has been indicated to be less than 10 ppb (Bologna *et al.,* 1999). Furthermore, in mushrooms (*Agaricus bisporus*) grown on polyacrylamide-containing medium, AA monomer was not detected at the detection limit of 0.5 µg/L (Castle, 1993). Thus, it appears that AA does not bioaccumulate in mushrooms and plants.

AA or its metabolite glycidamide has been detected as an adduct on the N-terminus of hemoglobin in AA-administered rats (Bergmak *et al.,* 1991), in occupationally exposed people (Bergmak *et al.,*1993), and in smokers (Bergmak,1997). Furthermore, Tareke *et al.,* (2002) demonstrated that rats fed a fried diet had significantly high levels of AA-adducted hemoglobin and suggested that the high background levels of hemoglobin-adducted AA observed in people without occupational exposure was derived from food (Tareke *et al.,* 2000). That report has since been followed by many reports that acrylamide is formed during the frying or baking of foods and is present at high concentrations in many carbohydrate-rich foodstuffs so prepared (Tareke *et al.,* 2002; Food Safety Programme, World Health Organization, 2002; Tsutsumiuchi *et al.,* 2004, Table 1). Two groups have reported that this compound can be produced by the Maillard reaction during heat treatment of foods (Mottram *et al.,* 2002; Stadler *et al.,* 2002).

Table 1. Amounts of acrylamide (AA) in processed foods

Foods	Main raw material	Mean (ng/g)
Potato snacks	Potato	64-3,570
Potato chips	Potato	723-2,250
French fries	Potato	457-458
Fried and sugar-coated dough strips	Wheat	975
Wheat snack	Wheat	52-222
Biscuit	Wheat	207
Instant ramen noodles (dry)	Wheat	138
Roasted green tea	Tea	287-486
Green tea	Tea	31
Roasted almonds	Almond	452
Fried honeyed-sweet potato	Sweet potato	304-375
Corn snacks	Corn	262-363
Banana chips	Banana	58
Roasted peanuts	Peanuts	56

adapted from Tsutsumiuchi *et al.,* 2004

Asking Nematodes Questions

Although an involvement of AA in some *C. elegans* neuronal processes was first suggested by Kamiya *et al.,* (1992), there has been no follow-up on this work to study the details of the suggested neuronal effects. As a matter of fact, until we began our work, no other works on AA in nematodes had been reported.

Here we describe our research on the effects of AA on *C. elegans,* an animal model for toxicology, by taking advantage of its wide knowledge base in genomics and proteomics as well as our own accumulated experimental and theoretical knowledge (Miwa *et al.,* 1980, 1982, 1983a, 1983b; Tabuse *et al.,* 1989; Sano *et al.,* 1995, Tabuse *et al.,* 1995).

Animals were grown on NGM (Nematode Growth Medium) plates containing various concentrations of AA and examined for the three parameters of growth, fecundity, and lifespan, which were then compared with those of the control animals grown under the identical conditions without AA (Hasegawa *et al.,* 2004a, b). We used AA concentrations ranging from the lowest measurable dose of 0.5 µg/L to an assumed toxic dose of 500 mg/L. As for growth and fecundity, essentially no effects were observed until the highest dose tested of 500 mg/L AA, wherein the animals showed retarded growth with significantly reduced body (Fig. 1) and brood size. The AA-unexposed offspring from the 500 mg/L AA-exposed parents were also affected; that is, these offspring also exhibited reduced brood size, even if they were transferred to and incubated on AA-free plates prior to hatching (Hasegawa *et al.,* 2004b). The effect was clearly transmitted from the parental generation to the next, and we term this "carry-over effect." No AA accumulation was demonstrated in either plants or mushrooms (Castle, 1993; Bologna *et al.,* 1999). In animals, however, AA accumulation may occur. Thus, it is interesting to know what is causative for the carry-over effect: AA itself or its metabolite.

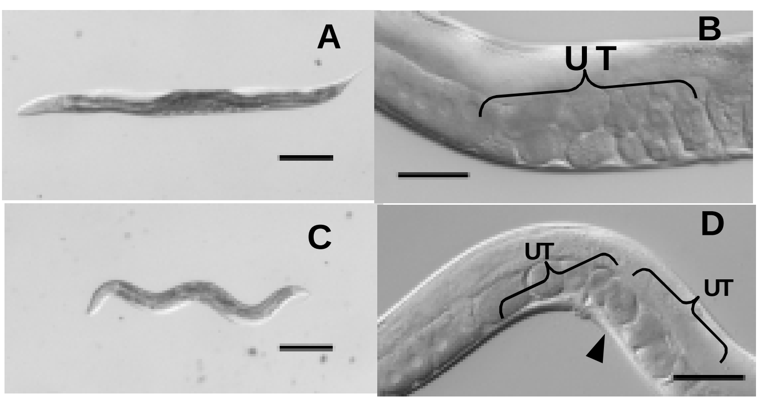

Fig. 1. Acrylamide (AA) effects on body size of *C. elegans*. Animals were grown on control plate at 20ºC for three days (A and B), mean size was 1439±49µm (N=25). More than 10 fertilized eggs are seen in one uterus (UT). Animals were grown on 500mg/L AA plate at 20ºC for three days (C and D), mean size was 1113±84µm (N=21). Although the body size was about two-thirds that of the average control animal, germ cells had matured and 2 to 3 fertilized eggs were seen in both uteri (UT). Arrowhead indicates vulva. Orientation: anterior is left, dorsal is top. Scale bar: 200µm (A and C), 50µm (B and D)

With respect to the *C. elegans* lifespan, a curious dose-response relationship was observed, whereby the AA concentrations over the extremely low dose range of 0.5 μg/L to 50 μg/L reduced the animal's lifespan severely, the moderate doses of 500 μg/L to 50 mg/L AA had practically no effect on the animal's lifespan, and the highest dose of 500 mg/L AA strongly reduced again the lifespan of the animals (Fig. 2).

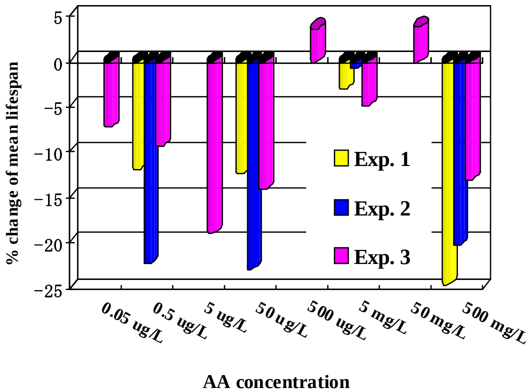

Fig. 2. Percent changes of the mean lifespan for the animals grown on different AA concentrations, compared with the control animals. Percent changes were; Exp. 1, -11.8% on 0.5 μg/L, -12.3% on 50 μg/L, -3.0% on 5 mg/L, and –24.5% on 500 mg/L. Exp. 2, -22.2% on 0.5 μg/L, -22.8% on 50 μg/L, -0.8% on 5 mg/L, and –20.2% on 500 mg/L. Exp. 3, -7.3% on 0.05 μg/L, -9.3% on 0.5 μg/L, -18.9% on 5 μg/L, -14.1% on 50 μg/L, +3.7% on 500 μg/L, -4.8% on 5 mg/L, +3.8% on 50 mg/L, and -13% on 500 mg/L.

Biphasic Dose Response

We usually consider two models for the dose-response relationship, the threshold model and the linear non-threshold model (Calabrese and Baldwin, 2003a, b). The former is a more widely accepted model: a larger amount of a chemical substance present in an organism should exert more or greater influence on the organism. Traditionally, the threshold model had been accepted for describing much of the toxicological, pharmacological, epidemiological, and clinical research. Recently, however, Calabrese and Baldwin (2003a, b) reported that a hormetic dose-response model, characterized by low-dose stimulation and high-dose inhibition is more common. Our finding with the AA effect on the animal is a better match for this model and has shown that the lower doses of AA reduced the animal's lifespan more severely than did the higher doses.

We have hypothesized that, over the lower concentration range of 0.5 to 50 μg/L AA, a detoxifying agent would not have been recruited to perform its function because the defense system of the animal failed to detect incoming AA. Over increasingly higher concentration ranges of 500 μg/L to 50 mg/L AA, however, the system would have started working in response to AA, and finally at more than 500 mg/L it would have been overrun and destroyed by AA.

Transcriptional analysis by using full genome DNA microarray

Here we would like to coin the word "toxicomics" to represent the field of toxicology that integrates genomic/proteomic knowledge and technology. Toxicomics evaluates and characterizes the entire genome and proteome dynamics as a given organism is exposed to toxic substances.

As previously described, since both the extremely low dose of AA at 0.5 μg/L and the high dose of 500 mg/L significantly reduced the *C. elegans* lifespan, we examined the effects of these two AA doses on expression of the entire *C. elegans* genome by using the full genome DNA microarray technology (Wang and Kim, 2003).

Two types of DNA microarray are now widely used; one is the Stanford-type microarray, which consists of cDNAs or synthesized DNAs spotted robotically on a glass slide (Schena *et al.,* 1995). The other is the Affymetrix-type DNA chip, which is composed of oligonucleotides synthesized in situ on silicon wafers by photolithography (commonly used in microelectronics and integrated circuit fabrication) based on combinatorial chemistry (Lipshutz *et al.,* 1999). Both utilize the same basic principles as do Southern and Northern hybridization; that is, extracted mRNAs are labeled with probes, hybridized to their complementary base-pair-containing spots/grids on glass slide/wafer, and scanned for detection of the expressed signals. In the Stanford-type microarray, to see the differences in gene expression between the control and experimental samples, extracted mRNAs, from both control and experimentally treated animals are labeled with fluorescence markers by reverse transcription and are each hybridized onto the DNA microarray. When control mRNAs are labeled with the red marker Cy3 and experimental mRNAs with the green marker Cy5, green spots are interpreted to indicate that the corresponding genes are up-regulated by the experimental treatment. Conversely, red spots indicate that those genes corresponding to the red spots are down-regulated by experimental treatment. Yellow spots indicate the same levels of gene expression for both control and experimental animals, suggesting that the genes involved are essentially unaffected by the experimental treatment (Fig. 3).

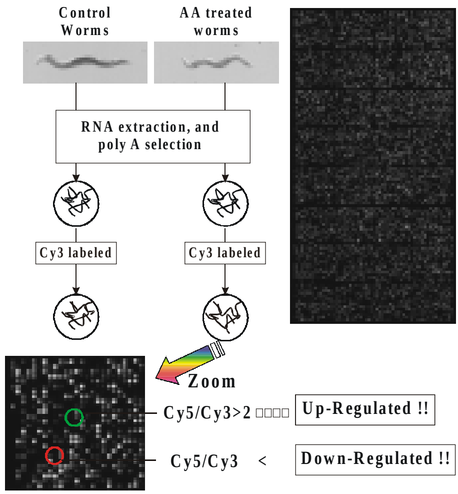

Fig. 3. Schema for microarray analysis. First synchronized L1 animals were grown for three days on control or AA plates at 20ºC, second total RNA was isolated, and third polyA mRNA was selected. Messenger RNAs (mRNAs) from control animals were labeled with Cy3 (red fluorescence marker), and those from the AA-treated were labeled with Cy5 (green fluorescence marker), and each was hybridized onto the full *C. elegans* genome DNA microarray containing 21,120 gene spots. The green spot means that the green signal overrode that for the red, indicating that the corresponding gene was up-regulated by AA exposure. Conversely the red spot indicates that AA down-regulated the corresponding gene.

Footnote: The Stuart Kim Lab at Stanford University (http://cmgm.stanford.edu/~kimlab/index_welcome.html) has designed and makes a DNA microarray that fully integrates almost all of the 21,120 known genes over the *C. elegans* genome. This DNA microarray analysis had been offered free-of-charge for non-profit organizations until the fall of 2003; but now those who request this service are asked to pay several thousand dollars for the hybridization step.

Animals synchronized at L1 were grown on control or 0.5 µg/L or 500 mg/L AA-containing plates at 20ºC for three days, and then mRNA was isolated from the independently cultured lines. We analyzed the expression patterns four times for each combination of either of the two acrylamide concentrations vs. control. RNA labeling and microarray hybridization were performed by the Kim Lab. The data obtained from the quadruplicate experiments were first normalized, and the normalized data were then statistically analyzed to identify genes showing significant differences in expression levels. We have framed the windows for statistically significant differences in gene expression at more than two-fold levels. In quite pleasant agreement with the lifespan profile, the extremely low dose of 0.5 µg/L AA was found to affect a substantial number of genes; that is, 14 genes were up-regulated and 56 genes were down-regulated. And as was expected from not only the lifespan but also other experiments, 500 mg/L AA up-regulated 438 genes and down-regulated 344 genes (Hasegawa *et al.,* 2004a). Some of those genes that expressed more than 2-times as many transcripts in 500 mg/L AA-treated animals as in the controls are shown in Table 2. Table 3 shows genes that were up- or down-regulated commonly by both 0.5 µg/L and 500 mg/L AA. Of the 438 genes up-regulated in 500 mg/L AA-treated animals, 32 genes are family members of the glutathione S-transferases (GSTs). Another 32 genes belong to a large family of major sperm proteins (MSPs), sperm-specific proteins that bind one another to form the sperm cytoskeleton required for sperm motility (Italiano *et al.,* 1999). They also function as signals to promote oocyte maturation and ovulation (Miller *et al.,* 2003). *C. elegans* hermaphrodites make both sperm and oocytes: about 150 sperms are produced in each of the anterior and posterior gonads during larval development prior to oocyte production. AA may affect spermatogenesis through major sperm proteins.

Table 2. Number of gene species up-regulated in 500 mg/L AA

Gene species	Number
GST related genes	32
MSP family	32
Family of G protein-coupled receptors	15
Dehydrogenase	12
Protein phosphatase	12
Protein kinase	12
Collagen	10
UDP-glucuronosyltransferase	9
C-type lectin protein family	5
Superoxide dismutase	1
Cytochrome P450	1

Table 3. Genes regulated commonly by both 0.5 μg/L and 500 mg/L AA

A. Up-regulated genes

*Gene name	Assigned	**RNAi phenotype
T13B5.8	Protein of unknown function	NE
E04F6.8	Protein of unknown function	WT
lys-4	Member of an uncharacterized protein family with similarity to *Entamoeba histolytica* lysozome	WT
C18B10.1	Protein containing a DUF40 domain of unknown function	WT

B. Down-regulated genes

*Gene name	Assigned	**RNAi phenotype
dhs-5	DHS-5 generally resembles short chain-type alcohol/other dehydrogenases, but has two predicted N-terminaltransmembrane sequences, and its closest relatives in vertebrates are known or putative steroid dehydrogenases, such as hydroxysteroid (17-beta) dehydrogenase 12 from mouse (also known as KIK-I or DHBK_MOUSE).	NE
F55G11.5	Member of an uncharacterized protein family	WT
fat-4/*des-5*	Delta5-fatty acid desaturase; has strong similarity to *H. sapiens* Hs.132898 gene product	WT
F55G11.5	Member of an uncharacterized protein family	WT
ZK353.7	Protein of unknown function	WT
C55B7.5	Protein of unknown function	Emb, Pvl, Ste, Stp, Rup, Gro, Unc
K04F10.6	Protein with strong similarity to *C. elegans* F31C3.2 gene Product.	WT
Y24F12A.1	Putative paralog of *C. elegans* Y37H2A.1	NE
C17H12.8	Protein of unknown function	WT
C08B11.8	Protein with moderate similarity to dolichyl-P-Glc :Man9GlcNAc2-PP- dolichylglucosyltransferase (human ALG6), which functions in dolichyl pyrophosphate-linked Glc3Man9 GlcNAc2 synthesis	WT
R12C12.5	Protein of unknown function	WT
T20D4.13	Putative ortholog of *C. elegans* F35F10.1 gene product WT	
F35C8.5	Member of the sterol desaturase family, which are involved in cholesterol and plant cuticular wax biosynthesis, has lowsimilarity to cholesterol 25-hydroxylase (human CH25H), whichis involved in oxysterol production and lipid and cholesterol metabolism	WT

*Gene name	Assigned	**RNAi phenotype
T08G11.4	Protein with unknown function	Emb, Gro, Lva, Lvl, Spn, Unc
byn-1	Protein with strong similarity to human bystin, which is involved in cell adhesion	Emb, Gro, Lva, Lvl, Pvl, Ste
F07C4.6	Protein containing one DUF18 domain of unknown function	WT
spp-5	Protein with similarity to bactericidal amoebapores that may act as an antibacterial agent	Lvl
C42C1.9#2	Protein of unknown function	WT

* Characterized genes are assigned three-letter names and uncharacterized genes assigned cosmid codes.

** RNAi phenotypes: WT, wild type; Emb, embryonic abnormal; Gro, slow growth; Lvl, larval lethal; Pvl, protruding vulva; Rup, exploded; Spn, abnormal spindle orientation; Ste, sterile; Stp, sterile progeny; Unc, uncoordinated; NE, not examined.

Glutathione S-transferases

GSTs, major cellular detoxification enzymes, form a superfamily of ubiquitous and multifunctional dimeric proteins (heterodimers or homodimers), which generally exist in every organism and play roles to detoxify both endogenous and exogenous compounds, such as therapeutics, carcinogens, and products of oxidative stresses by either glutathione conjugation, glutathione peroxidase activity, or passive binding (Salinas and Wong, 1999). In rats and mice, a major pathway for AA metabolism and detoxification is GSH (Glutathione) conjugation to AA by GSTs and eventual excretion in urine as mercapturic acid (N-acetylcysteine S-conjugate) and thioacetic acid derivatives (Odland *et al.,* 1994; Sumner *et al.,* 1999). To investigate the relationship of the GST expression to the biphasic-dose response against AA in the animal's lifespan, four different GSTs (gst-1, -4, -23, -30) were chosen at random for semi-quantitative RT-PCR analysis (Fig. 4). In accordance with the microarray results, all the expression levels of the chosen gst genes in animals treated with 500 mg/L AA were far greater than those for the controls. We may translate these results to suggest that the chosen GSTs do not act as detoxicants not only at the lowest range of AA concentrations as expected, but also even at the middle-high-range concentrations of AA. Thus they do not behave like defensive molecules the way we would like to predict; namely, they are unresponsive to AA over the lowest concentration range and increasingly responsive to AA over the mid- and high-ranges.

At the moment we do not know the mechanisms underlying the biphasic-dose response of the animal's lifespan. We are, however, optimistic about finding such mechanisms operating in the reaction of the animal to the presence of AA, for we have tools to overview and analyze the dynamics of the whole genome and proteome, such as DNA microarray for gene expression and multi-dimensional gel

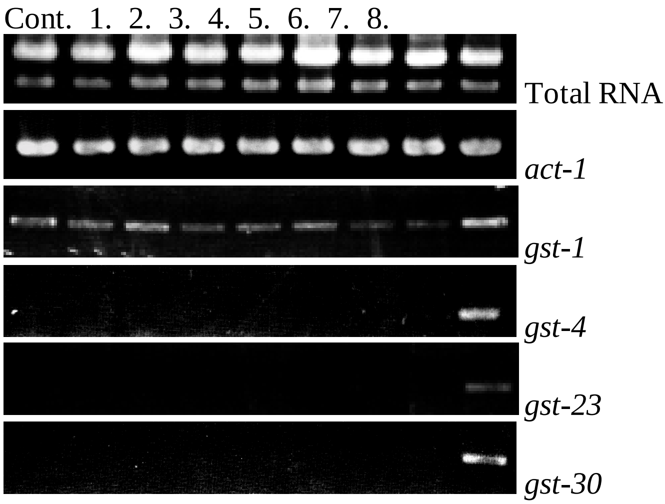

Fig. 4. GST expression analysis by semi quantitative RT-PCR. Total RNAs were extracted from animals grown on AA plates for three days at 20!. AA concentrations were , Cont, Control without AA; 1, 0.05 µg/L; 2, 0.5 µg/L; 3, 5 µg/L; 4, 50 µg/L; 5, 500 µg/L; 6, 5 mg/L; 7, 50 mg/L; 8, 500 mg/L. Total RNA indicates the quantity of extracted RNA applied to the gel, and *act-1* indicates the internal control.

electrophoresis for expressed protein profiling, just to name two, although it will likely take much effort and time to reach the goal.

Practically, and no less importantly than the research on such mechanisms, we should not forget to reiterate our interest in developing new biomarkers that can be used to find minute amounts of toxic substances in foods and our search to find common daily foodstuffs that detoxify, eliminate, or reduce AA, its effects, or its toxic metabolites. We aim to eliminate the fear of eating potato chips, bread, or other AA-containing foods as long as we eat "AA-detoxifying foods" together. And thus, we continue to search for detoxifying foods among our daily food sources, again using the nematode.

Acknowledgement

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PIONEERING CONTRIBUTIONS ON THE ROLE OF RESISTANCE GENES, TRANSGENES AND BACTERIAL BIOCONTROL AGENTS FOR THE MANAGEMENT OF RICE DISEASES

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PRELUDE

It was an awesome experience to enter into the portals of the then Agricultural College and Research Institute, Coimbatore back in 1963. I am very grateful for the six student years I spent at the institution during 1963-67 as an undergraduate student and 1967-69 as a post-graduate student (plant pathology) and another 4 yrs and 6 months I was able to spend as a research assistant before and after my Ph. D at the University of Hawaii in the U.S (1969-72 and 1976-78). But for these formative years of training, I would have lost contact with the agricultural community and her needs. In this paper, I list research contributions that emerged from my 27 years (1978-2005) of great career at the Centre for Advanced Studies in Botany at the University of Madras. I submit these as a tribute to Tamil Nadu Agricultural University during her Centenary.

Pioneering discoveries made by me and my research students that relate to three major areas of rice disease management are listed below:

Development of Bacterial Biocontrol Agents for Rice Pathogens

1. Introduction of *Pseudomonas fluorescens* to the nation as a potential biocontrol agent that suppresses plant pathogens (Unnamalai and Gnanamanickam, 1983).

From this very first introduction, several diseases of banana, citrus, groundnut (peanut) and rice were suppressed by seed treatments and foliar spray applications of *Pseudomonas fluorescens* (Ganesan and Gnanamanickam, 1987; Sakthivel and Gnanamanickam, 1987; Sivamani and Gnanamanickam, 1988; Anuratha and Gnanamanickam, 1989). The bacteria also caused enhanced yields in rice and groundnut (Savithry and Gnanamanickam; Sakthivel and Gnanamanickam, 1987).

2. Biological control of rice blast by seed treatment of rice with *Pseudomonas fluorescens* (Gnanamanickam and Mew, 1989). Blast (leaf and neck blasts) suppression was mediated by the production of an antifungal antibiotic (tentatively identified as phenazine-1-carboxylic acid (PCA).

3. Genetic analysis of antifungal antibiotic production by *Pseudomoans fluorescens* Pf7-14 (Chatterjee et al, 1996; Valasubramanian, 1994) (Fig. 1).

This led to the generation of *Tn*-5 mutants of the bacterium that were altered in afa (antifungal antibiotic) production, cloning of ant$^+$ DNA, and evaluation of the role of antibiotic production in the about 80% control of blast (leaf and neck blasts) (Fig. 1) and sheath blight of rice.

4. Development of *Pseudomonas fluorescens* and *P. putida* strains for the suppression of rice diseases. This research carried out over a number of years is presented in Table 1.

Table.1. Bacterial biocontrol agents developed for major diseases of rice. Center for Advanced Studies in Botany, University of Madras, India.

Disease	Pathogen (causal agent)	Biocontrol agent developed	Reference
Blast (Bl)	*Pyricularia grisea* (Teliomorph: *Magnaporthe grisea*)	*Pseudomonas fluorescens, Bacillus spp: B. polymyxa, B. pumulus, B. coagulans, Enterobacter agglomerans*	Gnanamanickam and Mew, 1992; Valasubramanian, 1994; Kavitha, 2002.
Sheath blight (ShB)	*Rhizoctonia solani* (Teliomorph: *Thanetophorus sasaki)*	*P. fluorescens, P. putida, Bacillus megaterium, B. polymyxa, B. pumulus, B. coagulans, Enterobacter agglomerans*	Vasantha Devi et al, 1989; Thara, 1994; Krishnamurthy and Gnanamanickam, 1996; Kavitha, 2002.
Sheath-rot (Sh-R)	*Sarocladium oryzae*	*P. fluorescens*	Sakthivel, 1987; Sakthivel and Gnanamanickam, 1987, 1989.
Stem rot (St-R)	*Sclerotium oryzae/Helminthosporium sigmoideum* (Teliomorph: *Magnaporthe salvinii*	*P. fluorescens*	Elangovan and Gnanamanickam, 1992
Bacterial Blight (BB)(Fig.2)	*Xanthomonas oryzae* pv. *oryzae*	*Bacillus* spp: *B. lentus B. cereus B. circulans,* and *P. fluorescens*	Vasudevan, 2002; Velusamy and Gnanamanickam, 2003.
Tungro disease	Rice Tungro virus (RTV)	*P. fluorescens* that kill the leaf-hopper vector of RTV	Ganesan, 1999

More than 5500 strains of plant-associated bacteria have been isolated, assembled and studied in Gnanamanickam's laboratory at University of Madras during 1983-2003.

Figures

[A]

[B]

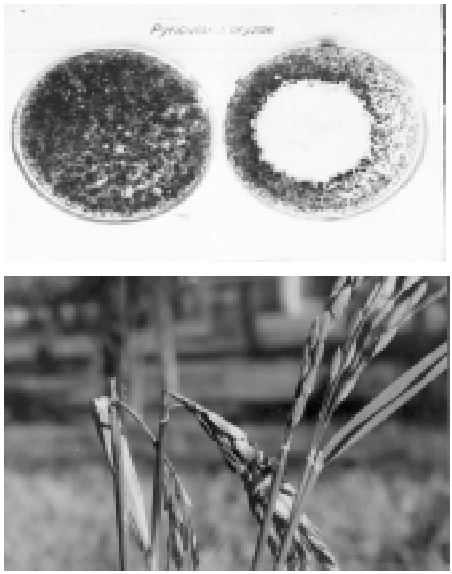

Fig. 1. Blast control by *Pseudomonas fluorescens* strain *Pf7*-14

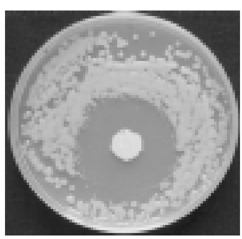

Fig. 2. Inhibition of *Xanthomonas oryzae* pv. *oryzae* by *Bacillus lentus* ALP18 in laboratory assays

[A] Laboratory assay shows inhibition of *Pyricularia grisea* (rice blast fungus) by *Pf7*-14.

[B] Rice panicles from a field experiments show suppression of neck blast due to treatment with *Pf7*-14 (plants on the right) and lack of protection against neck blast in plants treated with its afa^- mutant (plants on the left).

5. Identification of mechanisms involved in the biological control of rice diseases by *Pseudomoans fluorescens*. As a laboratory that carries out basic research, we were always interested in elucidating the mechanisms involved in biological disease suppression in rice. The following is a summary of many years of research furnished in Table 2:

Table 2. A summary of mechanisms identified in the biological suppression of rice diseases

Rice disease studied	Bacteria used	Mechanism(s) identified
Blast	*Pseudomonas fluorescens Pf7*-14	Antifungal antibiotics (phenazines, antifungal proteins), induced systemic resistance (ISR).
Sheath blight	*Pf7*-14, *Bacillus* spp	Chitinase, antibiotics, ISR
Bacterial blight	*P. fluorescens, Bacillus* spp (*B. lentus, B. circulans, B. coagulans, Bacillus sp.*)	Antibacterial antibiotics (kanosomine) (Fig.2), 2,4-diacetylphloroglucinol
Rice tungro virus	*P. fluorescens*	Antibiotics that kill the insect vector

6. A new and exiting discovery : Production of 2,4-diacetylphloroglucinol [DAPG]

By Indian strains of *Pseudomonas fluorescens* (first report from India by Velusamy and Gnanamanickam, 2003) and its implication in the biological suppression of rice bacterial bacterial blight (Velusamy et al, 2004).

Before 2004, production of DAPG has been implicated in the control of important diseases of tobacco and wheat and became increasingly well known as the agent that caused “take-all decline’ in wheat soils. Our report (first report for India) showed DAPG production in the tropical soils of India and and its role in the suppression of this major bacterial plant pathogen of rice, *Xanthomonas oryzae* pv. *oryzae* (Velusamy and Gnanamanickam, 2003;Velusamy et al, 2004) (Table 3).

Table 3. Plant-associated fluorescent pseudomonads which inhibited the growth of *Xanthomonas oryzae* pv. *oryzae* (*Xoo*) and produced 2,4-diacetylphloroglucinol (DAPG). (Velusamy and Gnanamanickam, 2003)

S. No	Place of collection	Code number of strain	Diameter (in cm) of inhibition zone of *Xoo*	Production of 2,4-DAPG[1]	Percent (%) suppression of rice BB	
					Net-house[2]	Field[2]
1	Karnataka	KAD7	1.8	+	56.87	53.93
2	Karnataka	IMV14	2.8	+	58.68	56.74
3	Karnataka	IMV2	2.8	+	36.78	33.18
4	Karnataka	BGR19	0.5	+	27.48	42.71
5	Kerala	PTB9	2.1	+	58.78	64.46
6	Kerala	MON1	3.3	+	19.70	37.13
7	Tamil Nadu	TVM8	1.2	+	16.32	23.51
8	Tamil Nadu	VEL17	2.3	+	23.33	54.08
9	Tamil Nadu	VEL10	0.7	+	17.03	17.52
10	Tamil Nadu	GDY4	2.1	+	30.73	41.44
11	Tamil Nadu	GDY7	2.3	+	51.57	45.30
12	Tamil Nadu	TRP5	1.7	+	33.68	34.54
13	Tamil Nadu	TRP18	2.3	+	53.15	48.34
14	Tamil Nadu	MDR9	2.1	+	30.68	23.29
15	Tamil Nadu	MDR7	1.3	+	57.11	54.43
16	Tamil Nadu	STR7	1.8	+	19.51	36.04
17	Tamil Nadu	VGP13	2.5	+	55.39	51.62
18	Tamil Nadu	MDR16	1.4	+	37.60	46.12
19	Tamil Nadu	PDY5	1.8	+	58.83	56.88
20	Tamil Nadu	VLB7	1.7	+	33.64	9.08
21	Tamil Nadu	KVR5	2.5	+	55.92	49.75
22	Tamil Nadu	TNI13	2.2	+	26.05	28.19
23	Tamil Nadu	KOV8	3.0	+	38.69	9.71
24	Tamil Nadu	RJP31	2.4	+	10.31	0.50
25	Tamil Nadu	KOV3	1.8	+	21.18	49.21
26	Tamil Nadu	PDU1	2.9	+	8.16	11.80
27	Tamil Nadu	PDU9	2.7	+	16.94	2.04
28	Control	-	-	-	0.00	0.00

[1]Production of DAPG was identified through a PCR-based screening procedure which amplified a 745 bp DNA fragment in these strains.

[2]Results of a replicated net-house/field experiment (RBD) conducted at the Regional Agricultural Research Station, Pattambi, Kerala. Each figure is a mean of 3 replications.

Rice Pathogens : Analysis of Pathogen Populations and their virulence characteristics

[A] Blast pathogen: *Magnaporthe grisea*

1. Genetics of rice blast fungus, *Magnaporthe grisea*

    Laboratory production of sexual structures of rice blast fungus, *Magnaporthe grisea.* Although several scientists had intensively studied the blast fungus in the laboratory, the sexual structures of *M. grisea* [perithecium, ascus and ascospores] could not be produced in the laboratory until 1995. Our laboratory was one of the two laboratories in the country to successfully produce these structures (Viji and Gnanamanickam, 1996) and demonstrate cross compatibility.

    The ability to produce the sexual stage of the blast pathogen in the laboratory led to further studies on the genetics of *M. grisea*.

2. Mating type distribution of *M. grisea*.

    Studies by Viji and Gnanamanickam (1997), Brindha and Gnanamanickam (1999) and Dayakar et al (2000) demonstrated the prevalence of *Mat*1-1 and *Mat*1-2 in field populations of *M. grisea* and identified *Mat*1-1 as the dominant and functional mating type.

3. Fingerprint groups or lineages of *M. grisea*.

    By the use of MGR (***M**agnaporthe* ***g**risea* **r**epeat element) 586, more than 600 isolates of *M. grisea* assembled from the southern states of Tamil Nadu. Kerala, Karnataka and Andhra Pradesh along with isolates also from Orissa and Maharastra were analyzed by the DNA fingerprinting and were grouped into 29 (named, A to Z) major genetic families or “lineages” (Sivaraj et al, 1996; Sivaraj, 1995).

In subsequent analyses, MGR DNA fingerprinting of isolates from northern states of India revealed the presence of 23 lineages. Isolates of the blast pathogen from the state of Meghalaya showed maximum genetic diversity (Dayakar et al, 2000).

In my laboratory, the DNA polymorphisms of *M. grisea* isolates that are pathogenic to finger millet and rice was analyzed by Viji et al (2000) by RFLP. In this analysis, DNA probes such as *MGR* 586, *grasshopper* and probes for the *Avr*-genes were used to distinguish the two pathogenic populations. The results revealed that the pathogen populations were distinct and did not show any shared RFLPS among field isolates of the pathogen that infected rice and finger millet. DNA fingerprinting analyses were carried out in collaboration with Morris Levy, Purdue University, USA.

4. Lineage-exclusion tests for *M. grisea* and gene pyramiding for durable blast resistance. [Molecular marker-assisted backcross breeding]

To identify blast resistance genes (R-genes) which would afford durable blast-resistance in southern India, representative strains from the above MGR lineages were inoculated on to the near-isogenic rice lines of CO-39 developed at IRRI each of which contained a single major R-gene for blast resistance. These tests showed for the first time that a combination of *Pi-1+Pi-2* genes for blast resistance can be quite durable against blast in southern India (Sivaraj et al, 2000). This information was very valuable not only for India but also for the rest of Asia and China.

When a traditional backcross breeding method was used to pyramid the *Pi-1+Pi-2* genes for blast resistance (also in combination with the use of molecular marker-assisted selection, MAS), the rice pyramids thus constructed in elite rice cultivars, CO39 and IR50 showed high levels of blast resistance. These have been tested in hot-spot locations for blast incidence in southern India and in IRRI, Philippines (Sivaraj et al, 2000; Narayanan, 2001; Narayanan et al, 2002).

Table 4. Incidence of rice blast observed on rice cultivar CO39 (blast-susceptible) and its near-isogenic lines carrying blast-resistance genes, *Pi-1* and *Pi-2* and pyramid rice lines carrying both genes planted in hot-spot locations. Field experiment, south India.

Rice cultivar/ line/pyramid	*Experimental location[a] and year*		
	Pattambi, Kerala		*Ponnampet, Karnataka*
	1996	*1997*	*1996*
CO39	*S*	*S*	*S*
C101LAC (Pi-1)	*S*	*S*	*R*
C101A51 (Pi-2)	*R*	*R*	*R*
Pyramid lines of Pi-1+Pi-2 (seven lines)	*R*	*R*	*R*

[a]Proven hot-spot locations for natural incidence of rice blast.

Disease reactions to blast: R = resistance with severity scores of 0 to 3, and S = susceptibility with severity scores of 4 to 9 in the SES system for rice.

[B] Bacterial Blight (BB) Pathogen, *Xanthomonas oryzae* pv. *oryzae*

Rice bacterial blight (BB) has been intensively studied in my laboratory for several years (1994-2004). Our major interest was to understand the genetic and pathogenic variability of the pathogen. Detection of the seedborne inoculum of the BB pathogen has been a debated issue. Whether the pathogen is successfully transmitted through the rice seed to initiate fresh incidence of BB in rice has not been answered satisfactorily (Gnanmanickam et al, 1996). Available evidences did not demonstrate evidence for seed transmission of the BB pathogen.

1. Use of monoclonal antibodies for grouping Indian strains of *X. oryzae* pv. *oryzae*.

   During 1994, in collaboration with Dr Anne Alvarez at the University of Hawaii, USA, I initiated a study with pathovar-specific monoclonal antibodies of the BB pathogen which improved the detection of *X. oryzae* pv. *oryzae* in infected rice seeds and also aided in making a serological classification of the Indian strains (Gnanamanickam *et al.,* 1994).

2. DNA fingerprinting of Indian strains of *X. oryzae* pv. *oryzae*.

In collaboration with Dr P. K. Ranjekar, National Chemical Laboratory, Pune, I fingerprinted a large number of Indian strains of the rice BB pathogen (Rajebhosale et al, 1997). In this study we used a set of hypervariable probes which included microsatellites, a human minisatellite probe, *avr* gene probe (*avrXa10*) and a repeat clone pBS101. Five major clusters/ groups were identified at 56% similarity thus suggesting high level of possible genetic polymorphisms within the field populations of the BB pathogen.

3. Identification of R-gene *Xa-23* in native accessions of wild rice *Oryza rufipogon* as a new and valuable source of resistance to Indian strains of *Xanthomonas oryzae* pv. *oryzae* (Srinivasan and Gnanamanickam, 2004, 2005).

4. Gene pyramiding of BB-resistance genes [Marker-Assisted Backcross Breeding].

Efforts were made to incorporate a combination of 4 BB resistance genes, *Xa4+xa5+xa13+Xa21* to improve the genetic resistance of elite indica rice cultivars, IR50 and Jyothi through backcross breeding in combination with molecular marker-assisted selection. There were reasons why we resorted to the use of a 4-gene pyramid. We identified sub-populations of *X. oryzae* pv. *oryzae* in Kerala that could overcome the resistance offered by the most useful BB resistance gene, *Xa21* (Brinda Venkatesan and Gnanamanickam, 2000). This virulent sub-population was not able to break down the resistance in the rice line NH56 [*Xa4+xa5+xa13+Xa21*]. Plants of IR50 and Jyothi improved for their resistance to rice BB were obtained through systematic backcross breeding combined with the use of molecular markers linked to *xa5, xa13* and *Xa21* (Brindha Priyadrisini et al, 2003; David Paul Raj, 2003).

C. Sheath Blight Pathogen: *Rhizoctonia solani*

Sheath blight used to be a minor disease but has recently become one of the most important production constraints for rice production both in India and many other rice-growing regions of the world. *R. solani* [teliomorph: *Thanetophorus cucumeris* (Frank)] is a fungus representing a collective species which has been divided into 13 anastomosis groups (AG1 to AG13). We have carried out detailed analysis on the Indian isolates that belong to anastomosis group pathogenic to rice, AG1 (David Paulraj, 2002).

In collaboration with Bruce McDonald (ETH-Zurich), recently we evaluated the population structure of 96 Indian isolates of *R. solani* AG1 1A using seven RFLP loci. The field population of Indian *R. solani* AG1 IA has shown characteristics that are consistent to their high levels of gene flow and frequent sexual reproduction (as indicated by their Hardy-Weinburg equilibium) among populations (Fig. 3) (Linde et al, 2005). Their RFLP profiles and a phenogram showing them in 2 major clusters with 3 sub-clusters under each major cluster which also compares them to a Texas (USA) population of *R. solani* are shown in Fig. 3 a,b.

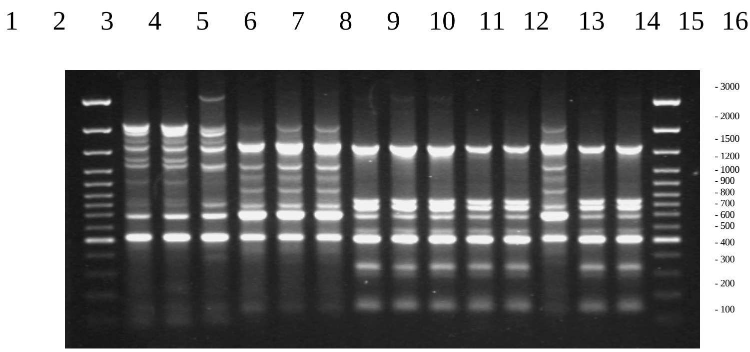

Fig.3a. Rep-PCR fingerprints of *Rhizoctonia solani* isolates from India

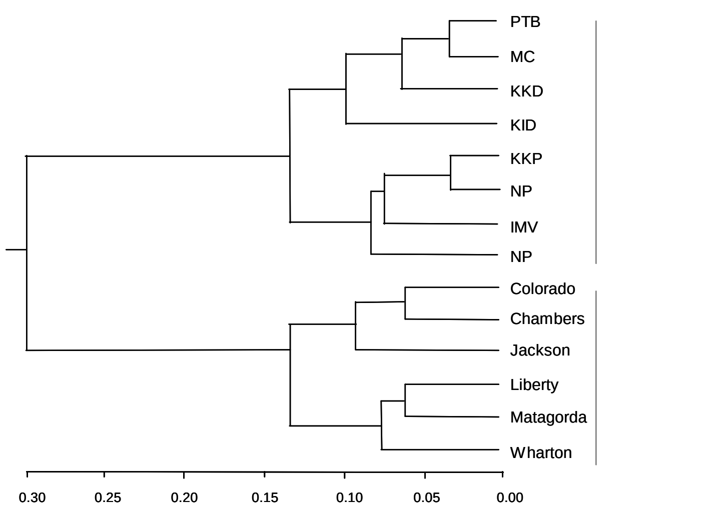

Fig. 3b. Phenogram derived by UPGMA based on Nei's genetic distance between Texas and Indian populations of *R.solani* AG1 IA

Development of transgenic rices with resistance to both blast and bacterial blight

In my laboratory, research towards the improvement of elite indica rice cultivars, IR50 and CO39 for blast resistance and cv. Jyothi and IR50 for bacterial blight resistance was carried out through pyramiding of R-genes and marker-assisted selection of resistant plants (as described in the previous section). In order to create multiple resistance in these rices, blast-resistant pyramids of IR50 and CO39 available in my laboratory were transformed with *Xa21* gene. The bacterial blight resistance gene *Xa21* is known to confer resistance to all known races of *Xanthomonas oryzae* pv. *oryzae* in India and the Philippines

This work was carried out in collaboration with Dr Swapan Datta of IRRI and was supported by the Rockefeller Foundation.

Starting materials for transformation

Target rice pyramids (carrying blast resistant gene/genes) for the transformation were, IR50 (Piz-5) and CO39 (Pi-1+Piz-5). They were used as the starting material for the rice tissue culture and transformation with Xa21 gene using particle bombardment. Immature embryos and mature seeds were used as explants in both the varieties for tissue culture process.

Construct used for bombardment

The plasmid pC822 that contains the Xa21 coding sequence was kindly supplied by Dr. P.C Ronald, University of California, Davis, USA. The primer U1 and I1, developed to amplify a 1.4-Kb DNA fragment of *Xa21* that was polymorphic to fragments amplified from other *Xa* genes were used for quick genetic analysis of the transgenic progeny. Plasmid pROB5 contains the selectable marker, the hph-coding region, flanked by the cauliflower mosaic virus (CaMv) 35S promoter and polyadenylation signals (Poly(A). This plasmid provides a selectable marker that confers resistance to hygromycin for cotransformation with the pC822 plasmid.

Particle Bombardment and selection

Immature embryos (IEs), Immature embryo derived callus (IECs) and Mature seed derived callus (MCs) were arranged and bombarded with the *Xa-21* + pROB5 plasmid (Purified by CsCl/EtBr method) by the particle gun PDC-1000/He system (BIORAD, Hercules, CA) following manufacturer's instruction. After bombardment, the explants were left in the dark overnight in the same medium. In the morning, the cultures were transferred to MS + 30g/l Maltose + 7.5g/l agar medium supplemented with 50mg/l hygromycin B for selection of transformed calli and incubated in dark at 27 C. The newly developing hygromycin resistant calli were subcultured in fresh media under continued selection pressure at every fortnight interval for 5 cycles.

Plant regeneration

The embryogenic calli were carefully selected and transferred to 50 ml flasks containing plant regeneration medium (For IR50, MS medium with 2mg kinetin/L and 1 mg NAA/L and for CO39, MS medium with 5mg kinetin/L and 1 mg NAA/L). The cultures were incubated for 2-3 week in 16h photoperiod of 3000-lux intensity at 26 C. Three to four week old plantlets were transferred to MS basal medium (MS_0) for rooting. These plantlets with vigorous roots were transferred to styrofoam boards with holes in a plastic tray containing Yoshida's culture solution. The regenerants in the culture solution is allowed to grow for 2 weeks for hardening and then it is transferred to soil directly in the transgenic green house with a day/night temperature regime of 29/23 C.

Molecular assays

These included, hygromycin phosphotransferase (hpt) assay, PCR analysis and Southern blotting. The protocols have been described adequately elsewhere (Narayanan et al, 2002; 2004).

Bioassay

The transgenic T_1 plants were grown in an IRRI containment greenhouse under the following conditions: 29 C and 85% humidity during the day and 25 C and 90% humidity at night. Since the plants contain both blast and blight genes, bioassay was done for both the pathogens individually and in combinations to see the effect of multiple genes in the genotypes. So, the bioassay was done in three ways:

Bioassay for blast resistance

The set of test cultivars CO39, IR50 (susceptible), C101A51 (Piz-5), 20 lines from each transgenic plant were sown in plastic trays. Inoculum preparation and inoculation was done as explained above. Inoculated seedlings were incubated in a moist chamber for 24 hr and then transferred to the dew misty chamber at 22-25 C for 7 days till scoring. Disease was scored 10 day after inoculation using a 0-to-9 scoring method.

Leaves of IR50 and CO39 (transgenic T_1) plants showed high levels of resistance to blast (Fig. 4). This observation is also supported by data on percent diseased leaf area (DLA) presented in Tables 5 and 6.

Table 5. Screening of IR50 transgenic plants (T_1) against the rice blast fungus *Magnaporthe grisea*

Genotype	Mean size of lesion (mm)	DLA%[a]	Score[b]
CO39	12± 0.8	65	9
IR50	8± 0.7	60	9
C101A51	1 ± 0.2	0.5	0-1
13-T_1	2 ± 0.4	0.3	0-1
14-T_1	2± 0.7	0.6	0-1
15-T_1	1± 0.8	0.8	0-1

[a] DLA %, Percentage diseased leaf area

[b] Score based on a scale of 0-9 (SES system, IRRI).

Table 6. Screening of CO39 transgenic plants (T_1) against the rice blast fungus *Magnaporthe grisea*.

Genotype	Mean size of lesion (mm)	DLA%[a]	Score[b]
CO39	11± 0.6	65	9
IR50	7± 0.6	60	9
C101A51	1 ± 0.3	0.5	0-1
C101LAC	1± 0.4	0.5	0-1
18-T_1	2 ± 0.4	0.3	0-1
19-T_1	2± 0.7	0.6	0-1

[a] DLA %, Percentage diseased leaf area

[b] Score based on a scale of 0-9 (SES system, IRRI).

Table 7. Reactions of transgenic IR50 plants carrying *Xa21* to races 2, 6, and 10 of *Xanthomonas oryzae* pv.*oryzae*

Genotype	Race 2 (PXO86)				Race 6 (PXO99)			
	7d		14d		7d		14d	
	MLL (cm)	Reaction	MLL (cm)	Reaction	MLL (cm)	Reaction	MLL (cm)	Reaction
IR50 (C)	5.3	S	7.8	S	5.8	S	9.4	S
IR24 (C)	13.5	S	15.8	S	14.5	S	17.8	S
IRBB21 (C)	1.3	R	2.4	R	3.4	R	4.7	R
IRBB4 (C)	4.6	R	6.8	S	6.4	S	7.9	S
T 13 R-1[1]	2.6	R	2.6	R	2.8	R	3.8	R
T 13 S-1[2]	5.6	S	7.8	S	12.8	S	15.3	S

[1] – Average of 15/20 T_1 progenies showing resistance to BB pathogen.

[2] – Average of 5/20 T_1 progenies showing susceptible to BB pathogen.

C- non-transformed parental lines; R-Resistant; S-Susceptible; MLL-Mean Lesion Length.

Bioassay for bacterial blight resistance

The set of test cultivars IR50, IR24 (susceptible controls), IRBB21 (near isogenic line for *Xa-21*), IRBB4 (near isogenic line for *Xa-4*), and 20 lines from each transgenic line were sown in plastic trays. Plants were tested against three different races of *Xanthomonas oryzae* pv. *oryzae* (*Xoo*) to differentiate the genes Xa-21 and endogenous *Xa-4* such as *PXO*86 (race 2), *PXO*99 (race 6) and *PXO*341 (race 10). The inoculum of each strain was prepared by incubating the bacteria on Wakimoto's medium (Medium composition: Modified Wakimoto's medium (MF-P): sucrose- 30 g, bacteriological peptone- 5g, calcium nitrate- 0.5g, sodium phosphate (dibasic)- 0.82g, ferrous sulphate- 0.05g, Agar- 15-17g pH- 6.0) for 72h at 30 C, then suspending each pure culture in sterile distilled water and adjusting the inoculum to about 10^9 cells per milliliter.

At the maximum tillering stage, each plant was inoculated with the above three strains of *Xoo* using the leaf clipping method at the transgenic greenhouse, IRRI. Plant reaction to each race of Xoo was scored 14 days after inoculation.

Resistance to bacterial blight by T_1 plants of IR50 and CO39 was observed (Table 7). Bacterial blight lesions of <2.0 cm length observed in transgenic plants are characteristic resistance reactions. The non-transformed BB-susceptible parent plants showed bacterial blight lesions of >10.0 cm length.

Bioassays for blast and bacterial blight resistance

All 20 lines of transgenic plants showed enhanced resistance to blast and bacterial blight (Fig. 4) similar to the results obtained in separate bioassays for blast and bacterial blight. These transgenic plants have to be evaluated in the rice fields in southern India under strict biosafety precautions and their field performances have to monitored carefully. These efforts are in progress.

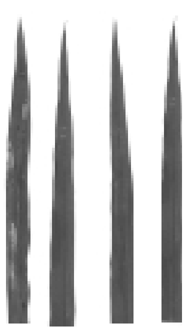

Fig. 4. Reactions of transgenic T_1 CO39 plants with *Xa21* introgressed with *Piz-5* for blast resistance when inoculated with IK81-3. Leaves 1 to 4 represent CO39, C101LAC, C101A51 (*Piz-5*), and transgenic CO39(*Pi-1+Piz-5+Xa21*), respectively

Concluding Remarks

The list of contributions from my laboratory are documented as a way of paying my tribute to TNAU. These contributions in three of the major areas of rice disease management, 1. Pyramiding of R-genes on the basis of molecular information on pathogen diversity and their virulence characteristics, 2. Generation of blast and bacterial blight-resistant transgenic indica rices (IR50 , CO39 and 3. Development of bacterial biocontrol agents for major rice diseases, have resulted in a whole new perspective on rice disease management. While these are still a list of options and molecular tools made available, they will have to be validated for field applications by future generation of researchers and rice pathologists.

Acknowledgements

My contributions to agricultural research were made possible by a number of research collaborations developed within India and outside India. I am deeply thankful to Swapan Datta (IRRI), T. W. Mew (IRRI), P. Ranjekar (NCL), A. Alvarez (U. of Hawaii), M. Levy (Purdue U), B. A.McDonald and G. Defago (ETH-Zentrum, Zurich) and M. Hofte (Ghent, Belgium).

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INDUCING RESISTANCE IN PLANTS TO DISEASES INCITED BY MICROBIAL PATHOGENS

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Resistance to diseases in plants may be enhanced by incorporating resistance genes in susceptible cultivars and this disease management strategy is considered to be the most desirable one. But unavailability of reliable sources of resistance and the requirement of long periods for development of cultivars with built-in resistance have limited the usefulness of this approach. Employing genetic engineering techniques for obtaining resistant cultivars appears to hold promise. However, in the light of expression of concern for the long term effects of genetically modified crops and plant products in several countries, the feasibility of exploiting the genetic engineering methods remains a question mark. In this context, the possibility of inducing natural disease resistance (NDR) mechanisms operating in existing cultivars with high yield potential to provide protection to crops and harvested produce against diseases, has attracted the attention of researchers in several countries. This approach does not involve the introduction of any foreign gene into the plant, but it regulates the expression of defense genes in the susceptible plants. Furthermore, this approach is as safe as the use of genetically resistant cultivars for the preservation of environment, since the same mechanisms of resistance are activated in plants with either genetic resistance or induced resistance. Intensive research is being carried out to select effective agents that can be used as inducers of resistance in crop plants to contain various diseases, as alternatives to the development of resistant cultivars through conventional breeding and genetic engineering methods (Narayanasamy, 2002).

Two types of induced resistance were recognized by Ross (1961 a, b) in tobacco inoculated with *Tobacco mosaic virus* (TMV). The resistance developed in inoculated leaves of Samsun NN tobacco against reinfection by TMV was called localized acquired resistance and the resistance induced in uninoculated leaves away from the site of inoculation was designated systemic acquired resistance (SAR).

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The resistance induced by TMV was nonspecific and the leaves became resistant to unrelated viruses and also to a fungal pathogen infecting tobacco(Ross, 1966). The plant growth-promoting rhizobacteria (PGPR) applied in soil are localized at the root surface of treated plants, but they induce resistance in leaves and stems far away from the root surfaces where they remain. This form of resistance known as induced systemic resistance (ISR) is dependent on the host plant's physical and chemical barriers activated by biotic and abiotic inducers of resistance to diseases (Kloepper *et al.,* 1992; Pieterse *et al.,* 1996). Inducible plant defenses such as SAR/ISR are a key component of a plant's repertoire of disease resistance mechanisms and are promising target to manipulate for improved disease control.

Characteristics of induced resistance

The development of SAR and its effectiveness may be influenced by the host plant species and the nature of resistance inducer. It is possible to induce SAR by restricted inoculation of microbial pathogens or attenuated/avirulent strains and treatment with various chemicals and plant products such as antiviral principles (AVPs) (Narayanasamy, 1990, 1993, 2003). The time required for development of SAR depends on the crop plant/produce and the type of inducer. SAR after its establishment may persist generally for several weeks. A single primary inoculation of cucumber and muskmelon was sufficient to protect the plants against many pathogens, but a second booster inoculation 2-3 weeks later, protected plants up to flowering. Induction of SAR in bean, tobacco, cucumber, soybean, sugar beet, and tomato under field conditions has also been observed (Madamanchi and Ku, 1991; Kloepper *et al.,* 2004). During SAR, plants successfully resisting a pathogen can become highly resistant to subsequent infection not only by the same pathogen, but also to a variety of other pathogens (Navarre and Mayo, 2004).

Mechanisms of systemic acquired resistance (SAR) and induced systemic resistance (ISR)

The mechanisms involved in the development of SAR have been studied by various researchers and excellent reviews by Ryals *et al.,* (1994) and Sticher *et al.,* (1997) are available. Hence only key points are briefly discussed here. Two phases in the development of SAR and ISR have been recognized. All events leading to the establishment of resistance are included in the initiation phase which is transient. During the second maintenance phase, the quasi-steady-state resistance occurs as a result of events of the initial phase

(Ryals *et al.,* 1994).The resistance induced following inoculation is considered to result from the translocation of systemic signals produced at the site of primary infection. Following inoculation of leaves , certain families of genes collectively known as “SAR genes” are activated. The time taken for the expression of SAR gene(s) may vary depending on the nature of the inducer. Both biotic and abiotic agents induce the same spectrum of SAR gene expression which is positively related to the development of resistant state in plants. The mRNAs encoded by the SAR genes and the encoded proteins have been characterized and the antimicrobial activities of the proteins so formed have been established. Different classes of SAR genes have been shown to encode chitinases and ß-1,3-glucanases which can degrade the cell walls of fungal pathogens. Thaumatin-like proteins (TLPs) are the products of another group of SAR genes and they can disrupt membrane integrity earning the nomenclature as “permatins”. Another group of SAR genes are responsible for the accumulation of pathogenesis-related (PR)-proteins. It is considered that different crop plants may possess different sets of SAR genes evolved in response to evolutionary pressure from the pathogens to which they are susceptible.

The recognition of the presence of the pathogen by the host plant initiates the process of development of SAR. Signals are released from the point of infection/penetration by the pathogen triggering resistance in adjacent and also in distant tissues. Salicylic acid (SA) is postulated as a putative endogenous signal of SAR. Induced resistance pathways are regulated by key signal molecules such as SA, jasmonic acid (JA) and ethylene which can alter gene expression substantially and have complex crosstalk (Glazebrook *et al.,* 2003). The accumulation of SA is positively correlated to the expression of SAR in tobacco inoculated with TMV exposed to different temperatures that affect the development of SAR (Yalpani *et al.,* 1993). Root inoculation of *Arabidopsis thaliana* with *Pseudomonas fluorescens* CHA0 resulted in partial protection of leaves against *Peronospora parasitca* causing downy mildew disease. Induction of ISR to *P. parasitica* required the production of 2,4-diacetylphloroglucinol (DAPG) in *P. fluorescens*, as application of DAPG at 10 to 100 µM mimicked the ISR effect, indicating the possibility of similar mechanism operating in other pathosystems also (Iavicoli *et al.,* 2003). The studies using several strains of *Pseudomonas* spp. showed that elicitation of ISR is typically dependent on SA and does not result in activation of *PR-1a* gene that encodes production of PR-1a protein (van Loon and Glick, 2004). The possible involvement of jasmonic acid (JA) in disease resistance has been suggested. Low concentrations of JA induce the activities of chalcone synthase (Creelman *et al.,* 1992), phenylalanine-ammonia lyase (PAL) (Gundlach *et al.,* 1992) and lipoxygenase (LOX) (Bell and Mullet, 1991) which play an important role in the development of resistance in plants. Treatment of plants with methyl jasmonate results in the accumulation of an antifungal defensin, but not PR-1 protein, the accumulation of which occurs following treatment with SA indicating the operation of different mechanisms of SAR development (Penninckx *et al.,* 1997). Cucumber plants expressing induced resistance were infiltrated with inhibitors to evaluate the role of flavanoid phytoalexin production in induced resistance. Elicited plants displayed enhanced levels of induced resistance. On the other hand, down regulation of chalcone synthase (CHS), a key enzyme of the flavanoid pathway following application of inhibitors led to nearly complete suppression of induced resistance. The results supported the view that induced resistance in cucumber was primarily related to the rapid *de novo* biosynthesis of flavanoid phytoalexin compounds (Fofana *et al.,* 2005).

Nonpathogenic microorganisms may induce defense reactions through different mechanisms. *Pseudomonas putida* strain BTP1 induced systemic resistance in beans against gray mold pathogen *Botrytis cinerea*. In the treated plants, higher levels of linoleic and linolenic acids were observed with parallel increases in the activities of the key enzymes lipoxygenase and hydroperoxide lyase involved in the synthesis of these acids. The results strongly suggested that oxylipin pathway may be associated with the development of resistance in beans against this pathogen infecting several fruit and vegetable crops (Ongena *et al.,* 2004).

Following the expression of ISR, multiple potential defense mechanisms are activated leading to the enhanced activities of chitinases, ß-1,3-glucanases, peroxidases and accumulation of PR proteins and phytoalexins with antimicrobial properties and formation of protective biopolymers such as lignin, callose and hydroxyproline-rich glycoproteins (HPRGs). These compounds may either directly inhibit the pathogen development or reinforce natural barriers present in the host plants. Elicitation of ISR in sugar beet by *Bacillus mycoides* and *B. pumilus* was associated with higher peroxidase activity and increased production of one chitinase isozyme and two isozymes of ß-1,3-glucanase (Bargabus *et al.,* 2002, 2004). In investigations using *B. pumilus* strain T4 for the treatment of tobacco against wildfire pathogen, *Pseudomonas syringae* pv. *tabaci* different results were obtained. It appears that different pathways appear to be in operation, when ISR is elicited by selected strains of *Bacillus* spp. than when ISR is elicited by *Pseudomonas* spp. The specific signal transduction pathway that is triggered during ISR by *Bacillus* spp. depends on the strain, the host plant and the pathogen to be controlled (Kloepper *et al.,* 2004). Application of the PGPR *Bacillus cereus* protected the tomato plants against fungal and bacterial pathogens. The dialysates obtained from the suspension of *B. cereus* cells, when applied to the roots of tomato, offered protection to tomato plants against the pathogens. The results indicated that the macromolecules synthesized by the PGPR and released in the environment may act as elicitors of systemic resistance (Romeiro *et al.,* 2005).

Applications of induced resistance for crop disease management

Various investigations carried out to assess the usefulness of and feasibility for large scale application of induction of resistance to field crop diseases and postharvest diseases caused by microbial pathogens under natural conditions have provided encouraging results. A wide range of biotic and abiotic (physical and chemical) inducers of disease resistance has been tested for their efficacy for the control of field crop diseases and postharvest diseases. The effectiveness of the different kinds of agents in inducing disease resistance is discussed in the following sections.

Inducing resistance using biotic inducers

Biotic inducers of disease resistance comprise of living avirulent or attenuated strains of pathogens and antagonistic microorganisms. In some pathosystems, the pathogens themselves may induce SAR in uninoculated tissues/organs of the inoculated plants.

VIRUSES AS INDUCERS OF DISEASE RESISTANCE

Induction of SAR was first demonstrated in tobacco cv. Samsun NN which develops local necrotic local lesions on leaves inoculated with *Tobacco mosaic virus* (TMV). The resistance induced seems to be related to the necrotic lesions caused by infection, irrespective of the nature of infecting agent. The PR-protein induced by *Tobacco necrosis virus* (TNV) in cucumber was a chitinase and the plants inoculated with TNV were resistant to the bacterial angular leaf spot disease caused by *Pseudomonas syringae* pv. *lachrymans* (Métraux *et al.,* 1988). Systemic induction of PR-proteins may be due to enormous increase in the endogenous levels of salicylic acid (SA). Following inoculation with TMV, there was a steep increase in the SA levels (70 folds) in the leaves of Xanthi nc. tobacco. Application of SA resulted in the production of PR-1 protein in Xanthi nc., but no detectable change in the constitutive expression of high levels of PR-1 protein in the hybrid (*Nicotiana glutinosa* x *N. debneyi*) could be discernible. The results indicated the regulatory role of SA in disease resistance and PR-protein synthesis (Yalpani *et al.,* 1993). Inoculation of tomato plants with TNV induced resistance to the late blight pathogen *Phytophthora infestans*. Accumulation of 6 PR-proteins was detected by using specific antisera and the basic fractions of these PR-proteins were inhibitory to *P. infestans*. In addition, marked increase in the activity of peroxidase (PO) both in the inoculated and uninoculated resistant upper leaf tissue was observed prior to development of SAR. The synthesis of three new PO and one ß-1,3-glucanase isozyme was induced in tomato plants showing SAR (Anfoka and Buchenauer, 1997). The resistance induced by TMV in tobacco against *Peronospora tabacina* appears to depend on volatile or diffusible compound(s) (Xie and Ku, 1997). Induction of resistance by viruses in other crops such as cucumber by TNV against powdery mildew disease (Sticher *et al.,* 1997) has been reported. Infection by TMV induced resistance in tobacco cv. Havana against powdery mildew disease. In the TMV-infected plants, the cell wall hydroxyproline content increased significantly, suggesting that accumulation of hydroxyproline-rich glycoprotein (HPRG) may be associated with SAR-activation against powdery mildew pathogen (Raggi, 1998).

Immunological techniques have been employed to detect and quantify the defense proteins, in addition to the detection of the microbial pathogens (Narayanasamy, 2001, 2005). The products of defense genes include several enzymes such as peroxidase (PO) and polyphenol oxidase (PPO) which catalyze the synthesis of lignin and phenylalanine-ammonia lyase (PAL) required for the production of phytoalexins and phenolics. These enzymes are considered to have an important role in the development of disease resistance in plants. The PR-proteins like ß-1,3-glucanases (PR-2) and chitinases (PR-3) may degrade the cell walls of fungal pathogens resulting in the lysis of cells. Thaumatin-like proteins (TLPs) (PR-5) have antifungal property and enhance the resistance of plants to microbial pathogens (Chen *et al.,* 1999). A bacterially produced rice thaumatin-like protein was inhibitory to several plant pathogens such as *Fusarium oxysporum f. sp. cubense, Botrytis cinerea, Drechslera oryzae* and *Rhizoctonia solani* causing economically important diseases (Jayaraj *et al.,* 2004). However, the usefulness of this protein under field conditions has to be demonstrated.

FUNGI AS INDUCERS OF DISEASE RESISTANCE

Inducing resistance to field crop diseases

The possibility of inducing resistance in cucumber, muskmelon or watermelon by employing the pathogen *Colletotrichum lagenarium* causing anthracnose was first demonstrated by Ku (1987, 1990). The primary inoculation of cotyledons with this pathogen induced SAR to several diseases caused by fungi, bacteria and viruses, in addition to the anthracnose disease. Systemic induction of SAR genes and formation PR- proteins has been observed in several pathosystems such as tomato - *Phytophthora infestans* (Christ and Mosinger, 1989), tobacco - *Peronospora tabacina* (Ye *et al.,* 1990), potato – *P. infestans* (Schroder *et al.,* 1992; Enkerli *et al.,* 1993), and French bean - *Colletotrichum lindemuthianum* (Dann *et al.,* 1996). Many of the PR-proteins including PR-1, ß-1,3-glucanases (PR-2), chitinases, PR-4 and osmotin (PR-5) are known to have antimicrobial activities. Resistance may be induced by nonpathogens in some pathosystems. The operation of a general resistance mechanism was observed in tomato against wilt pathogen *Fusarium oxysporum* f. sp. *lycopersici*. Resistance to wilt disease was induced in tomato inoculated with a nonpathogen *Penicillium oxalicum* resulting in reduction in disease severity, area under disease progress curve (AUDPC) and extent of stunting . Histological studies showed that the treated plants did not lose the cambium, had lower number of bundles and less vascular colonization by the pathogen. Renewed or prolonged cambial activity in treated plants resulting in the formation of additional secondary xylem may be a reason for the reduction in disease severity. Since *P. oxalicum* did not cause any symptom on the tomato cultivars susceptible and resistant to wilt, it can be safely employed to protect tomatoes against this disease (de Cal *et al.,* 1997, 2000). *Phytophthora cryptogea*, a nonpathogen of potato, induced resistance against *P. infestans* in the susceptible St. Cecilia potato under field conditions (Quintanilla and Brishammar, 1998). The binucleate *Rhizoctonia* (BNR) species, induced systemic resistance to *Rhizoctonia solani* causing root rot and *Colletotrichum lindemuthianum* infecting bean, when inoculated on the hypocotyls prior to challenge inoculation with the pathogen. This biotic inducer elicited significant systemic increase in all cellular fractions of peroxidases, ß-1,3-glucanases and chitinases. The increases in peroxidases and glucanases (2-8 folds) showed positive correlation with induced resistance (Xue *et al.,* 1998).

Trichoderma hamatum strain 382 induced resistance in cucumber to root rot, crown rot, leaf and stem blight caused by *Phytophthora capsici*. The effectiveness of protection provided was equal to that offered by the chemical inducer, benzothiadiazole (BTH). The biotic inducer remained spatially separated from *P. capsici* in plants in the split root and leaf blight bioassays, suggesting that the resistance induced was systemic in nature (Khan *et al.,* 2004). *Trichoderma virens,* an effective biocontrol agent against cotton root rot disease, has been shown to induce defense-related compounds in the roots of cotton. The effect of seed treatment with *T. virens* on the elicitation of defense responses was assessed. The role of terpenoid compounds in the control of root rot disease caused by *Rhizoctonia solani* was studied by analyzing the extracts of cotton roots and hypocotyls grown from *T. virens*-treated seeds. Terpenoid synthesis and peroxidase activity were enhanced in the roots of treated plants, but not in the untreated controls, The terpenoid pathway intermediates deoxyhemigossypol (dHG) and hemigossypol (HG) strongly inhibited the development of *R. solani*, indicating that terpenoid production is the major contributor for the control of the root rot disease. Furthermore, a strong correlation between the biocontrol and induction of terpenoid was revealed, when the strains of *T. virens*, *T. koningii* and *T. harzianum* were compared. The results indicated that induction of resistance by *T. virens* occurred through the activities of terpenoids acting as elicitors (Howell *et al.,* 2000). In the further study, it was observed that heat stable proteinaceous compounds were elicited following treatment of roots with effective strains of *T. virens.* One compound had a MW between 3 and 5 K and was sensitive to proteinase K. Several bands could be recognized in the gel after subjecting the active material to sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE). One band exhibited cross reaction with an antibody to ethylene-inducing xylanase from *T. viride*. Another band (18K) induced production of terpenoids, in addition to increasing the peroxidase activity in cotton radicles and this protein showed highest similarity to a serine proteinase from *Fusarium sporotrichoides* ((Hanson and Howell, 2004).

Inducing resistance to postharvest diseases

Induction of resistance to postharvest diseases using biotic agents capable of eliciting resistance responses in fruits and vegetables holds promise as a new technology and as an alternative to the use of synthetic fungicides. Several species of yeasts have been shown to be effective, since they are able to grow rapidly and colonize wound sites present on the fruit/vegetable surface where infections occur and out-compete postharvest pathogens for space and nutrients. In addition, some of them may induce resistance in host tissues resulting in significant reduction in decay development. Antagonistic yeasts are capable of inducing resistance responses as in the case of *Pichia guilliermondii*, as evidenced by the increased production of defense-related enzymes and antimicrobial compounds (Wisniewski and Wilson, 1992). *Aureobasidium pullulans*, another yeast antagonist, could reduce the decay in apples due to *Botrytis cinerea* and *Penicillium expansum* causing gray and blue mold diseases respectively. The enhanced resistance of treated apples was associated with the transient increase in ß-1,3-glucanase, chitinase and peroxidase activities commencing from 24 hours after treatment and reaching the maximum levels at 48-96 hours after treatment (Ippolito *et al.,* 2000). Enhancement of natural resistance in strawberry to *B. cinerea*, following treatment with *A. pullulans* was also reported by Adikaram *et al.* (2002).

The yeast species *Candida oleophila* included in the commercial product Aspire as a basic component, induced systemic resistance in grapefruit to *Penicillium digitatum* causing green mold disease. Scanning electron microscopic observations revealed inhibition of spore germination and germ tube growth to a great extent in wounds made near the yeast-treated sites (Droby *et al.,* 2002). Likewise, the onset of systemic resistance in fresh apples to gray mold disease coincided with the increase in the activities of chitinase and ß-1,3-glucanase in systemically protected tissues (El Ghaouth *et al.,* 2003). Cytochemical studies on the changes in the exocarp tissues of citrus fruits treated with *Verticillium lecanii* indicated the accumulation of callose and lignin-like compounds at sites of colonization by the green mold pathogen *P. digitatum* resulting in the restriction of decay development in the treated fruits compared with the untreated control fruits. The significant differences observed in the rate and extent of colonization between control and treated citrus fruits, in addition to the reduction in cell viability, demonstrated that *V. lecanii* and chitosan, a natural compound extracted from crabshell, possessed similar ability to induce transcriptional activation of defense genes leading to the accumulation of structural and biochemical compounds at strategic sites (Benhamou, 2004). *Cryptococcus laurentii* either alone or in combination with methyl jasmonate (MeJA) significantly reduced the intensity of brown rot and blue mold diseases in peach caused by *Monilinia fructicola* and *Penicillium expansum* respectively. In addition, the treatments induced higher activities of defense-related enzymes, chitinase, B-1,3-glucanase, phenylalanine ammonia lyase and peroxidase resulting in enhancement of resistance in treated peach to these diseases (Yao and Tian, 2005).

BACTERIA AS INDUCERS OF DISEASE RESISTANCE

Inducing resistance to field crop diseases

Plant growth-promoting rhizobacteria (PGPR) are among the various groups of microorganisms that can elicit defense responses in treated plants. Induction of ISR by PGPR depends on the presence of two bacterial determinants: lipopolysaccharides (LPS) and siderophores. The O-antigenic chain of outer membrane LPS from

Pseudomonas fluorescens WCS417r and WCS 374 was found to be responsible for ISR induced in radish against *Fusarium oxysporum* f. sp. *raphani* (Leeman *et al.,* 1995). Salicylic acid (SA), a siderophore produced by *P. aeruginosa* 7NSK2 was important for the induction of ISR to *Botrytis cinerea* in bean and this resistance was iron-regulated (Meyer and Höfte, 1997). The PGPR may induce a set of plant defense reactions, culminating in the production of physical barriers and creation of a fungitoxic environment that may adversely affect the development of microbial pathogens. Bacterization of pea roots with *P. fluorescens* strain 63-28, resulted in the wrinkled appearance and collapse of hyphae of *Pythium ultimum*, as revealed by electron micrographs. Significant modifications of epidermal and cortical cell walls and deposition of newly formed barriers were observed in roots challenged with *F. oxysporum* f. sp. *pisi.* The wilt pathogen possibly failed to penetrate the cells of treated plants, because of the depositions onto the inner surface of the cell walls of callose-enriched wall appositions. The pea root bacterization resulted in direct antifungal activity against *P. ultimum*, while the indirect action by reinforcement of host cell walls and acceleration of synthesis of phenolic compounds resulted in the inhibition of wilt pathogen (Benhamou *et al.,* 1996). In addition to the disease control, PGPR may also improve the plant growth. These bacterial inducers protected cucumber plants against anthracnose (*Colletotrichum orbiculare*) and bacterial angular leaf spot (*Pseudomonas syringae* pv. *lachrymans*) diseases and also increased the plant growth significantly resulting in higher yields under field conditions (Wei *et al.,* 1996). Combined application of the chitinolytic PGPR, *Serratia marcescens* strain GPS5 on groundnut foliage, followed by challenge inoculation with late leaf spot pathogen *Phaeoisariopsis personata* reduced the lesion frequency by 64% compared with chitosan alone. In the pretreated groundnut leaves, enhanced activities of ß-1,3-glucanase, peroxidase (PO), phenylalanine ammonia lyase (PAL) and chitinase were observed up to 13 days after inoculation (Kishore *et al.,* 2005).

Seed treatment with *P. fluorescens* reduced the damping-off of sugar beet seedlings. The results of ELISA and microscopy showed the presence of the bacteria on inoculated seeds and its inhibitory effect on the development of both mycelial biomass and sclerotia formation by the pathogen (Thrane *et al.,* 2001). Treatment of sugarcane setts with *P. fluorescens* and *P. putida* induced accumulation of chitinase in germinating settling, whereas application of these PGPR strains induced chitinase activity systemically in sugarcane stalk tissues. The enhanced chitinase activity was related to suppression of development of red rot disease caused by *Colletotrichum falcatum* (Viswanathan and Samiyappan, 2001).

Defense proteins and enzymes were induced following treatment of tomato plant with *P. fluorescens* and inoculation with *F. oxysporum* f. sp. *lycopersici.* (Ramamoorthy *et al.,* 2002).

P. fluorescens strain 89B-27 induced systemic resistance to *Cucumber mosaic virus* in cucumber cv. Straight 8 leading to consistent reduction in mean numbers of symptomatic plants coupled with delay in the symptom expression. No viral antigen could be detected in the asymptomatic plants throughout the experimental period (Raupach *et al.,* 1996). The strains Pf 1 and CHA0 of *P. fluorescens* were able to induce systemic resistance in rice against rice tungro disease, when these strains were applied as seed treatment, root dipping or foliar spray (Narayanasamy, 1995). Tomato plants were protected by the treatment with *P. fluorescens* against *Tomato spotted wilt virus* (Kandan *et al.,* 2002). Enhancement of the activities of defense-related enzymes such as peroxidase and phenylalanine ammonia lyase was observed in many crop plants treated with the PGPR (Narayanasamy, 2005a).

INDUCING RESISTANCE USING ABIOTIC INDUCERS

Resistance to diseases may be induced by applying various kinds of abiotic inducers which may be classified into two groups: i) physical agents and ii) chemical agents.

Physical Agents

Exposure to ultraviolet (UV) light, gamma radiation and high temperatures has been demonstrated to increase the level of resistance of host tissues/organs to several postharvest diseases caused by microbial pathogens. Induction of resistance is confined to the tissues/organs exposed to the physical agents and development of systemic resistance in such cases has not been observed in any of the pathosystems tested.

Ultraviolet (UV) light

Application of low doses (< 280 nm) of UV-C light has been effective in inducing resistance to several postharvest diseases affecting many fruits and vegetables (Narayanasamy, 2005b). Enhanced resistance of grapefruits cv. Marsh Seedless, following UV irradiation against green mold decay caused by *Penicillium digitatum* was noted by Porat et al. (1999). Immunoblotting analysis using citrus-specific chitinase and ß-1,3-endoglucanase antibodies revealed that UV irradiation, wounding of fruits or a combination of these two treatments induced accumulation of a 25 kD chitinase protein in the fruit peel tissue. Accumulation of the phytoalexins scoparone and scopoletin in the flavedo tissues of orange and grapefruit exposed to UV-C was considered to result in the higher levels of resistance to decay development during storage (D'hallewin *et al.,* 1999, 2000). UV-C treatment of apples provided the most effective protection against blue mold caused by *P. expansum* due to induction of resistance, as reflected by area under disease progress curve (AUDPC) assessment (Capdeville *et al.,* 2002). Similar beneficial effects of UV-C treatment for the control of storage rot of strawberry (Marquenie *et al.,* 2002) and gray mold disease of apples caused by *Botrytis cinerea* (El Ghaouth *et al.,* 2003) have been reported.

Heat treatments

The microbial pathogens causing postharvest diseases may be eliminated by prestorage heat treatments for short periods, depending on the location of the pathogens and their sensitivity to temperatures below 60°C. Postharvest heat treatments is a potential nonchemical disease management strategy acting directly by inhibiting the pathogen growth, activating natural disease resistance mechanisms of the host tissues and slowing down the ripening process. A hot water brushing (HWB) technique developed by Porat et al. (2000) involves a 20-second rinsing of fruits with hot water at 59°C or 62°C, as they move along a belt of brush rollers. The HWB treatment effectively protected grapefruits against green mold disease caused by *Penicillium digitatum*. In addition, the treatment significantly reduced chilling injury (CI) index and percentage of fruits displaying CI symptoms. Cleaning of fruits and improvement of general appearance without any surface injury are the additional advantages of HWB technique. Another method, hot water dip (HWD) was also found to provide effective protection to lemons against the blue mold disease (Nafussi *et al.,* 2001).

Chemical Agents

A wide range of inorganic and organic compounds in addition to natural compounds of plant and animal origin has been tested *in vitro* for their efficacy to induce resistance to plant diseases. But only very few of them have been demonstrated to have the potential for large scale application under field conditions.

Inorganic compounds

Induction of resistance to a plant disease by using phosphate salts was first demonstrated by Gottstein and Ku (1989). Cucumber plants sprayed with phosphate developed resistance to anthracnose disease caused by *Colletotrichum orbiculare*. Application of 0.1 M phosphate salts on the upper surfaces of maize leaves induced systemic resistance to *Puccinia sorghi* causing rust disease. Preinoculation application of phosphates provided an additional advantage of stimulating plant growth. Phosphates are considered to generate an endogenous SAR signal, because of calcium sequestration at the points of phosphate application (Reuveni *et al.,* 1994). Similar enhancement of resistance of cucumber plants to powdery mildew pathogen (*Sphaerotheca fuliginea*), following the application of phosphates was also observed. The activities of peroxidase and ß-1,3-glucanase were increased in the protected noninoculated leaves of cucumber plants (Reuveni *et al.,*1997). These results indicate the possibility of exploiting the induction of SAR for the protection of crops against microbial pathogens by using inexpensive chemicals without obvious adverse effects on the crops. In the case of postharvest diseases, vacuum infiltration of Ca into the apple fruits was more effective than field application in protecting the fruits against gray mold disease (Conway and Sams, 1983). Exogenous application of silicon (Si) as sodium metasilicate reduced the development of *Penicillium expansum* and *Monilinia fructicola* infecting sweet cherry fruit at 20^{o}C. The extent of reduction in decay was correlated to the concentrations of Si applied. Treatment with Si induced significant increase in the activities of PAL, PPO and PO in sweet cherry fruit. In addition, the biocontrol efficacy of the yeast antagonist *Cryptococcus laurentii* was markedly increased, when it was combined with Si application (Qin and Tian, 2005).

Organic compounds

Among the organic compounds, salicylic acid (SA), 2,6-dichloroisonicotinic acid (INA), jasmonic acid (JA) and methyl salicylate (MSA) have been tested frequently for their efficacy to induce systemic resistance to diseases. They appear to induce the same spectrum of SAR gene expression to levels comparable to that induced by biotic inducers. Resistance to *Cumber mosaic virus* (CMV) was induced by SA and this resistance was due to the restriction of systemic movement of CMV. SA-induced resistance was abolished by the application of salicylhydroxamic acid (SHAM) (Naylor *et al.,* 1998). Several of the pathogenesis-related (PR) genes expressed during the development of resistance, produce compounds inhibitory to microbial pathogens. Potato has marked differences in SA metabolism and signaling from tobacco, as reflected by high basal SA concentration in all tissues examined including roots and tubers. However, it responds to exogenous application of SA, showing high levels of expression of *PR-1* (Navarre and Mayo, 2004).

Application of INA on green bean (*Phaseolus vulgaris*) resulted in marked increase in the activities of chitinase and ß-1,3-glucanase and accumulation of SA (Dann *et al.,* 1996). Postharvest application of JA and methyl jasmonate (MJ) reduced decay due to *P. digitatum* in grapefruit cv. Marsh Seedless following natural or artificial inoculation, by enhancing natural resistance of the fruits at both high (24°C) and low (2°C) temperatures (Droby *et al.,* 1999). Treatment of seeds of melon with MJ and ethylene significantly enhanced the resistance levels against *Didymella bryoniae* (gummy stem blight), *Sclerotinia sclerotiorum* (white mold) and *Fusarium oxysporum* f. sp. *melonis* (wilt). MJ treatment increased exochitinase activity in melon seedlings, whereas ethylene induced both exochitinase and peroxidase activities. The results indicate that some inducible defences and associated resistance are independently enhanced in melon seedlings by the action of MJ or ethylene, suggesting the coexistence of different resistance mechanisms (Buzi *et al.,* 2004). Application of MJ enhanced the populations of the biocontrol yeast *Cryptococcus laurentii* and protected the peach fruit against the brown rot and blue mold diseases caused respectively by *Monilinia fructicola* and *Penicillium expansum*. The yeast and MJ, when applied alone or in combination, induced resistance to these diseases by activating the defense-related enzymes (Yao and Tian, 2005). Field application of methyl salicylate (MSA) reduced the decay caused by *Botrytis cinerea* by one third compared with controls. MSA was converted into SA and increased the activity of chitinase. Since MSA is one of the natural volatile compounds in strawberry fruits, it can be applied as a nontoxic alternative to fungicide application (Kim and Choi, 2002). Pretreatment of barley leaves with indole-3-acetic acid (IAA), tryptamine and tryptophan solutions protected the barley plants against blast disease caused by *Magnaporthe grisea* (Ueno *et al.,* 2004).

Natural products

Natural products of plant and animal origin have been found to be effective against some economically important diseases affecting both field crops and harvested commodities. Application of antiviral principles from sorghum and coconut leaves has been demonstrated to be effective against virus diseases affecting groundnut, rice and tomatoes (Narayanasamy, 1983; Narayanasamy and Ganapathy, 1986; Narayanasamy, 1990; Muthulakshmi and Narayanasamy, 2000; Narayanasamy, 2003). Leaf extract of *Datura metel* was found to have both antimicrobial activity and ability to induce resistacne against rice pathogens *Rhizoctonia solani* and *Xanthomonas oryzae* pv. *oryzae* (Kagale *et al.,* 2004). The unsaturated fatty acids from the zoospores of *Sclerospora graminicola* induced resistance in pearl millet against the same pathogen (Amruthesh *et al.,* 2005). Chitosan, derived from crab-shell, has been shown to be effective against several diseases. Chitosan applied as seed coating and substrate amendment effectively protected tomatoes against the wilt disease (Benhamou *et al.,* 1994). The effectiveness of chitosan in protecting crops such as cucumber against damping-off (El Ghaouth *et al.,* 1994) and tomatoes against late blight and wilt diseases (Oh *et al.,* 1998) has been reported. Treatment of fruits and vegetables prior to storage provided effective protection against important diseases such as *Rhizopus* rot (Wilson and El Ghaouth, 1994) and gray mold diseases (Reddy *et al.,* 2000) in strawberry, brown rot in peaches (Li and Tin, 2001) and green mold disease in citrus (Benhamou, 2004). Chitosan treatment elicited various defense-related responses such as reinforcement of structural barriers and production of antimicrobial compounds.

Plant activators

The bio-efficacy of plant activators such as DL-ß-aminobutyric acid (BABA), benzo-(1,2,3)-thiadiazole-7-carbothioic acid S-methyl ester (BTH) and acibenzolar-S-methyl (ASM, derivative of BTH) in protecting plants by inducing resistance to diseases has been assessed. Treatment of grapefruit with ß-aminobutyric acid (BABA) induced resistance to green mold disease caused by *P. digitatum*, in a concentration-dependent manner, protection being most effective at a concentration of 20 mM. Various defense-related responses in grapefruit peel tissues, including activation of chitinase gene expression, protein accumulation and increase in PAL activity were observed (Porat *et al.,* 2003). Induction of resistance by BTH in several crops to various diseases has been demonstrated: in sugarcane against red rot disease (Sundar *et al.,* 2001), in cauliflower against downy mildew (Ziadi *et al.,* 2001), in rose against black spot disease ((Suo and Leung, 2002), in rice against bacterial blight (Babu *et al.,* 2003), in melons against white mold and gummy stem blight diseases (Buzi *et al.,* 2004) and in pear against fire blight disease (Sparla *et al.,* 2004). The effectiveness of acibenzolar-S-methyl (ASM, as Actigard 50 WG) a synthetic inducer of SAR and PR-protein production, was assessed against fire blight disease in apple trees. The severity of fire blight disease caused by *Erwinia amylovora* on inoculated shoots of Fuji apple was reduced in a dose-dependent manner and when it was combined with streptomycin, the effectiveness of protection was enhanced (Maxson-Stein *et al.,* 2002). Likewise, induction of resistance to scab disease in Japanese pear by treatment with ASM and production of defense-related enzyme phenylalanine ammonia lyase in pretreated pear leaves following inoculation with the pathogen *Venturia nashicola* were observed (Faize *et al.,* 2004).

The disease management strategy based on inducing resistance in crops and harvested produce to diseases caused by microbial pathogens has the potential for large scale application under field conditions. Various kinds of biotic and abiotic inducers of disease resistance have been identified and their usefulness as alternatives to synthetic fungicides, bactericides and viricides has been indicated by researchers. However, in certain pathosystems like groundnut - late leaf spot(LLS) disease (Zhang et at., 2001) and citrus - canker disease (Graham and Leite Jr., 2004), the inducers of resistance tested, did not prove to be effective in protecting the plants. The need for further screening and selecting the effective ones has to be recognized to provide protection to such crops to the required level, as in the case of groundnut LLS (Kishore *et al.,* 2005). The mechanisms of induction of resistance to different microbial pathogens have not been understood clearly indicating that further research is required to throw more light on them.

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UNCOMMON OPPORTUNITIES FOR PLANT PATHOLOGY

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INTRODUCTION

Knowing pretty well that foretelling the course of development invariably ends as a hopelessly wrong prediction, we continue to do it for reasons of shear excitement. And if the prediction becomes true then he becomes a "visionary". To attain such a status many work tirelessly and here is one such effort.

In the beginning, research in Plant Pathology was to establish the etiology of the disease, understand the life cycle and in establishing the taxonomic status of the causal agent. The next phase was on designing various control measures that resulted in the formulation of Bordeaux mixture and other complex fungicides. Researches of Biffin led to breeding for disease resistance, a new tool to contain plant disease, in understanding the genetic basis of disease resistance and in varietal development. Stakman explained the reason for the breakdown of such varieties and the concept of races and virulence gained ground. The Gene-for Gene theory of Flor, in our opinion is one of the landmarks in the development of plant pathology. Both plant pathology and genetics became the inseparable two sides of the coin. Vanderplank further sharpened the skills of plant pathologists in handling disease control through the resistant host.

The role of bacteria, virus, viroid, mycoplasma and an array of submicroscopic disease causal agents, the role of vectors in transmitting these organisms, ultra structure details, serodiagnosis, and cleansing the material free of these organisms attracted global research efforts.

The microbes provided several restriction enzymes, plasmids, promoters, sequences and vectors as tools for gene transfer / expression and strengthened fundamental molecular biology research. Genomics, nanobiology, gene discovery, gene regulation, understanding molecular basis of cell death, application of computational science, sanitary & phytosanitary issues and risk analysis are likely to gain more attention. We venture to probe into what it is likely to be.

Programmed cell death

In host-pathogen interaction in many plants host cell death leads to disease resistance or susceptibility depending upon the lifestyle of the pathogen. Suppression of programmed cell death (pcd) is commonly caused by the invading pathogens in case of animal systems. However, in case of plants, invading pathogen often triggers pcd leading to disease resistance, in the form of hypersensitive response. It is now clear that host cell death is intimately linked to a number of signaling pathways that influence other defense processes. In contrast, cell death also promotes the aggressiveness and also helps in dissemination of some pathogens during pathogenesis. Therefore, understanding cell death mechanisms is essential in both host disease resistance and susceptibility responses. Depending upon host- pathogen interaction, if cell dies by different mechanisms, this information could be selectively used to target different pathways, which could lead to the development of diagnostic tools. This would help in the dissection of cell death and defense regulatory networks. It has recently been reported that cell death associated with pathogenesis in plants has common regulatory and mechanistic features with apoptosis in animals (Liang *et al.,* 2003).

Cell death mechanisms during resistance response

Disease resistance associated with hypersensitive response (HR) is one of the most important cell death responses in plants which involves coordinate activation of many defenses – that limit pathogen growth (Greenberg, 1997). It is now proved in most host-pathogen interactions that HR is triggered because of the correspondence between a dominant host-resistance (R) gene and a dominant pathogen avirulence (Avr) gene as suggested in a classical gene-for-gene hypothesis (Flor, 1971). This is due to either direct or indirect interaction between the *R*-gene and *Avr* gene products depending upon the *R-Avr* gene pairs. The direct physical interaction between plant disease resistance gene *(Pto)* and *AvrPto* kinases has been reported (Tang *et al.,* 1996). In another study, Jia *el al.,* (2000) showed direct interaction between blast resistance gene *Pita* and *Avr* gene of *Magnaporthe grisea* leading to disease resistance.

It has been suggested that HR is an active process of the host and may be a form of programmed cell death (pcd), hence host cells must be metabolically active and in some cases, HR requires active host protein synthesis for its induction by fungi (Heath, 2000). Genetic control with positive and negative gene regulation of HR has also been suggested in subsequent studies. Even morphology of cell undergoing the HR at late stages suggests that it is a form of pcd with some apoptotic features (Lavine *et al.,* 1996). Ultra structural analysis of morphological events that occur during the HR in *Pseudomonas syringe* infected lettuce showed early changes in mitochondrial morphology (Swelling and cristae disorganization) which is similar to what occur in animal cells undergoing apoptosis (Wakabayashi and Karbowski, 2001). At the later stages of infection, membrane dysfunction and progressive vacuolization of the cytoplasm have been reported. However, apoptosis related chromatin condensation and endonucleolytic cleavage have not been reported in HR of plants. To address some of these issues, Greenberg and Yao (2004) analyzed interaction between *Puccinia coronata* and oat and interaction between *Arobidopsis* and avirulent strains of *P. syringae*. They observed that cells adjacent to the first cell that die have the apoptotic features of chromatin condensation and endonucleolytic cleavage but no evidence of oncosis in both the interactions was obtained. They suggested that cells in an infection zone might die by multiple mechanisms, which require further investigations.

Simple experimental systems can be used to study the signaling requirements and mechanisms of cell death during HR. Particularly, pathogen-derived molecules like elicitors which induce HR have been used either by applying them directly to plant cells or by expressing the genes for these elicitors in plant cells. In some studies direct infection of plant cell cultures with the pathogen propagules has been used. Such systems are potentially very powerful for identifying HR signaling components for determining the relationship between cell death and other defense-related events and analysis of organelle changes in cell death. These approaches have been used to study the oxidative burst (Heath, 2000) and ion channel (Atkinson *et al.,* 1996, Wendenhenne *et al.,* 2002) implicated in HR.

The contribution of HR, in resistance response can be studied by selective inhibition of HR. This can be done by knowing the components of cell death machinery and the selectivity of the reagents used to inhibit the machinery (Greenberg and Yao, 2004). For instance, in plants there is some evidence that the HR involves the induction of caspase-like activities. If in plants these caspase-like activities are truly specifically involved in activating pcd, then they provide an ideal target to disrupt, in order to test the involvement of the HR in resistance. However, to establish rigorously whether these plant caspase-like activities are solely involved in the cell death control, is a challenge for the future analysis of mechanisms of cell death in susceptible host-pathogen interactions.

In susceptible host-pathogen interactions, cell death leads to successful colonization and replication of the pathogen. Induction of cell death with apoptotic features has been reported in oat infected by pathogens like fungi, viruses and bacteria (Yao *et al.,* 2002). They obtained apoptotic like events in the directly infected cells and or in the neighboring cells depending upon the infectious agents. These morphological features showed that cells die with same mechanism. However, more rigorous and comprehensive tests of the use of apoptotic cell death inhibiters should be performed to examine whether it is because of the alteration of pathogen growth or disease symptoms. A baculovirus protein p35 showed reduced cell death in tomato tissues treated with a mycotoxin (Linoln *et al.,* 2002). These plants also showed reduced symptoms with a number of pathogens. It has also been reported that tomato plant containing N resistance gene and baculovirus protein p35 had less dehydrated cell death and enhanced spread of the tobacco mosaic virus (del Pozo and Lam, 2003). The alteration of both susceptible and resistance responses by the same anti caspase protein suggested that cell death pathway target is common to both the HR and susceptible host responses.

There are still many unanswered questions about the role, regulation and mechanism of pcd during host-pathogen interaction. It is still unclear whether there exist multiple mechanisms of cell death execution and regulation in infected genes and in different plant species. Is cell death truly important for disease resistance or susceptibility. Since, ectopic expression of anticaspase p35 protein in plants affects cell death in both the HR and susceptible host-pathogen interactions, it might be possible that common basal cell death machinery is engaged during different responses. It might be possible that if some pcd steps are common in between resistant and susceptibility responses other aspects of pcd are different (Greenberg and Yao, 2004). In future, analysis of the role of cell death in plant pathogenesis by inhibiting cell death machinery selectively and simultaneously and to monitor other defence and pathogenesis-related events as well as contribution of pcd in resistance and susceptibility should be established. This will help in detecting the potential targets for genetic engineering of novel resistance genes by modifying the expression of host genes that facilitate susceptibility.

Molecular interaction among plant and pathogens

Many models have been proposed in the recent past to explain the interaction between plant and plant pathogens. However, current knowledge is insufficient to explain precisely these interactions depending upon the nature of pathogen. Such interactions can be explained both by pathogen and plant derived molecules. Pathogen derived molecules such as avirulence gene products involved in host-specificity and association of hrp gene products with hypersensitive response are important in obligate pathogens. On the other hand necrotrophic pathogen produced a wide range of extra cellular enzymes, which enabled pathogen entry in the host cell by degrading cell wall polymers. Besides, some plant produced pathotoxins, which kills plant cells preventing them from responding in a coordinated manner to resist infection.

Plant derived molecules specifically involved in plants possessing resistance genes are specific to the pathogen races. These are generally ineffective against other pathogens. Hence, a very specific molecular signaling reaction should occur between avirulence gene product and a resistance gene product i.e. receptor. Resistance gene products have conserved protein domains involving membrane-spanning regions leucine-rich repeat which are associated with proteins involved in protein/protein binding. There are many R-genes, which are involved in signal transduction e.g. transcription factors, which are present as gene families. Hence, different family members respond to different stimuli. Besides, pathogenesis related proteins (PR-proteins) increase after infection and is thought to be associated with resistance response.

Evolution of resistance genes

High variability in pathogens leads to break down of resistance in many plants. This is because of the high mutation rate of many plant pathogens. The mutants who have changed from avirulent to virulent will have a selective advantage as their host-range has been broadened and they will multiply more efficiently. Plants, however, have a wide range of recognition specificity and susceptibility is the exception, suggesting that co-evolution between host and pathogen frequently occurs in nature. Genome organization of *R*-gene locus in plants can provide clue to the mechanism by which sequence diversification in plant resistance gene is promoted. Some R-genes such as *Hm1* and *RPM1* (Johal and Briggs, 1992, Grant *et al.,* 1995) are only present as a single copy gene and are absent in susceptible plants. However, most of the R-genes are organized in complex loci and contain an array of homologous genes. These R-gene clusters are, *Rp1, Rpp5, Xa21, Pto, Dm3, I2, N, M,* and the *Cf* genes. The tandem array organization of homologous sequences probably facilitates inter- and intragenic recombination events, unequal crossing over and gene duplications (Michelmore and Meyers, 1998). Therefore, decoding of complete plant genome sequences, i.e.

Arabidopsis (The *Arabidopsis* Genome Initiative, 2002) and Rice (IRGSP, 2004) has opened a vistas of many new studies about genome organization of specific R-locus in different plant species. The future studies will thus be centered on the genome analysis of model plant species and comparative sequence analysis of specific locus as well.

Nanobiology

The technology, which deals with the nano-meter sized objects, which is developed at materials, devices and systems, is called as nano-technology. Future achievement in scientific knowledge and its commercial application will be at the nanomaterial levels. This nano-level technology would be having far reaching affects in all walks of life and in scientific breakthrough as well. In biological science, if we consider a single cell, it is made up of various sub-micron size domains like proteins which is about 5nm in size and can be easily compared with the smallest manmade nanoparticales. Understanding complex macro-molecular structures at nano-scale would be an exiting area of research in the biology. Many supra molecular and self-assembly structures like various membranes and protein complexes, being biological origin form an interface between nanotechnology and biotechnology. The characteristics of these biological structures can be exploited in nanostructure design and development. The single molecules (DNA and protein) of these nanostrctures, and their manipulations can be observed by Scanning Tunneling Microscopy (STM) and Atomic Force Microscope (AFM). In plant pathology, nanotechnological methods can be employed in various applications. These includes, bio-detection of plant pathogens, labeling of protein molecules with fluorescent probes to study the protein-protein interactions, detection of specific proteins expressed during host-pathogen interaction, identification and detection of specific pathogen population dynamics in different types of soils by using nanoparticales as biotags. For instances, biological coating may include antibodies, biopolymers like Collagen (Sinai *et at.,* 2003) and making nanoparticales biocompatible by making monolayers of molecules on them (Zhang *et al.,* 2002).

During the post genomic era, when huge amount of protein and DNA sequence data will be available for different organisms including plants and plant pathogen, need for the development of high throughput screening technologies will increase. Even various micro array technologies being used during these days would likely to reach up to saturation level when number of array elements exceeds several million folds. In that case, a three dimensional approach, based on optical bar coding of polymer particles in solution can reliably be produced and detected by means of number of unique tags (Han *el al.,* 2001). The organic dyes used in various bio-tagging applications have been successfully replaced with single quantum dots of compound semiconductors (Park *el al.,* 2003). Such bio-tagging techniques would be very useful in pathogen detection at a single cell level or even detecting traces of harmful chemicals in the food and feed with greater precision and high throughput manner. Basic understanding of host-pathogen interaction can be achieved by studying the protein-protein interaction and analysis of various defense responses at nano-scale levels. Being an important part of living cells, structure and function analysis of specific proteins is highly essential. We know that gold nanoparticles are widely used in immuno-histochemistry to identify protein-protein interactions. However, the multiple and simultaneous detection capabilities of this technique are fairly limited. Single dye molecules can be easily detected by using a well-established technique like, "surface enhanced Raman scattering spectroscopy (Cao *et al.,* 2003). By combining both methods in a single nanoparticle probe, one can drastically improve the multiplexing capabilities of protein probes. A sophisticated multifunctional probe built around a 13 nm gold nanoparticle has been designed. They coated the nanoparticles with hydrophilic oligonucleotides containing Raman dye at one end and terminally capped with a small molecule recognition element (e.g. biotin). Since, this molecule is catalytically active and can be coated with silver in the solution of Ag (I) and hydroguinone. Once the probe is attached to a small molecule or antigen it is designed to detect the substrate, which is exposed to the silver and hydroquinone solution. Silver plating is happening close to the Raman dye, which allows for dye signature detection with a standard Raman microscope (Cao *et al.,* 2003). The major thrust in further development of nano-materials would be to make them multifunctional and externally controlled, so that these can be converted into nano-devices.

Functional genomics of pathogens and plants

Genome analysis of pathogens

Structural genomic studies of many plant pathogens are underway in different international and national consortium. Complete genomes of bacterial pathogens *Xyllela fastidiosa* (Simpson *et al.,* 2000) and *Ralstonia solanacearum* (Salanoubat *et al.,* 2002) and fungal pathogen *Magnaporthe grisea* (www.broad.mit.edu/ annotation/ fungi/ magnaporthe) have already been decoded. Besides, genome sequencing of various pathogen genomes are underway in different international genome initiatives. These projects also include expressed sequence tags (EST) projects from a variety of developmental and infection stages as well as targeted sequencing of contigs of bacterial artificial chromosome clones representing selected regions of the genomes. These large scale sequencing approaches have great promise in understanding the molecular basis of pathogenicity and specificity in pathogens by facilitating the isolation of novel virulence and avirulence genes as well as by helping in identifying targets for chemical control. Mining for the candidate genes for above functions will be of great use in near future.

Gene silencing is a very popular technology currently being used in different pathogens. Gene silencing can be associated with a lack of specificity, if a family of closely related genes is targeted. There are various approaches used for gene silencing in different pathogens. Van West *et al.,* (1999) showed that a promoter less full-length cDNA clone of the *inf 1* could be used without modifications to transform *Phytophthora infestans* and to generate silenced strains. Other methods for targeted gene knockout are being developed (Kamann, 2000). In addition to loss of function assays, gain of function or complementation assays can be set up by using heterogeneous pathogen species. The candidate genes of interest that are known to lack a functional copy of the gene often carry a mutated orthology. Though lot of work on structural and functional genomic studies of plant pathogens is underway world over, there is no report on these aspects from India. There is a need to use genomics approaches for the analysis of highly evolving wheat rust races, and other highly variable pathogens. This will help in better understanding of the molecular basis of pathogen virulence and avirulence gene.

Genome analysis of plants

After the complete genome sequencing of *Arabidopsis* (The Arabidopsis genome initiative, 2000) and Rice (IRGSP, 2004) many plant genome initiatives are now underway. We will get complete blue print of important plant genomes in a few years time. The whole genome sequence data are in public domain that can be used in various ways for the development of superior genotypes of major crops. However, once large sets of sequence data are available, the research focus needs to shift to functional analysis of the newly discovered genes. The major challenge in the post genomic era would be to link a sequence to phenotypes with as little experimental effort as possible. Using computational tools for data mining robust high throughput functional assays would be used routinely.

Seed as the wrapped technology

Seed is an important input in agriculture. In the beginning, local land races that were grown as a mixture were purified and released as varieties since they had distinct yield advantage. Following this crossing between two superior lines and selecting from the segregating progenies, plants having superior traits adopting the pedigree system of improvement came into practice. The development of disease resistant varieties integrated into the seed not only good agronomy but also plant protection more so the fungicidal effects as many of these lines had inherent resistance to diseases. So the use of fungicides for disease control became unnecessary.

High seed moisture levels impair the seed quality and this favors the growth of a number of microbial organisms on the seed surface that interfere with the seed viability. When seeds are used for sowing, these contaminated seeds rot in the soil or produce weak seedlings that have low yielding potential. Also there are several bacterial, fungal and virus diseases that are seed borne in nature. Through them infection foci is established in a young crop and under congenial weather, the pathogen spreads causing considerable crop loss. To contain this, seed treating fungicides were developed and since the organo-mercurials had environmental consequences, they were to be withdrawn and replaced with better ones. Seed encapsulation with beneficial biocontrol organisms, VAM, nitrogen-fixing organisms are now becoming common.

There is a new opportunity now for the seed business to wrap pesticide inside. The transgenic cotton (Bt cotton) carries inside the gene fragment from *Bacillus thuringiensis* that produces insecticidal proteins against *Heliothis armegira* (American boll worm). By doing so now the cotton hybrid carries with it a good plant protection weapon. By encapsulation techniques biocontrol agents and beneficial organisms can be embedded to the seed exterior. The *Bt* gene parked in the genome of cotton carries the specific insectide and hence, seed has become a multiple delivery system (transgenics, resistant varieties, cross protection).

Plant-Pharma is becoming a reality as plant genome has been amended to produce vaccine against some of the human virus diseases. So the delivery of vaccine for public health can be made simple and Plant-pharma transgenic banana can reach-out to remote corners of the country. The need to have refrigerated facilities to store vaccine etc may become unnecessary. However our plant pathologists and the seed industry is still not geared to reap the benefit of this development. Plant virology has several things in common with animal and human viruses, particularly the serosystems.

Cropping system pathology

A specific cropping system can play important role in the perpetuation, infection and spread of plant pathogens in different epidemiological regions. Different cropping systems exist in different agro climatic regions of India both in irrigated and dry land agriculture. Even pathogen diversity and prevalence are also specific to the both upland and low land areas. Hence, disease management strategies would also be cropping system dependent. For instance, northern plain zones of India has witnessed the grand success of "Green Revolution" starting from the seventies because of a very specific Rice-Wheat cropping system along with intensive use of fertilizers, chemical pesticides and irrigation. Hence, pathological problems were also specific to this cropping system. However, now the agriculture is being diversified. Farmers are being attracted to grow short duration cash crops like vegetables. This has also changed the pathogen profiles in these areas leading to the study of pathogens, specific to the changed cropping system. There is thus complete shift in the disease management strategies. One has to find new ways to tackle such problems for increased agricultural production.

With the introduction of genetically modified (GM) crops, in the existing cropping system, plant diseases have to the managed differentially. Though in India only GM cotton hybrids MECH-12, MECH-162 and MECH-184 developed by MAHYCO hybrid Seed Company have been released for the commercial cultivation in March 2002, in the beginning, these 3 hybrids covered about 40,000 ha area in the central and southern parts of the country. These GM cotton contain *Bt* insecticidal gene derived from the soil *Bacterium Bacillus thuringiensis* that impart resistance to the bollworm insects, i.e. American boll worm *(Hellicoverpa armigera),* spotten bollworm *(Earias insulana / E. vitells)* and pink bollworm (*Pectinophora gossypiella*). Planting of Bt-cotton is expected to curtail excessive use of broad-spectrum insecticides used every year for the control of these pests. However, this technology is also not free from the threat and concerns. Apart from the concerns of health and environmental hazards, horizontal gene transfer and issues of the development of antibiotic resistance, emergence of new insects and diseases, which were otherwise virtually non-existence in nature may become predominant. For instance, Bt-cotton hybrid MECH 162 was found more prone to the Para wilt during its first year of cultivation in India (Bambabale *et al.,* 2004). Where as another transgenic Bt-cotton hybrid MECH12 is known to be sensitive to jassids. Though it is very early to predict possible success or failure of Bt-cotton in India, it is going to take a sizeable area under cultivation in the years to come. In near future, we can also expect more number of GM crops in the cropping system in India. Hence, one has to be cautious about the incoming new plant protection problems. Though most of the GM crops, which are in pipeline for their release in India, are targeted to insect resistance, we can expect new disease problems in epidemic proportion specifically because of the "Vertifolia effect". The genetically uniform crops (specifically GM) might be cultivated on a larger scale hence, occurrence of devastating epiphytotics cannot be ruled out.

Therefore, a comprehensive plan should be developed for the use of GM crops over time and space. We should combine more than one gene in a cassette, possibly, insect and disease resistance genes together, and then transfer them to the desirable genotypes. Secondly, different genes, if used singly, can be deployed in different zones as per well-known gene deployment strategy being followed for the control of wheat rusts. Thirdly, GM crops can be successfully used as one of the components of integrated pest management programmes. It has already been demonstrated successfully for the pest management in Nanded district of Maharastra, India (Bambawale *et al.,* 2004). With the increased awareness and health consciousness, now pesticide free or organically grown crops are being preferred in India. This will further add new or changed plant pathological problems in the ecosystem. Organic farming though considered environmentally safe, its effect on pathogen population, specifically dynamics of soil borne pathogens have to be looked differently. This will definitely help in finding new bio-control agents from the ecological nitche and their formulations has to be improved for integration in the production of chemical free plants. Are the new types of crop cultivation suppressing or increasing particular types of pathogen population, have to be studied more systematically and comprehensively.

New pesticide application procedures

Application of pesticides for the management of biotic stresses (diseases, insects and weeds) has great role in maintaining crop health. Specific research efforts focused on the improvement of pesticide application in agriculture is essential for crop protection and environment safety as well. Foliar application of fungicides is an important method used for the management of infectious plant diseases by creating chemical barrier on leaf, stem or flower surfaces against the incoming pathogens. A spray method must provide the best combination of practical usefulness and good coverage to both upper and lower surface of the leaves. A suitable spreader-stickers or spray adjuvant can be added to the fungicides. In soil borne diseases, drench applications of fungicide may be more effective. For this, a very close attention should be paid to soil type, texture and pH, which influence the efficacy of the fungicides. Proper timing of fungicide application is another important consideration. In most of the cases, fungicides are not effective in plant disease management, if pathogen infection has already occurred in the plant tissues.

Basic fungicide application strategy should be focused on application system development, drift management, efficacy enhancement and remote sensing. Future research on application system should include, sensor controlled hooded sprayers, new approaches to direct chemical injection and aerial electrostatic sprayers. For the accurate field application, on-board flow controllers should be used. Aircraft parameters such as boom position and spray release height can be suitably altered to determine their effect on the drift. The basic drift management research should be focused on testing of low drift nozzles, evaluation of pulsed spray technologies and evaluation of drift control adjuvant. After application, the fate of fungicide in soil should be studied which is mainly dependent on the soil properties. Soil characteristics heavily influence the fungicide efficacy and dissipation in the environment. With the changing agricultural practices, fungicide formulations have also been changed. For the control release of fungicides in the target areas, microencapsules of fungicides play an important role (Review, Tsuji, 2001). Micro encapsulation of pesticides has considerably improved handling safety due to hazards and exposure reduction.

Recent advances in electronics, remote sensing and computer application have resulted in the precision application of pesticides. Advances in electronics has played an important role in the developments related to the control use of pesticide by better matching applications to the target requirements. This may require spatial distribution of weed, pest or disease or methods by which the target, particularly a crop canopy can be described with respect to a given application (Miller, 2003). Hence, specific infected crop patches should be identified and selectively sprayed with the effective fungicides. Patch spraying can considerably reduce the excessive use of pesticide in the target environment. In widely spaced row crops like vegetables, fully automated detection system based on image analysis can be developed which will guide the application of pesticides only in crop rows. In case of cereal crops, studies have been shown that saving in fungicide use may be possible, particularly at earlier stages of growth by adjusting spray delivery to measured canopy characteristics.

In many countries specifically in USA, Remote sensing systems are being used to identify disease-infected areas in the field so that spray can be directed only to those areas. In India too, this can be employed specifically in those crops where fungicides are used over a wide areas like Apple Scab or potato late blight for specific application of fungicides in the infected patches.

Pesticide transport models are being used as a tool to develop effective pesticide management studies by the use of Root Zone Water Quality Model (RZWQM) as discussed by Malone *et al.* (2004). The model RZWQM is a physically based agricultural systems model that includes sub-models to simulate pesticide infiltration, run off, water distribution and chemical movement in the soil, macro pore flow and chemical movement through macro pores, evapotranspiration, heat transport, plant growth, organic matter / nitrogen cycling, pesticide process, chemical transfer to runoff and the effect of agricultural management practices on the process. It has been shown that if key input parameters are calibrated, RZWQM models can adequately simulate the process involved in pesticide in different agro climatic zones of India for effective and specific use of fungicide in different crops.

With the increased emphasis on protected cultivation in India, management of diseases in the green house environments could be tackled by using specific fungicide application. A new approach to fungicide application in green houses has been named as ‘Envirosol technology’. This technology uses carbon dioxide to deliver pesticides as aerosol droplets into enclosed spaces like green houses. Envirosol products such as Permigas, Pestigas, and Insectgas are commercially available. For instances, Floragas and Hortigas have been developed as post harvest fumigants for the treatment of cut flowers and asparagus (Carpenter and Stocker, 1992). Growers use high volume spraying with motorized pumps and reduced-volume spraying with thermal pulse-jet foggers in controlling green house diseases and insect pests. These applications too have runoff of excessive pesticide. Hence, specific user-friendly green house fungicide application technologies have to be developed in the future.

Environmental pollution and increased health hazard linked to the excessive use of pesticide would be the major concern in the years to come. Therefore, effective regulation and risk management of pesticide contaminants in the environment, development of reliable pesticide monitoring technology is essential. Currently gas-liquid chromatography (GLC) and liquid chromatography (LC) methods are being used (Lee and Kennedy, 2001). However, immuno analysis can provide a powerful monitoring technique, which is scalable for high throughput, rapid, accurate and relatively inexpensive technique. This technique is versatile in application, can be custom made for different quantitative and qualitative analysis of pesticide residues and tests can be conducted at field level. Immuno diagnostics and their application in the monitoring of chemical contaminants in the environments warrant immediate attention.

Judicious use of pesticide and improved methods of application can greatly reduce the environmental and health hazards. Chemigation, direct injection, closed system handling, and fertilizer impregnation technology would be of great use in this endeavor. Besides, fungicide should be used as an important component of integrated pest management for reduced use of chemicals. An effective education programme about the specific and judicious use of pesticide can play an important role in future programmes on pest-management and increased agricultural production.

Harmonizing trade related plant pathology SPS, PRA etc

Liberalization of world trade in agriculture with the advent of WTO has thrown up challenges and has also opened up new vistas for growth. The devastating effects of introduced diseases and pests along with the movement of agricultural produce and products have been known throughout history. However, global legal standards in the form of sanitary and phytosanitary measures (SPS) have been promulgated recently. The SPS measures include :

- to protect animal or plant life or health from risks arising from the entry, establishment or spread of pests, diseases, disease causing and/or carrying organisms,
- to protect human and animal life and health from risks arising from additives, contaminants, toxins or disease causing organisms in food, beverages or feedstuff.

It also recognizes Government's right to take sanitary and phytosanitory measures but stipulates that they must be based on science, should be applied only to the extent necessary to protect, human, animal and /or plant life or health and should not discriminate between members. We have to ensure that the member countries do not misuse this agreement to act as a barrier to trade.

Possessing one of the largest and diverse agriculture, India understands well the implications of SPS agreement and wishes to apply it to our advantage to facilitate export and import of agri-products. Due to removal of quantitative restrictions in import, there might be a huge inflow of agricultural commodities for which the matching testing facilities at our quarantine stations should be upgraded. A network approach has to be worked out at national level.

The SPS agreement also encourages the use of pest risk analysis (PRA) on the basis of an evaluation of actual risks involved and the appropriate level of protection defined. Survey and surveillance of various pests and pathogens should be taken up as per IPPC norms for identification and declaration of pest free areas, which may be of great help in promotion of exports. This will require regular and constant technical survey/surveillance, which needs coordinated efforts by all States and UTs. Meeting the sanitary and phytosanitory requirements of most of our developed country trading partners also calls for substantial investments in developing adequate infrastructure facilities. Standards have to be established for all agricultural and food products and action should be taken to notify them. We cannot prescribe higher standards for imports than that are prescribed for domestic products. Also it is necessary to assess the difference between Indian and International standards and analyze the reason for the gap and work out the manner of harmonizing our standards with the international standards wherever required.

Thus, though there are provisions for member countries to control entry of materials according to their national standards yet the sanitary and phytosanitary measures require a more concerted effort from the less developed countries to protect their own interests of export and import. Standards need to be established for all agriculture and food products.

Summary

In the last 100 years, there has been an impressive growth of plant pathology as a science in India. Plant pathology developed into various spheres of activity beginning with an emphasis on the correct diagnosis of the various causal agents, their culture maintenance and taxonomic research. Simultaneously, disease control strategies were developed through breeding for disease resistance, agronomic manipulations, chemical control etc. Thus, the science of plant pathology contributed significantly towards the stability of agricultural output and in averting the outbreak of epidemics.

In the last two decades there is a great deal of shift towards molecular taxonomic characterization of the bacterial plasmid downstream between the host and pathogen and signaling a pathway in inducing host resistance. With the increased globalization of agricultural trade and commerce issues related to quarantine research, risk analysis, level of residue in food material has started drawing attention. Transgenic technology offers great opportunity for designing virus resistant plant and in the incorporation of resistance to nematode and insect pests. There is no strict boundary between disciplines now trans-discipline knowledge become essentiality to be in the forefront of development.

Application of physical and computational sciences gives us an opportunity to monitor crop damage and in making yield assessment through simulations. Application of micrometeorology has led to the development of accurate disease prediction systems and by using the highly specific molecules that are fungicidal in nature plant disease can be effectively kept below the economic threshold. Application of nano-science and molecular biology and plant-pharma are emerging new opportunities. The next hundred years, therefore, will see a totally different development and will call for an in-depth knowledge for making continued progress.

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DESIGNING VEGETABLES WITH IMPROVED NUTRITIONAL CONTENTS

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INTRODUCTION

Vegetables are the major source of plant proteins, vitamins, minerals, plant fibres and various functional nutrients. In addition, vegetables also contain bioactive compounds such as simple phenols, carotenoids, flavanoids, indoles, glucosinolates, organosulfides, polyphenols, protease inhibitors, phytoestrogens, isothiocyanates and others. Therefore, vegetables have an extremely important role to play in human nutrition and health. It is well known that nutritionally secure population is the engine for economic growth and development. In Indian and Chinese culture different vegetables have different functions, some are warm and others are cold. The Chinese call it the **"Yin and Yang"** effect to the human body. In fact the vegetarians in India and around the world depend on plants as the main protein, vitamins and minerals source in their diet. In ancient literature in India and in Indian medicine, vegetables, spices and herbs are the key ingredients (Krishnaswamy, 2004). Vegetables contain not only known healthy nutrients but also toxic chemicals which when consumed in right amounts improve health and overcome non-contagious nutritional disorders (Duncan, 1988). However, we have to recognize that all nutrients (and antinutrients) in the food play a collective role, synergistically, each nutrient playing a part in a team (Gopalan *et al.,* 1989). "It will be a poor strategy to converge, what is essentially an orchestra in to a solo." In this paper, the genetic variability for nutritional traits in selected vegetables, opportunities to make genetic improvement, progress made at AVRDC-the World Vegetable Center and strategic role of biotechnology in making nutritional improvements in vegetables will be presented.

Food Security and Nutritional Security

Agricultural production of staples, especially that of rice and wheat and to a lesser extent maize and millets, increased in all countries (APO, 2001). In spite of it, each day 800 million people go to bed hungry and 170 million children under 5 years of age are malnourished. It has been branded as an avoidable tragedy (IFPRI, 2002). It is true that cereals are the mainstay of the poor people and cereal production is essential for sustaining the livelihood of the poor. In the past, "to a large extent our policy framework and investment priorities for agriculture were designed for addressing the issue of food security in the country" said Dr. Manmohan Singh, the Prime Minister of India in a recent interview (IFPRI FORUM, 2005). Since the "green revolution" countries like India are no longer in chronic shortage of staples. Therefore, the Government's policy framework will focus on providing incentives to specific high value crops. Vegetables and fruits are among those crops.

More than 2 billion people worldwide, especially those living in poorer countries suffer from micronutrient deficiency (Graham and Welch, 1996). A growing awareness for nutrition and health among many segments of the population in developed and developing countries is drastically changing the dietary habits of the people. Obesity, heart disease due to high cholesterol, cancer due to lack of fiber in the diet, HIV AIDS among other things are motivating people to increase the proportion of fruits and vegetables in their diet. Furthermore, in recent years frequent outbreaks of animal diseases such as mad cow disease, avian flu, SARS, foot and mouth disease and mass poisoning of seafood have created insecurity about food safety among the public. As a result more and more people are becoming partially or wholly vegetarians. The demanding and discriminating public is becoming very critical when purchasing food. The consumers are very conscious about the nutritional information of vegetables that they consume. Commodities with less or no cholesterol, vegetables rich in vitamin A or C and those with high iron or antioxidant properties are gaining rapid entry into public nutrition. Therefore, at present the vegetable breeders are not only looking for higher yields, adaptation and resistance to biotic and abiotic stresses but they are also focusing on vegetables with better nutritional composition that meets the palates and fancies of the consumer. Since consumers are still not ready to pay a premium price for vegetables with better nutritional composition the breeders try to improve the nutritional composition retaining the high yield and other desirable traits.

Food and nutritional security are the key targets of the Millennium Development Goals of the United Nations. In terms of nutrition, the intake of vitamin A, iron, iodine, zinc, riboflavin, vitamin B-12, Vitamin B-6 and calcium are grossly insufficient compared to the recommended daily allowance (RDA) in poorer section of the population around the world. In addition these poor people who cannot afford fruits and vegetables may also be deficient in folic acid and vitamin C, especially children, women of reproductive age and elderly. Such malnutrition makes them vulnerable to debilitating diseases such as anemia, aging and premature death (Flores and Gillespie, 2001). The 1992 International Conference for Nutrition, The World Food Summit in 1996, and The World Summit for Children in 2002 identified the following eight major nutritional challenges requiring concerted efforts: They are low birth weights, child hood under-nutrition, under-nourished adults, pandemic anemia, extensive chronic vitamin A deficiency, chronic diseases due to childhood malnutrition, increasing obesity, and iodine deficiency (Rajagopalan, 2004). In addition to food supplements, and food fortification it is essential to consider food-based approach, especially through increased consumption of appropriate vegetables and fruits to reduce the micronutrient malnutrition substantially. Plant-based foods prevent diseases such as cancer, heart attack, and premature aging and also promote positive health (Johnston, 1994).

The Major Nutritional Traits

In the developing countries major micronutrient problems were due to deficiency in vitamin A, resulting in blindness, iron resulting in anemia and iodine. Of the above, iodine has been conveniently corrected by adding iodine to the salt. Since there are many vegetables and pulses that are rich in vitamin A and iron respectively the plant breeders try to look at the opportunity to select for higher nutritional content. From the medical side vitamin pills were distributed to the vulnerable groups to overcome the deficiency problem. However, the food-based approach was considered as more sustainable, natural, low cost alternative compared to distribution of pills through aid. In the western countries, especially in the USA the plant breeders looked at the proximate concentrations of vitamins A, C, niacin, riboflavin, thiamine, potassium, phosphorous, calcium, iron, and sodium (Steven, 1974; Munger, 1988). The major focus was on vitamins A and C. However, recently the attention is also given to zinc and iron. The phytochemicals that are present in various vegetables and their action in human body is given in Table 1.

Table 1. Various phytochemicals in vegetables and their role in human nutrition (modified from Leslie Kay, 2005)

Phytochemical	Food	Action
Allylic sulfide (allicin)	Garlic, Onion	Intercepts and detoxifies
Beta-Carotene	Carrots, Squash, Tomato, Chilies, Peppers, Sweet potato	Protects the immune system
Canthaxanthin	Paprika	Antioxidant

Capsaicin	Cayenne peppers, chilies, red peppers	Prevents toxic molecules from invading and damaging cells, anti-inflammatory
Carotenoids (600 identified)	Dark green, colored and orange colored vegetables such as tomatoes, peppers, spinach, amaranth, etc.	Blocks carcinogen from entering the cell; helps repair DNA
Cumarin	Curry leaf, turmeric, mustard	Antioxidant
Diadzein (isoflavone)	Vegetable soybeans, soybeans, tofu	Blocks estrogen from binding to receptors
Flavonoids	Many vegetables, vegetable soybean	Prevents carcinogenic hormones from attaching to cells
Folic acid	Vegetables, vegetable soybean	Anticarcinogenic
Genistein (isoflavone)	Tofu, soy milk and vegetable soybeans	inhibits the formation of blood vessels that assist tumors to grow
Gingerol	Ginger	antioxidant
Isoflavones	Soybeans, beans, peas, tofu	interferes with harmful estrogen action and may reduce the risk of breast and ovarian cancer
Isothiocyanates, Indoles	Broccoli, cauliflower, cabbage, kale	blocks carcinogens from damaging a cell; interferes with the action of a pre-cancerous form of estrogen
Lutein	Spinach, collard greens, kale	reduces blindness in the elderly (prevents age-related macular degeneration)
Lycopene	Tomatoes	may decrease risk for prostate cancer
Monoterpenes	Kale	Inhibits cancer cell growth and detoxifies carcinogens

Omega-3 fatty acids	*Portulaca oleracea*	may decrease the risk of heart disease
Organosulfur compounds (Glucosinolates, ACSOs and their degradation products	Brassicas, onion, garlic, leek	health promoting and cancer fighting
Phenolic acids ferulic and chlorogenic	Potato, beans	antioxidant
Polyacetylenes including falcarinol	Carrot, Parsnip, green tomato, lettuce	health promoting, antioxidant
Saponins	Vegetables, soybean	
Tannins, catechin, epicatechin polymers	Lentils, black-eyed peas	antioxidant
Zeaxanthin	Kale, mustard, horseradish, collards	Antioxidant, enhances immune function

Vijayalakshmi,*et al.* (2003) recommended four strategic choices for food-based approaches to alleviate micronutrient deficiency: 1) increasing the production of micronutrient-rich foods; 2) increasing intake of micronutrient-rich foods; 3) improving bioavailability of micronutrients; and 4) developing varieties with increased micronutrient contents, decreased content of inhibitors and increased contents of substances that promote absorption and bioavailability of micronutrients. In addition to improving the nutritional composition of the vegetables the above strategies are equally important not only to increase the population's access to micronutrient-rich foods but also to increase the consumption and ensure that the micronutrients can be absorbed and utilized by the body (Ruel, 2001)

Vegetable Breeding Objectives

In the past the vegetable breeders, as well as the major food grain breeders, focused their research attention primarily on yield, resistance to fungal, bacterial and viral diseases, tolerance/resistance to insects, tolerance to various abiotic stresses such as temperature, moisture, soil acidity, soil alkalinity and other hedonistic traits to produce economically productive vegetables. Vegetable breeders did recognize the importance of improving the nutritional value of vegetables as early as 1940 but none of the improved varieties with higher vitamin content became popular in the market (Munger, 1988). In the early days consumers were more interested in the appearance, flavor and taste rather than nutritional value of vegetables. As a result the vegetable breeders did not pay much attention to nutritional quality (Stevens, 1974). Furthermore, vegetables are sold by weight, volume or number and not by the amount of nutritional value. Even though a variety may be highly nutritious, it will fail if its yield and disease resistance is not as good or better than the existing varieties. Since the cost involved in selecting for a specific trait increases in a breeding program exponentially with increasing number of genes, unless there is a guaranteed return for such a trait the plant breeders had hard time to get funds for such a program. In developing a vegetable variety ultimately the farmers must grow and make a profit. The processors must buy, process and market it. And the consumers are willing to pay the right price and consume it. Therefore, in setting breeding objectives and priorities the early plant breeders have to keep the nutritional quality improvement in the back burner.

Variability for Micronutrients in Vegetables

Among the vegetable crops, tomato, carrot, potato, peppers, legumes, sweet potato, crucifers and spinach were studied more intensively for the nutritional composition. Variability for vitamin A and C were reported by a number of authors (See White and Selvey, 1974 and Quebedeaux and Bliss, 1988). In carrots the carotene concentration varied from 0.12 to 9.6 mg/100 g. In sweet potato the content varied from 0 to 18 mg/100 g. In tomato the highest amount observed was 10.1 mg/100 g and 88% of which was b-carotene which is 20 times higher than the common tomato (Stevens, 1974). Green bell peppers had only 500 IU/100 g whereas red chili had 11,000 IU/100 g. The vitamin C content in tomato varied from 6.4 to 119.4 mg/100 g. Early breeders try to understand the variability for micronutrients and minerals, try to develop rapid, precise, dependable, repeatable, efficient and economical assay methods to identify the superior ones in the population. They also studied the gene action and heritability of the traits and paved the way for developing varieties with improved nutritional qualities (Gabelman, 1974; Gabelman and Peters, 1979; Simon and Peterson, 1979; Simon, 1988; Stevens, 1979).

AVRDC-the World Vegetable Center focuses its research on those selected micronutrients, which have been determined to be deficient among most vulnerable sectors of the population in the world, specifically children and women. They are vitamins A, C and iron. A few other micronutrients, which come primarily from vegetables such as folic acid, antioxidants and isoflavones are also considered. AVRDC's nutrition laboratory conducts research in close concert with the plant breeders and other scientists in screening the breeding materials for nutritional contents. Screening a number of vegetables from a home garden program at AVRDC revealed that there is sufficient variation in micronutrient contents both within and between vegetable species (Table 2).

Table 2. Variation in nutrient contents in vegetables included in the home garden in 1998 at AVRDC (AVRDC, 1999)

Name	Dry matter (%)	Fibre (%)	Sugar (%)	Vitamin C (mg/100 g)[a]	Calcium (g/100 g)[b]	Iron (mg/100 g)[b]	Carotene (mg/100 g)[a]
Amaranth	7-12	10-13	--	4-84	1.7-2.5	15-43	3.6-10.9
Basil	9	--	--	44	--	18	5.8
Carrot	10	--	--	--	--	10	7.1
Chinese kale	8-11	11-13	8-20	93-153	1.3-3.2	15-45	2.4-6.1
Chinese radish	6-8	8-12	14-19	73-133	1.4-2.7	18-42	3.2
Choy-sum	6-9	8-11	13-23	31-104	1.7-2.3	68-107	2.3-5.1
Chrysanthemum	7	--	--	26	--	20	3.5
Common cabbage	5-6	12-13	31-33	52-63	0.7-1.0	9-21	0.0-0.1
Coriander	13	--	--	137	--	12	6.6
Fennel	5	--	--	9	--	7	--
Indian mustard	6-11	10-13	14-26	62-112	2.0-2.9	6-53	1.5-5.9
Kale	7-8	10-13	--	47-132	1.7-2.4	12-38	2.9-5.8
Kangkong	5-11	13-14	9-26	62-112	2.0-2.9	34-57	2.4-5.9
Leaf-beet	6	--	--	150	--	16	2.9
Sweet potato leaf	11	--	--	52	--	18	3.0
Chien-pao-tsai	6	12	18	81	2.2	34	1.9
Mustard	6-7	11-12	--	72-111	1.1-2.0	13-36	3.2-4.8
Non-heading Chinese cabbage	5-7	10-13	12-28	23-112	1.4-3.4	24-69	1.3-3.3
Paitsai	5-7	10-12	--	31-83	1.6-2.7	18-40	1.3-4.2
Pakchoi	5-8	8-12	16-26	52-120	1.9-3.4	21-97	2.3-5.0
Peppers	17	--	--	219	--	5	3.3
Rape	7-9	10-13	--	43-90	1.7-2.5	13-43	2.6-5.8
Spinach	7	--	--	40	--	26	4.3
Sweet peppers	5	--	--	62	--	9	0.4
Vegetable soybeans	28	--	--	--	--	12	--

a. Values based on fresh weight
b. Values based on dry weight

AVRDC's research efforts, in addition to screening, include 1) identification of opportunities where nutritional improvements can be made without compromising the requirements for the producers, processors and consumers, 2) developing simple, efficient, reliable, rapid and economical screening methodologies, 3) determining the bioavailability and developing simple, socially and culturally acceptable methods to enhance the bioavailability of micronutrients and 4) assessing the impact of nutrient rich vegetables in the community.

To answer the question whether there is genetic variability for micronutrients available to exploit and develop improved varieties, the resounding answer is yes. Based on a number of surveys carried out in China it is estimated that at least 50% of the soils used for crop production worldwide is low in availability of one or more micronutrients (Han, *et al.* 1994). Under such conditions of micronutrient deficient soils growing micronutrient efficient varieties of crops represents a strategy of "tailoring the plant to fit the soil" compared to the strategy of "tailoring the soil to fit the plant (Foy, 1983). The physiological mechanism by which the micronutrient efficient plants absorb the micronutrients has also been well understood (Graham and Rovira, 1984 and Brown, *et al.* 1994).

Anti-nutritional factors like phytates, tannins, neurotoxins, glycoalkaloids, oxalates, flatulence and trypsin inhibitors have been observed in vegetables and beans. It is possible to minimize or remove some of these negative nutritional factors. A new germplasm is used to develop resistance to diseases, insects or abiotic stress factors. In so doing there is a danger of increasing the level of unacceptable toxic or nutritionally deleterious compounds (Kerr, 1974). Since lowering of some of these factors will have an unacceptable effect on production this route of lowering the negative factors such as phytates and tannins may not be a desirable proposition at least in some crops (Graham and Welch, 1996).

Genetic Improvement of Nutritional Factors

Tomato is one of the principal crops of AVRDC and it is also one of the economically important vegetables around the world. According to Food and Agricultural Organization's 2004 estimate about 100 million t are produced from about 4 million ha. The annual per capita consumption of tomatoes in South Asia is estimated to be around 5 kg or 14 g per day.

In 1974 Stevens stated that the b-carotene content of red and yellow fruited tomatoes, *Lycopersicon esculentum* ranged from 0.10 to 1.91mg/100g. The content in L. pimpinellifolium was 0.66 to 1.92mg/100g and that of green fruited *L. peruvianum* was 0.07 to

0.36mg/100g. Stevens (1974) reported that Lincoln in 1943 found the b-carotene content of a cross between red *L. esculentum* and green fruited *L. hirsutum x L. esculentum* varied from 0.06 to 6.75mg/100g. In another similar study by Kohler a cross between tomato variety Baltimore and *L.hirsutum* and between Rutgers and *L.hirsutum* a selection was found to have 10.1mg/100g crude carotene of which 88% was b-carotene which is about 20 times the b-carotene level of the common tomato varieties like Rutgers. From the latter cross the variety, CaroRed with ten times the b-carotene level as that of Rutgers have been developed (Stevens, 1974). CaroRed had a distinct red- orange color, which was not preferred by the consumers, although when the color was masked the consumers liked the flavor and taste.

Tomato has significant quantities of b-carotene and vitamin C and therefore, ranks high as a source of vitamins A and C due to high consumption in many countries (Davies and Hobson, 1981). Lycopene, the major carotenoid in tomato fruit along with b-carotene and ascorbic acid are powerful antioxidants and they help lower the risks of certain cancers, heart disease and age-related diseases (Bramley, 2000; Clinton, 1998; Heber and Lu, 2002; Rao and Agarwal, 1998). Therefore, improvement of tomato for content of antioxidant (AO) and overall antioxidant activity (AOA) could benefit health of people in both developing and developed countries (Hanson, *et al.* 2004). At AVRDC in Taiwan they evaluated 50 *L. esculentum* and three *L. pimpinellifolium* (L.) Mill. entries for contents of lycopene, b-carotene, ascorbic acid, total phenolics and two assays for AOA(anti-radical power (ARP) and inhibition of lipid peroxidation (ILP)) for two years. They found high levels of genetic diversity for the AO and AOA. The group means of the wild species, *L. pimpinellifolium* entries were significantly higher than *L. esculentum* group means for ARP, ILP, lycopene, ascorbic acid, phenolics and soluble solids concentration. Results showed that ranking of entries were consistent in both the years and there was no year by varieties interaction. The study has also found that lycopene, b-carotene, ascorbic acid, soluble solids and total phenolics were all positively correlated with ARP (r=0.90**) and ILP (r=0.83**) suggesting that the phenolics are major contributors to AOA in tomato fruit. They found that the fruit size was negatively correlated with ARP (r= -0.74**) and ILP (r= -0,71**) and therefore, it is a challenge to combine large fruit size with high AOA. The ILP and ARP used to assay AOA can be effectively adopted by plant breeders to improve AOA in tomato (Hanson, *et al.* 2004).

AVRDC has developed high b-carotene, multiple disease resistant productive cherry tomato lines. The Hualien District Agricultural Improvement Station released AVRDC's cherry tomato lines CHT1200 and CHT1201 as Hualien ASVEG No.13 and 14 respectively. Their b-carotene contents were 2.14 to 3.00 and 2.38 to 2.89 mg/100 g respectively. Both the lines were orange colored and sweet to taste with a brix value of about 11 to 14 in the production areas (Chen, 2004).

AVRDC has also developed fresh market tomatoes with high b-carotene. Line CLN1314F, a high beta fresh market tomato, has a beta-carotene content of 6.55 mg/100 g fresh weight. There is a modifier to the Beta gene called Mo that enhances the effect of Beta. It should be mentioned here that b-carotene tastes bitter if the content gets too high (> 4 mg/100 g) (Peter Hanson, personal communication). A single dominant gene B (linked to indeterminate growth habit) favors b-carotene biosynthesis (at the expense of lycopene). Genes that enhance lycopene (crimson gene, og^c) results in decreased provitamin A content (Tigchelaar, 1988). The linkage between indeterminate growth habit and B has been broken and now determinate tomatoes with B gene are available. It is possible to increase total carotenoid content with genes such as high pigment (hp) or dark green gene. High pigment and dark-green genes were mutations found in tomato, not derived from interspecific crosses. The Beta gene in CaroRed originated from *L. hirsutum* but the same gene is found among segregants from interspecific crosses with *L. cheesmanii* and probably *L. chilense* too (Peter Hanson, personal communication).

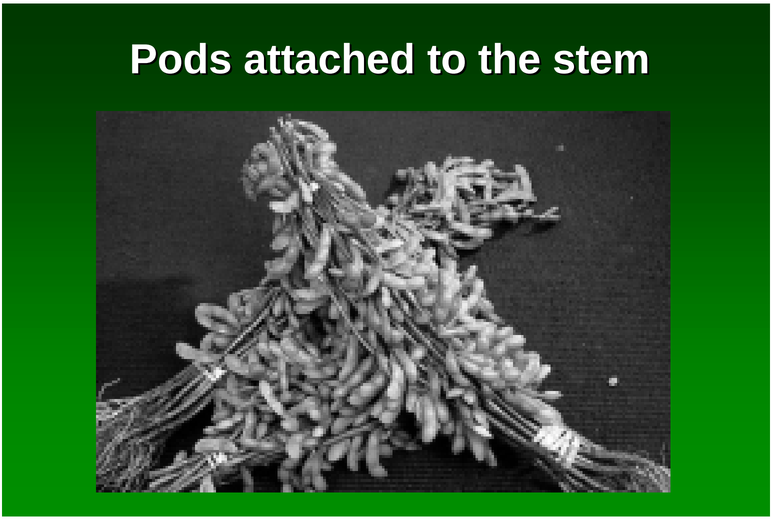
In Bangladesh, where vitamin A deficiency is one of the major problems, the vegetable breeders screened AVRDC breeding lines. Six high beta entries and local check variety, Ratan, were tested in replicated trials at six stations of the Bangladesh Agricultural Research Institute (BARI) and Mennonite Central Committee station in Noakhali. Most entries produced yields comparable to Ratan. Generally fruit firmness and shipping quality of the high beta entries were superior to Ratan; consequently, the high beta lines were more amenable for transport to distant markets. Subsequently, the Bangladesh Agricultural Research Institute officially released the high b-carotene line CLN1314G as 'Apurba'. The b-carotene content of 'Apurba' was 6.59mg/100g and the fruit size was 182g. Even though the fruit color is orange both the home gardeners and the school garden programs readily accepted the variety and it is gaining popularity. The pedigree of CLN1314G is (CLN399-19-6-18-17-17 x CRA84-26-3) x 'Stock-Beta-Beta alcobaca-alcobaca". The Beta line was received from the Tropical Agricultural Research Station-

Mayaguez, Puerto Rico (Peter Hanson, personal communication-Thrasher Foundation Final Report from AVRDC). A new set of determinate, high b-carotene tomato lines with code name CLN2110/ CLN2112/ CLN2366 lines showed better fruit set than CLN1314 but lower bacterial wilt resistance. Because of their high acid content the CLN2110/2112/2366 may be welcomed in parts of South Asia where sour-tasting tomato is preferred for cooking (Peter Hanson, personal communication). A number of private seed companies have used both AVRDC and other pre-breeding materials and developed high lycopene and high beta tomatoes. Taking advantage of our lines the processing companies like Kagome in Taiwan developed high lycopene varieties and used them to make "High Lycopene" tomato juice as a health drink since lycopene is a powerful antioxidant. It has gained popularity among the public.

Pepper (*Capsicum* sp.) is an important condiment in India and in many countries around the world. It is also a major source of a number of antioxidants (AO) including carotenoids, ascorbic acid, tocopherols and phenolics. From AVRDC-the World Vegetable Center's *Capsicum* core collection 46 accessions were evaluated for content of nine AO (five carotenoids, ascorbic acid, tocopherols a and g, and total phenolics) and two AOA assays for 2 years in Taiwan (Hanson, *et al.* 2004). Of the 46 accessions evaluated 36 were *C. annuum* (of which 7 were pungent and 29 had varying levels of pungency) and 5 each were *C. baccatum* and *C. chinense*. The study found that on a dry weight basis , non-pungent *C. annuum* as a group had higher concentrations of ascorbic acid (65%), total phenolics (36%), a-tocopherol (11%), and b-cryptoxanthin (36%) compared to the group mean of pungent accessions. But comparisons based on fresh weight basis indicated that pungent *C. annuum* as a group contained significantly higher contents of all AO except ascorbic acid compared to non-pungent *C. annuum*. The authors recommend the inhibition of lipid peroxidation assay (ILP) for characterization or selection for AOA in *Capsicum* breeding. They also found that phenolics and ascorbic acid make important contributions to AOA of pepper fruit. Since, brown fruited bell peppers were found to have the highest content of provitamin A (Simonne *et al.* 1977) including carotenoids b-carotene and b-cryptoxanthin, inheritance of carotenoid contents in brown-fruited peppers would facilitate developing high carotenoid peppers (Hanson, *et al.* 2004). Several researchers observed high levels of AO and AOA in Ancho/ Poblano peppers/chilies (Mejia *et al.,* 1988; Lee *et al.,* 1995; Hanson *et al.,* 2004). Therefore, more germplasm from that group may be worth further examination for breeding purposes.

Carrot was one of the first vegetables studied for its carotene content as early as 1932. The variability for carotene content in 10 varieties was 0.12 to 9.6 mg/100 g (Stevens, 1974). The b-carotene and a-carotene ratio varied considerably among varieties. The color of carrots varies from red, orange, yellow and violet. The red and orange colored varieties have more b-carotene than the yellow and violet colored varieties. The carotene content in carrot varieties, on a fresh weight basis, varied from 41 ppm in the popular old variety Chantenay to 475 ppm in HCM. Mass selection was successful in selecting for high carotene levels >700 ppm (45 to 80% b-carotene) (Simon, 1988). At least seven different genes controlling the type, amount and distribution of carotenes in carrot have been identified (Imam and Gabelman, 1968*,* Umiel and Gabelman, 1972; Buishand, J.G. and W. H. Gabelman, 1979; Simon, 1988). Fourteen genes controlling color in carrots have been identified (Gabelman, 1974). To fulfill the adult RDA of 1000 retinol equivalent vitamin A with an 80 ppm carotene 100 g carrot need to be consumed (assuming 1/6 carotenes and 1/12 of other provitamin A are converted to Vitamin A (Simson, 1983). If we improve the carotene content to 400 ppm then only 20 g carrot would be able to meet the RDA. Similar to tomato the processing companies are taking advantage of high carotene carrots in making high b-carotene carrot juice and mixed vegetable juices rich in vitamin A and C, all of which are gaining popularity among the health conscious consumers.

Vegetable soybeans are harvested when the pods are still green but the green beans fill the seed cavity. They are marketed with pods attached to the stem or pods detached from the stem. Green pods are sold fresh or frozen. The shelled beans are also sold fresh or frozen. Green pods and beans are shown in Fig. 1. Normally vegetable soybeans are large seeded (>30 g for 100 seeds dry weight), sweet to taste (about 12% sugar content). From planting to harvest it takes only about 75 to 85 days depending on season and location. In countries like South Asia and Africa people do not like the flavor of soybean. Therefore, AVRDC looked at the genetic variability for flavor in vegetable soybean. A group of soybeans called *Dadachamame* in Japan have a unique taro or jasmine flavor similar to aromatic rice. It is reported that the flavor is due to the chemical, 2-acetyl-1 pyrrolin, similar to the chemical found in rice (Fushimi and Masuda, 2001). At AVRDC we found that the flavor (presence of the chemical) in soybean is governed by a single recessive allele and therefore in its homozygous state it has taro or jasmine flavor (AVRDC, 2003). AVRDC has incorporated the desirable flavor into the vegetable soybeans and they are ready for testing and popularization in South Asia and Africa. Vegetable soybeans are also rich in isoflavones, vitamin E (a powerful antioxidant) and lecithin, which are all good for health.



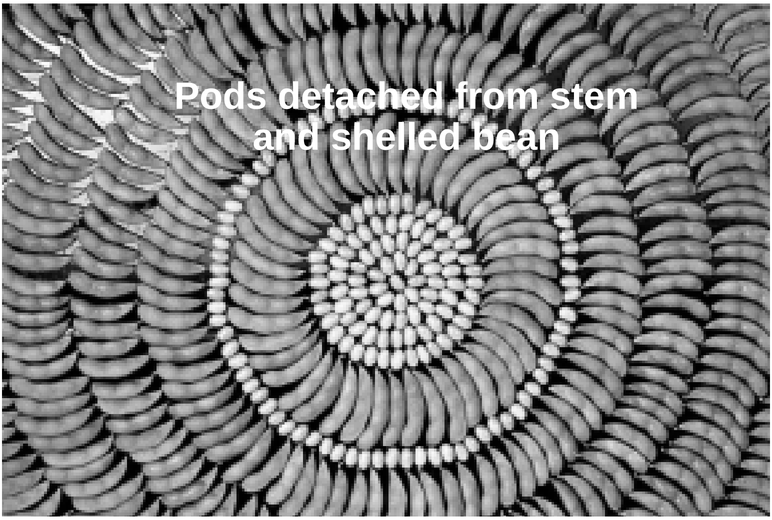


Fig .1. Soybean Pods and Beans

AVRDC has recognized that a large number of local vegetables in different Asian and African countries are neglected over the introduced exotic vegetables such as tomato and pepper. In India as many as 1800 plant species belonging to 180 botanical families are being used in Ayurvedic and Siddha medicine from which over 30,000 efficient and safe medicines are prepared (Paroda, 2004).

Improving consumption of crops that are already rich and high in nutritional content would be more effective and less expensive than breeding for higher nutritive contents (Munger, 1988). For the developing countries in the tropics and subtropics crops like vegetable Amaranth (*Amaranthus sp),* Choi Sum, (*Brassica chinensis* parachinensis group), Kangkong (*Ipomoea aquatica)* and Drumstick (*Moringa oleifera)* are efficient nutrient producers and they should be given serious consideration for the developing countries (Munger, 1988). Therefore, in order to conserve and utilize the biodiversity AVRDC has launched an initiative to collect, characterize, evaluate, document and utilize the indigenous vegetables in Asia and Africa with financial support from the Asian Development Bank, GTZ/BMZ (in Germany) and USAID. In screening these indigenous vegetables for nutritional composition tremendous variability was observed both within and between species collected so far in Asia as well as in Africa (AVRDC, 2003, 2004a). Moringa (*Moringa oleifera)* is a common indigenous vegetable in South and Southeast Asia and Africa. But it is not known in East Asia and other countries. Recently it has become very popular in Taiwan due to its health benefits. From a survey of over 120 species of Asian vegetables for nutrient contents, AOA and indigenous knowledge of their medicinal uses AVRDC found *M. oleifera* to be one of the most promising ones (Yang *et al.,* 2005). All four species examined namely, *M. oleifera, M. peregrina, M. stenopetala, M. drouhardii* from India, Arabia, Kenya and Madagascar respectively were high in AO, AOA and vitamins A, C and E ; iron, calcium, and low in oxalates. Cooking enhanced the bioavailability of iron from both Moringa and mungbean when cooked together (Yang *et al.,* 2005). Among the four species evaluated the leaves of *M. oleifera* had the highest amount of b-carotene (15 mg/100 g), and iron (9.2 mg/100 g). *M. stenopetala* was rich in protein (5.8%), ascorbate (400 mg/100 g). *M. peregrina* had the highest tocopherol content (28 mg/100 g). *M. drouhardii* had the highest content of calcium (745 mg/100 g).

Biotechnology and Nutritional Improvement in Vegetables

From the time of the rediscovery of Mendel's laws of heredity, in the past 100 years the science of genetics has risen to identify the chemistry of genes and the ability to isolate genes and transfer to desired plant. Biotechnological methods commenced with simple tissue culture in the 1950s and 60s have advanced to an unbelievable development of single nucleotide polymorphic markers based on high density DNA arrays, a technique popularly known as 'gene chips (Chee *et al.* 1996). Using 'gene chips' the microarray technology will facilitate marker-assisted selection (MAS) in vegetable breeding

(Ortiz, 1998). The advances in plant transgenics, genomics, proteomics, bioinformatics and metabolomics all point to the era of tailoring vegetables to meet the needs of nutrition and health conscious consumer through biotechnology assisted by conventional breeding. Within the above major areas nutritional genomics has emerged recently. Nutritional genomics is a general approach to gene discovery that is most relevant to compounds of nutritional importance that are synthesized or accumulated by plants and other organisms (e.g. vitamins and minerals). It is a powerful approach for dissecting and manipulating essential micronutrient pathways in plants (Sattler and Penna, 2004).

The genetic potential to improve the protein content, oil content and quality, starch biosynthesis, dietary fiber and functional food value has been reviewed in detail (Murphy and Peterson, 2000). In addition papers in the same review describe the intellectual property rights to protect the value of the value added designed crops and the market and marketing aspects of designer crops. The combined forces of biotechnology and conventional breeding continue to aim at enhancing crop yields, improving the nutritional quality of the vegetables while preserving the environment. As the society becomes wealthier and as the gap between the 'haves and the have-nots' narrows the nutritional and health quality of foods that we eat will become more important than the food productivity (Ortiz, 1998). As long as the scientific community is honest and can weigh the risks and explain the various pros and cons of the transgenic crops and convince the public and the authorities with sufficient documentation on ecological and health aspects the controversy against GMO among the public and consumer will gradually disappear. The urban and periurban farmers have to change their vegetable production to meet the demands of the populations with improved wealth and conscious about health and longevity. Vegetable varieties rich in vitamins, minerals, antioxidants and health promoting compounds will be in greater demand than before. The higher income will enable them and they will be willing to pay a better price for vegetables they consume. The public will view biotechnology as a scientific advancement to fight hunger and malnutrition around the world.

CONCLUSION

From the above brief review it is clear that vegetables can be designed to meet the demands and needs of the consumers. A World Bank report estimated that deficiencies in Vitamin A, iron and iodine alone, cause economic losses equal to 5% of GNP each year due to sickness, poor work output, lost education and other factors in South Asia. High quality vegetables with improved nutritional and health characteristics could be developed through a multidisciplinary cooperative effort among plant breeders, biotechnologists, biochemists, nutritionists, plant pathologists, entomologists and others. Researchers should carefully study and respond to market forces, user demand and public views. There is sufficient heritable genetic variability present in the germplasm of various vegetables for different nutrients. Simple, efficient, reliable, rapid and economical methodologies to evaluate them for screening the breeding populations have been developed for some of the nutrients. With concerted efforts vegetables with higher contents of the most important micronutrients such as vitamin A, C, iron, calcium, folic acid, isoflavones, antioxidants and lower contents of undesirable nutrients such as oxalates, nitrates, neurotoxins and others can be developed to meet the demands of the consumer. The bioavailability of some of the nutrients and how to enhance the bioavailability have also been studied. Biotechnology and information technology combined with powerful computers will play a major role for conventional breeders to efficiently develop improved crop varieties in the future. Periurban and urban gardening farmers will be required to adapt varieties with improved nutritional and health traits to meet the demands of the urban population with higher income. Improved income of the poor people allows them purchase more expensive vegetables, which help to diversify diet and nutrition. Extensive expansion of the supermarket chains around the world is expected to demand for high quality vegetables year round. They will scout to obtain such quality produce from anywhere in the world. Supermarkets will serve as sourcing agents and likely dictate the variety to be grown to meet the demands of the discriminating customers. The vegetables should have consistent quality regardless of location where and when it is grown and shipped. It is a challenge indeed for the plant breeders to develop varieties, which have such wide adaptation. Specific location adapted varieties have little value for international shippers. The quality of vegetables should be duplicated in diverse locations with varying agroclimatic conditions with the same variety (Shanmugasundaram, 2003). In addition to improving the nutritional quality of existing vegetables such as tomato, peppers, carrots and vegetable soybean it is extremely important to identify indigenous and underutilized vegetables with improved nutritional and health qualities to serve as the vehicle if micronutrients are introduced in a cost effective way without affecting the local tastes and traditional farming practices to the nutrition and health conscious consumers. Through biotechnology it is also possible that such nutritional and health promoting genes from indigenous vegetables can be isolated and conveniently introduce them to the existing consumer accepted popular vegetables.

Since the modern consumers are well aware of the importance of micronutrients and phytochemicals for nutrition, health and longevity the dietary recommendations include greater diversity of vegetables and fruits (Peters *et al.,* 2003; Weisberger, 1999). Although it is difficult in the tropics and subtropics, where vegetable supplies are highly seasonal and daily per capita availability falls drastically below the recommended level of 200 g (Ali and Tsou, 1997), the potential for achieving such diversity is bright. Increased intake of diverse nutrient and phytochemical rich vegetables require multiple strategies including development and adoption of tropically adapted varieties with higher densities of micronutrients and health promoting phytochemicals, overcoming seasonality of vegetable production so affordable vegetables are available to poor consumers throughout the year and developing and extending better methods of preparation and processing in order to improve micronutrient bioavailability. AVRDC-the World Vegetable Center will continue to serve as a leader in each of these areas to collaborate with public and private sector in the national program in order to fulfill its mission to "improve nutrition and reduce poverty in the tropics" (AVRDC, 2004b).

Designing vegetables with improved nutritional and health promoting factors will become a routine objective in the future for the new robotic era consumer along with high yield, disease and insect resistance to protect the environment and stress resistance to tailor the plant to exploit the unexploited natural habitat.

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NEW VISTAS IN IMPROVING PRODUCTIVITY AND UTILIZATION OF TROPICAL TUBER CROPS *

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INTRODUCTION

Inadequate supply of food which can alleviate hunger and combat malnutrition of a sizeable percentage of Indians will be one of the future threats for the country, when viewed against the scenario of the rapid population growth. The World Food Conference (1974) made a resolution that '**every man, woman and child has an inalienable right to be free from hunger and malnutrition'.** According to a survey conducted by the National Sample Survey Organization (NSSO, 1993-94), approximately 5% of the rural families and 2% of the urban families of India do not get two square meals a day and the situation would have certainly worsened in the past five years. Although serious efforts have been made in the recent past to improve food supply to the poor by way of introducing the Targeted Public Distribution System (TPDS) and other programmes, the progress achieved in ensuring nutritional security by supplying what the people need for a healthy life, is inadequate. The World Food Summit (1996) stated that '**Food security exists when all the people, at all times have physical, social and economic access to sufficient safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life',** which emphasizes that food security and nutritional security are two intermingled terms. It is in this new paradigm of growth *vs* food supply that root and tuber crops become increasingly significant as energy and nutritional storehouses.

Food security from tuber crops

The International Food Policy Research Institute (IFPRI) forecasts that the foodgrain demand in developing countries will increase by75% between1990 and 2020 and the parallel increase for livestock products will be 155%. The IMPACT projections made by IFPRI in July, 1999 suggest that global demand for roots and tubers will increase by 37 percent between 1995 and 2020. The world-wide demand for cassava and other minor roots and tubers is projected to increase by 49 per cent and for sweet potatoes and yams by 30 per cent. A rapid expansion in the demand for roots and tubers for livestock feed has been experienced in Asia and is likely to continue as demand for meat products will increase rapidly in the coming years besides a sharp increase in export of animal feed.

Tropical root crops have been classified as the third most important food crops of man and possess high photosynthetic ability coupled with the capacity to yield under poor and marginal soils, adverse weather conditions etc. These attributes make tuber crops ideal for cultivation in the Less Developed Countries (LDCs) of the world. Cassava and sweet potatoes *account* for about 30% of the total production of root crops from developing countries, the rest being made up of potatoes, cocoyams and others (Scott *et al.,* 2000). It is estimated that *about* 6% of the world's dietary energy is supplied by root crops, especially potatoes, cassava and sweet potatoes. Although root crops have generally been branded as 'poor man's crops' supplying low cost energy and bulk to the diet and little else by way of nutrition (Horton, 1988), their potential as nutritionally rich sources of b - carotene, anti-oxidants, dietary fibre and minerals like calcium has begun to be recognized as a result of the multifarious research programmes worldwide.

Root and tuber crops are plants which produce structures that are used as human or animal feed. They are the third important food crops of human kind after cereals and grain legumes and constitute either staple or subsidiary food for about a fifth of the world population. Tropical Root and Tuber Crops (TRC) have their own role as an important staple in several countries in South America, Africa, South-East Asia, etc. Inspite of the near satisfactory level of production of cereals and grain legumes, the socio economic condition of small and marginal farmers in most countries in the above region necessitated them to depend on TRC as their staple. Tuber crops have a higher biological efficiency as food producers and show the highest rate of dry matter production per day per unit area among all the crops. The crops involved are cassava, sweet potato, yams, aroids and few minor tuber crops. These crops are rather less understood (perhaps less seen above the ground !) and have the capacity to withstand adverse biotic and abiotic stresses. These crops are very important in the context of food and nutrition security and assumes great relevance due to the ever increasing population.

They are also recognized as the most efficient converters of solar energy, Cassava producing 250×10^3 Kcal/ha and Sweet potato 240×10^3 Kcal/ha as compared to 176×10^3 for rice, 110×10^3 for wheat and 200×10^3 for maize. These crops are known to supply cheap source of energy especially for the weaker sections of the population. Tuber crops can be broadly classified as temperate and tropical groups. Potato is primarily a temperate crop whereas all other edible tuber crops come under tropical tuber crops. Having been classified as the third most important food crops of man, they possess high photosynthetic ability coupled with the capacity to yield under poor and marginal soils, adverse weather conditions etc.

India's population having touched 1000 million a few months ago still depends on agriculture as the primary occupation, some 60% depending upon the same. The population growth is expected to reach 1560 million by 2020 AD and still there will be 23% people below poverty line. Inspite of the increasing production and availability of food grains, there will be a net shortage of nearly 26 million tonnes by 2020 AD. This is an equivalent of 80 tonnes of root and tuber crops. In order to meet this unfortunate scenario, tuber crops constitute the important link to fit the food security gap and they can accept the challenge.

In times of famine, TRC have come in handy to overcome catastrophies and provide relief from hunger. The ever increasing population levels coupled with rapidly shrinking cultivable area and increasingly fragile resources lead to a vast scope for diversification and value addition of tuber crops and hence they offer a great opportunity for increasing the production and productivity.

Research on TRC is being concentrated in Brazil, Colombia, Peru, Nigeria, Vietnam, Indonesia, the Philippines, China, the South Pacific Islands besides India; post harvest aspects of TRC are also being considered in the advance laboratories in UK, USA, etc. The global importance of the research achievements on TRC has been emphasized in various meetings of the FAO, IFAD, IFPRI, etc. There is also an increasing concern and awareness for the use of TRC for other uses *viz*. Cattle feed, poultry feed and industrial uses. There has been active industrial utilization like production of sweeteners (maltose, fructose, malto-dextrins etc.), modified starches, fermented products (Foods, beverages, alcohol, organic acids etc) which are technologically possible and further attempts need to be made to refine economical & technical feasibility of these processes. Medicinal properties of tuber crops have not been exploited so far in full.

Social & nutritional security

The size of farm holdings show a peculiar trend and in fact the number of small and marginal holdings go on increasing and has constituted nearly 76% of the total agricultural holdings during

1990-91. The landless agricultural labourers, landless people and other weaker sections are denied the much needed social security because of lack of land for cultivation or access to modern technologies or both. This vulnerable group of people deserve to be attended by adequate food so that they become socially acceptable. Root and tuber crops like cassava and sweet potato help in bridging the social security gap. Besides, being easy to grow even in sub marginal lands and wastes lands, the input requirements are extremely low hence within the rich of even socially deprived group of people.

The WHO estimates show that in many of the under developed and developed countries, several nutritional disorders are prevalent. Deficiencies due to protein, Vitamin A, Vitamin C and Calcium could be easily alleviated by taking precaution to consumption of root and tuber crops like cassava, sweet potato, yams and aroids. There are specified RDA (recommended dietary allowance) which is possibly met by the root and tuber crops @ 500 gms per head per day. Diseases like night blindness could be corrected by consuming Vitamin A rich cassava and sweet potato. Since these crops are affordable to the poor people, the nutritional balance can be easily achieved.

Role of tuber crops

There are 15 odd tuber producing crop species which form the mandatory crops of the Central Tuber Crops Research Institute, India. There are two major crops Cassava and Sweet potato, three Yam species (*Dioscorea alata, D. esculenta* and *D. rotundata)*, five Aroids species (*Colocasia esculenta, Xanthosoma sagittifolium, Amorphophallus paeniifolius, Alocasia macrorrhiza, Cyrtosperma chamissionis*) and five minor tuber crops *(Solenostemon rotundifolius, Pachyrrhizus erosus, Maranta arundiacea, Psophocarpus tetragonolobus, Canna edulis*).

Research on tuber crops in India is undertaken mainly at the Central Tuber Crops Research Institute (CTCRI) under the aegis of the Indian Council of Agricultural Research (ICAR). Since inception in 1963, CTCRI has contributed enormously to the research and development of tuber crops and is presently an internationally recognized Premier Institution, dedicated solely to tropical tuber crops research. Nearly four decades of research have led to several innovations such as improved high yielding/ early maturing varieties, cropping systems for various agro-ecological zones, integrated pest and disease management packages for better production, technologies to reduce post harvest losses and enhance the prospects of utilization in the food, feed and industrial sectors etc.

Tuber crops are cultivated in India mainly in the southern, eastern and north-eastern states. Cassava is grown in India in an area of 2.6 lakh hectares with a total production of 1.06 million tonnes. Cassava production is mainly from the states of Kerala, Tamil Nadu and Andhra Pradesh. Trends in the area and production of cassava in these states during 1992-97 present a grim picture of only a marginal increase in 1996-97, the principal reasons being increased per capita income leading to better purchasing power of people, surplus availability of cereals to a major section of the society, shrinkage in area due to shift in cultivation to more remunerative crops etc. Lack of adequate expansion to non-traditional and backward areas is another factor , which has culminated from the poor awareness on the potential of tuber crops in meeting hunger and alleviating poverty. Sweet potato is cultivated mainly in the states of Bihar, Orissa, West Bengal and Eastern Uttar Pradesh. Area (1.2 l ha) and production of sweet potato also has indicated a declining trend which points to the imperative need for improvement of market prospects through value addition and product diversification. Other tuber crops like yams and aroids are not yet commercially cultivated, being confined only to the home gardens in almost all the States.

However, all the favourable attributes, there is a temporary set back of this group of crops in terms of its status in agricultural economy of our country. The earlier emphasis on cereals to cope up with the food production calls for a rethinking in the wake of disproportionate population growth and rapidly shrinking cultivable areas and increasingly fragile resources. Consequently, striking at alternate crops as sources of energy would lead to tuber crops as an inevitable choice to play the role. Further, tuber crops as such provide a vast scope for diversification and value addition, offering a great opportunity for non-traditional uses within the country and for exports, definitely posed to open the gates of market economy for these crops.

History of tuber crops research

Though the tuber crops are alien in nature and were introduced into India, their potential as a staple food or secondary staple has been identified during the early part of the 19th century. Organized research and development work on potato was initiated by some of the Indian States during the first quarter of the 19th century mainly in the erstwhile provinces of Bombay and Madras. The early investigations included variety evaluation, standardization of agrotechniques, studies on major pest and diseases and storage of seed materials. The crop spread to different states in India viz., Assam, Bengal, Bihar, Uttar Pradesh, Punjab and Himachal Pradesh.

However, research on potato was started in 1935 when the Imperial Agricultural Research Institute, New Delhi established a research station at Shimla and the potato research got a fillip with the establishment of the Central Potato Research Institute at Shimla. At present more than 95% of the research work on potato is handled by the Central Potato Research Institute and All India Coordinated Research Project on Potato functioning in the State Agricultural Universities. Similar is the case with tropical tuber crops and organized research on cassava was initiated initially, followed by other crops. The first step in this direction was the initiation of a scheme in the fifties on cassava under the aegis of the erstwhile Travancore University at Thiruvananthapuram with major emphasis on varietal evaluation. From then onwards between ICAR and Travancore Cochin Government, collaborative programmes on cassava, sweet potato, yams and aroids were in operation. This was followed by the establishment of Central Tuber Crops Research Institute (CTCRI) at Thiruvananthapuram (in 1963) to carry out research on all aspects of tropical tuber crops. At present research on these crops are conducted at CTCRI at Thiruvananthapuram, its Regional Centre at Bhubaneswar and the centres under the All India Coordinated Research Project on Tuber Crops (other than potato) functioning in 10 different State Agricultural Universities and 3 ICAR Institutes/ Regional Centres.

The CTCRI, an organ under the Indian Council of Agricultural Research (ICAR), Ministry of Agriculture, Government of India has the mandate to conduct extensive and intensive research programmes for the overall improvement of root and tuber crops in the country. The laboratories of CTCRI located at Sreekariyam, Thiruvananthapuram have been able to generate a large number of technologies for production and post harvest handling aspects besides acting as the Centre for training in modern research methodologies and technology upgradation of scientific manpower. The CTCRI has to its credit, released nearly 35 varieties on various tropical root and tuber crops for cultivation in the country (list placed elsewhere). The CTCRI also functions as the service centre for the All India Coordinated Research Project on Tuber Crops (other than potato) which has the mandate to conduct location specific and multi-location adaptation trials on various TRC to suit the different agro-climatic regions of India.

AREA, PRODUCTION AND PRODUCTIVITY

The average yields for roots and tubers in most of the developing countries are far below the potentials. Better yields for tropical root and tuber crops would bring significant benefits to the food systems of the developing countries. R & D support is therefore, very crucial and investments in research both at national and international levels will be highly rewarding.

Most of the tropical tuber crops are positively correlated with area under rainfed agriculture and are development shy. These crops find place mainly in those areas where other crops may not be cultivated profitably. For eg., analysis made in India (Khatana and Arya, 1999) for sweet potato crop reveals that it is grown in the area which gets sufficient rains and are inhabitated by poor and tribal farmers. Its positive correlation with area under paddy shows that it is grown more under rice based cropping systems, where farmers plant sweet potato after the harvest of paddy in the same field to take the advantage of the residual moisture and fertilizers. Increased profitability in growing other crops and increased income due to improved agriculture linked with availability of irrigation water and inorganic fertilizers will push tropical root and tuber crops to less productive fields, marginal and frazile sites. **Under such circumstances and background, research agenda for root and tuber crops have to be drawn very carefully to generate more eco-friendly technologies that can be transferred effectively.** Research system both in India and abroad have developed many technologies on tropical root and tuber crops but most of them could not be transferred successfully. A shift in approach for flagging more relevant research issues is, therefore, essential at this juncture.

Cassava

Cassava is grown in an area of 16.37 m. ha globally with an annual output of 164.75 m. tonnes of tubers. Nigeria occupies first position in area under cassava accounting for 16.5% of the world area producing 18.5% of world cassava. Congo (2.1 m ha), Brazil (1.91 m ha), Thailand (1.26 m ha) and Indonesia (1.3 m ha) are the major cassava growing countries of the world constituting 50% of the area under cassava, producing 64% of the world cassava. The world average productivity is 10 t/ha. Here it is interesting to note that though India is not having a major area under this crop, its productivity is the highest in the world (24.5 t/ha). Area, production and productivity under cassava has been showing stagnation for the past five years

In India cassava is cultivated in an area of 0.24 m ha producing 6 m tonnes. Area and production under cassava followed the global trends in the early nineties and at present, stagnation is being observed. Kerala where the crop was first introduced in India accounted for 50% of area under cassava (0.13 m ha). Tamil Nadu accounts for 32% of area (0.08 m ha) and 9% of area is in Andhra Pradesh (0.02 m ha).

New end uses for Cassava

Cassava starch has got high viscosity which enables its use as a binding material in pelleted fish feeds. Sustainable aqua-culture systems are essential for the progress of fisheries developing countries in the next millennium. This depends to a large extent on the development of alternate economical fish feeds with cassava and its desirable attributes like high energy content and adhesive quality of starch can be a forerunner.

Research conducted at CTCRI has highlighted the use of sago (granulated cassava starch) as a solidifying agent (nay, agar-agar) in plant tissue culture media. Biodegradable plastics & cold water miscible starch are 2 new technological innovations from CTCRI and deserve appreciation. Augmentation of the domestic demand through findings like this will be helpful. The setback faced by Thai cassava industries after 1995, consequent to the decreased opportunities for export to European Union, also hinges on the need to diversify the use and enhance internal demand for sustainability of industries.

Sweet potato

Approximately 80% of the world sweet potato are grown in Asia, just under 15% in Africa and about 5% in rest of the world. Among the Asian countries, China is the largest producer leaving far behind Indonesia. Sweet potato is cultivated in an area of 9.2 m ha with an annual production of 138.4 m tonnes in China which occupies first position in area globally accounting for 68.3% of the world area producing 87% of world sweet potato. Remaining area is under countries like Uganda, Vietnam, India, etc. Area, production and productivity of sweet potato is showing an increasing trend globally. In India, it is grown in an area of 0.14 m. ha producing 1.17 m tonnes with a productivity of 8.3 t/ha. Sweet potato area is concentrated mostly in Orissa, Bihar, West Bengal and Uttar Pradesh.

Lack of stability in tuber production as seen in various seasons and locations is the major problem in the cultivation of sweet potato. Studies are initiated to assess the causes of non-tuberization, uneconomical yield performance as well as integrated nutrient management. Studies will be undertaken to identify the most compatible and profitable cropping system involving sweet potato suiting major sweet potato growing States.

Sweet potato weevil is a menace. Integrated Pest Management (IPM) practice has been developed with sex pheromone as one of its component. A further efficient and refined IPM practice will be developed by including Kairomone, Parasitoids and Pathogens. A wide range of virus and virus like symptoms were observed of late in Sweet potato fields. A detailed study will be made on yield loss due to virus diseases, identification of viruses, etiology of the virus disease, virus purification and developing serodiagnostic system for the virus diseases.

Sweet potato : a potential pigment crop

There is an increasing public concern on the health hazards when using synthetic colouring agents day by day. This has gradually led to an increased effort to identify and extract natural pigments, which are safe for use in food products. Sweet potato is a promising crop with lots of variability in pigment content in germplasm collections. This can be favourably put to use in selecting high pigment cultivars and also developing cultivars with enhanced pigment levels. **Ayamurasaki**, a high pigment Japanse cultivar, is popularized in Japan for extraction of anthocyanins for food industries. An understanding of the biochemical mechanisms underlying pigment synthesis in sweet potato can also open up the gates for genetic transformation to produce pigment-rich varieties. What has been globally possible in the use of Paprikas in chilli is true for sweet potato as well.

Yams & Taro

Yams are largely grown in Nigeria with 66% of global area and 65% of global production. It is cultivated in an area of 3.28 m ha with a productivity of 9.1 t/ha in the world. World area and production under yams is showing increasing trend while the productivity is showing the declining trend. Yams are mostly cultivated in the African countries like Burkino Faso, Cote Devoire, Ghana, etc. In India, it is mostly cultivated in Southern India in homestead gardens. In some pockets of Tamil Nadu and Andhra Pradesh, it is cultivated in large areas. There is an urgent need to introduce high yielding varieties in yams and improve the production.

Standardization of agro-techniques of Yams in relation to the existing cropping system as well as sole crop of Yam will be undertaken. Studies on standardization of agro-techniques of Aroids has already been initiated and will be evaluated in the existing cropping system involving annuals and perennials. Production, evaluation, multiplication and distribution of quality planting materials of Yams has been initiated in collaboration with the State Department of Agriculture/ Horticulture.

Taro blight is the major threat to the taro growers. Studies on influence of various factors on disease development and its epidemiology will be undertaken to evolve a suitable prediction and forecasting. Further studies will be on screening of new accessions for resistant sources and identification of suitable bio-control agents.

LEADS MADE IN THE R & D FRONT

Regardless of the above situations of advantage, the tuber crops could also be helped through the R & D efforts of CTCRI which has resulted in the following hi-tech achievements.

Crop Improvement

- CTCRI has a rich diversity of germplasm of all tuber crops consisting of 1741 accessions of Cassava, 1268 of Sweet potato, 1443 of Aroids, 976 of Yams and 336 of other tuber crops; in all we have about 5764 accessions.
- Thirty new varieties of tuber crops have been released so far. A high yielding triploid clone "Sree Harsha" was released, which is ideal for the industrial belt of Tamil Nadu. Two short duration (6-7months) varieties in Cassava *viz* Sree Jaya and Sree Vijaya, the world's first hybrid Sree Shilpa in *Dioscorea alata*, Gouri & Sanker in Sweet potato (for eastern region) and Sree Padma in *Amorphophallus* have been released very recently and these are simultaneously tested and popularised in several districts in the South.
- A novel dwarf genotype of White yam (*D. rotundata*), "Sree Dhanya" has been released; this dispenses with the "Trail-support system" and reduces the cost of cultivation by 40%.
- A variety of Coleus "Sree Dhara" with large tubers has been released.

Production Technology

- Short duration legumes like bunchy variety of groundnut and vegetable Cowpea were found to be ideal inter crops for Cassava.

- Multiple cropping systems have been developed for low land and upland.
- *Amorphophallus* is an ideal inter crop for Coconut gardens besides banana.
- For single crop Paddy fields, Rice followed by short duration Cassava is profitable.

Crop Protection

- A very effective IPM package for the control of sweet potato weevil with synthetic sex pheromone as the principal component was developed.
- Crop rotation sequences for low land situation for the management of Sweet potato weevil are evolved.
- Tissue culture protocols were developed for all tuber crops as well as for disease elimination.
- Importance of using healthy, virus free planting material for Cassava mosaic disease has been standardised and the healthy nursery programme is recommended in disease prone areas.

Post Harvest Utilization

- Some of the important technologies developed include process for the production of alcohol, cassava starch based biodegradable plastic, cold water soluble starch from Cassava, technique to extract starchy flour with modified textural attributes from Cassava, ensiling technology for the *in situ* utilisation of Cassava as animal feed, by-product utilisation of Cassava starch factory waste as poultry feed etc.
- Processing equipment developed include hand-operated, pedal-operated and motorised chipping machines, electrical and solar dryers, mobile starch separation plant for Sweet potato etc.
- Two types of harvesting tools and peeling knife were developed for cassava.
- An effluent treatment system for the decontamination of effluents from starch/sago factories was developed.

YIELD SUSTENANCE THROUGH QUALITY PLANTING MATERIAL

Decline in Area

It has been observed that there is a considerable decline in the area of cassava in India over last two decades. The cassava area which was 3.90 lakhs ha during 1975 has declined to 2.43 lakhs ha 1991 thus registering a negative growth rate to the tune of 5%. The major factors contributing to this situation area the increasing availability of cereals coupled with an organized public distribution system and crop preference of farmers in favour of commercially more paying and less labour intensive crops like rubber, coconut, etc. The classic case is the phenomenal growth in area of rubber even in small holdings from mere 2.17 lakh ha during 1971 to nearby double the area during 1991 in Kerala. Similar is the case with coconut which ahs displaced the cassava area considerably. The decline in area is also attributed to availability and preference for "high status" food commodities like rice, wheat, etc. The major factor affecting the differential pattern of cassava consumption in rural and urban areas in Kerala include cassava's rapid post harvest deterioration, the increased demand for convenience foods and improved availability of rice (Baulch,1989).

Scope for Area Expansion

Meeting the challenge of additional production, could be achieved by area expansion both under traditional areas by fitting in existing cropping system or by extending to non-traditional areas. The biological advantages like thriving well in marginal and rainfed conditions come in its favour for area expansion in the non-traditional regions of the country like Andhra Pradesh, Maharashtra, Gujarat, Orissa and Karnataka. The sequential cropping involving cassava in lowland situations and as inter crops in upland either adjusting the age or spacing of the plantation crops could increase the area in Kerala. The projections for the X Five Year Plan (area and requirement of QPM) are tabulated below:

Table 1. Projections for the X Five Year Plan with regard to Tuber Crops area and production

Crops	Present Status		Projected for Xth plan	
	Area ('000 ha)	Production ('000 m.t.)	Area ('000 ha)	Production ('000 m.t.)
Cassava	245	5868	500	10000
Sweet Potato	140	120	400	500
Yams	100	1500	200	6000
Colocasia	80	800	200	2400
Amorphophallus	60	1500	120	4000

With the targeted area and production at the end of the X Five Year Plan as projected above, it is envisaged that planting material production has to be oriented as proposed below.

Table 2. Projected planting material requirement for the X Plan period

Crop	Area ('000 ha)	Planting material required
Cassava	500	1 million stems
Sweet Potato	400	35 million vine cuttings
Yams	200	800 tons
Colocasia	200	300 tons
Amorphophallus	120	1500 tons

A major problem in increasing tuber crop productivity is non-availability of disease free quality planting materials. Rate of multiplication in most of these tuber crops is also very low. Hence it takes a long time for quality planting materials to reach farmers if the traditional method of multiplication is followed. Another hindrance in the availability of quality planting material of tuber crops is its low storage life. Dormancy period varies from crop to crop with zero or no dormancy in colocasia to 2-3 months in yams and amorphophallus. Low cost technologies need to be generated to prolong the storage life of planting material, which should easily be adoptable, by farmers.

Most of the tuber crops are prone to various viral, fungal and bacterial diseases, which cause enormous economical losses. Such diseases have been found to propagate through vegetative planting material and hence production of healthy and disease free planting material is very essential. The major disease problems and the measures adopted to tackle/combat them are presented here.

In order to obtain the desired and sustainable levels of production of tuber crops, the most important component will be the production and distribution of high quality planting material. In this direction, the CTCRI has initiated several steps as detailed below:

MODERN CONCEPTS IN QPM PRODUCTION

Meristem culture

CTCRI has initiated work on elimination of virus through meristem culturing of cassava in the 1980's. The concentrated efforts have resulted in production of virus free mericlones of all the popular varieties of cassava. Over 90 percent of the meristem cultured seedling were free from the disease. These virus free mericlones were taken to field and multiplied in large quantities. Meristem culture has been found effective for cleaning off systemic infection like virus in vegetatively propagated crops. The procedure involved in this method is micro dissection of meristem from shoot buds and growing them on growth media containing specific levels of growth regulators. The medium used for meristem culture was Murashige and Skoog along with growth regulators. The media comprised of organic and inorganic salts, Vitamins and sucrose dissolved in distilled water. Plant growth regulators were also added to the medium (0.1 NAA mm, 0.1 BA mm, 0.1 GA mm). pH of the medium was adjusted to 5.7. Agar 8g/l was dissolved in the medium by boiling and this was then transferred to culture tubes. The culture tubes were then covered with aluminium foil and sterilized in an autoclave at about 15 PSI for 20 mts.

The buds after sprouting were collected from nursery beds, surface sterilized in 0.1% $HgCl_2$ (mercuric chloride) for about 2 mts. These were then thoroughly washed with distilled water to remove any traces of the sterilant. The sterilized buds were than subjected to micro dissection by which all the scale leaves and leaf primordia were removed till the meristematic dome along with one leaf primordium was exposed. This was then slowly separated by an oblique cut just below the base of the dome and was inoculated into the culture tube containing the medium. Inoculation was carried out under aseptic conditions inside a laminar flow hood to prevent contamination from external sources. 5 cultures were inoculated per each accession. The cultures were then incubated at 25-28^{o}c and 8 hours light (3000 lux). Meristem culture was also carried out with apical buds collected directly from plants growing in field in order to compare its effect with those collected from nursery plants. Meristem cultures were found to develop within 7-30 days. A total of about 985 accessions have so far been established in *in vitro* through meristem culture.

Micropropagation

Cultures showing shoot development were transferred to MS basal medium for further growth. The triploid variety Sree Harsha showed a drastic delay in regeneration, taking more than a month. 150 healthy cultures of the released variety Sree Harsha completely infested with CMD has been cleaned and multiplied for hardening and transfer. Nodal cultures originated from nursery explants showed better growth than those from field grown plants Hardening was done prior to the transfer of *in vitro* grown plants to field conditions, mainly to give the plant time to adjust to the hard conditions of temperature and light on transfer to field. Micro propagated plants (2-3cms height) having short internodes, green leaves and healthy growth with roots were transferred. The plants were slowly removed from the media without damaging the roots and washed to remove the media and were planted into plastic cups (dia 8 cm) filled with vermiculite. For providing the plants with high humid environment, they were placed on trays filled with wet soil and covered with a bell jar. After 2-3 weeks, the plants having attained a height of 10-15 cms were transferred to the field.

133 cassava accessions (200 cultures) which included cassava indigenous-83, cassava exotic-23, inbreds-15 and popular varieties-12 were subjected to hardening procedure of which about 80 percentage of the cultures were successfully transferred and established in field. The *in vitro* active gene bank functioning at CTCRI has 1224 accessions (Table 3).

Table 3. *In vitro* Active Gene Bank in tuber crops

Sl. No.	Crop	No. of accessions
1	Cassava	618
2	Sweet potato	296
3	*D.rotundata*	115
4	*D.alata*	122
5	*D.esculenta*	48
6	*Colocasia*	4
7	Wild species of *Dioscorea*	12
8	Chinese potato	2
9	Other tuberous species	7
	Total	**1224**

PRODUCT DIVERSIFICATION AND VALUE ADDITION

The global population is projected to reach 7.5 billion by 2020 which is expected to catalyse the production and utilization of tuber crops. Population growth leads to decline in farm size and thus necessitates the cultivation of crops that can yield more energy in shorter periods. It is also estimated that keeping pace with the dietary habits of people, there is likely to be an increased demand for processed food products in developing countries. A vision statement to the year 2020 states '**by 2020, roots and tubers will be integrated into the emerging markets through efficient and environmentally sound production of a diversified range of high quality competitive products for food, feed and industry**'. Although there has been remarkable increase in the quality and quantity of global food supplies during the second half of the twentieth century, about one out of five people in the developing countries are unable to meet their basic nutritional needs for a healthy life. A greater use of crops like cassava and sweet potato in specially processed forms is thus envisaged in the coming years.

Two decades of research at CTCRI on processed products from tuber crops have led to a number of "on farm-friendly" technologies for making stable and marketable food products. Cassava rava (a product simulating wheat semolina) and porridge are two novel products made from cassava tubers at CTCRI. The relative ease of preparation and low product cost make them ideal processed products capable of ensuring economic security to the producers. Other cassava products which do have market potential include fried chips, starch based wafers, pappads etc. Research at CTCRI has also shown that sweet potato is ideal for making nutritionally rich products like jam, soft drinks and pickles. Cassava is exclusively used for the production of approximately 3.0 lakh tonnes of starch/ sago annually and the factories are spread over the districts of Salem and Dharmapuri in Tamil Nadu as well as East Godavari in Andhra Pradesh.

Cassava silage for cattle feeding and broiler feed from cassava starch factory waste are two other value added products from cassava, the technologies perfected at CTCRI. Cassava silage prepared from chopped cassava tubers and rice straw (90:10) has extended shelf life (over 12 months) and could increase the milk yield by about 20% and improve the growth of calves (14% increase in body weight). Thippi or cassava fibrous waste discharged from the starch and sago factories is a major pollutant in the (1100 odd) factory premises. Thippi can be effectively converted into broiler feed by simple low cost methods. Economic broiler farming is possible by switching over to this feed. Nevertheless, awareness on such processed products, which can add enormous value to the produce and simultaneously elevate their economic status, is low among the tribal/rural population. Creating such an awareness is thus an imminent need of the hour, in order to achieve the goal of food and economic security for India.

Processing and harvesting equipment

Several equipment suitable for the processing small and large scale processing of tuber crops have been developed at CTCRI which help reduce the post harvest losses and the tedium associated with harvesting and processing. These include chipping machines, harvesting tools, peelers, dryers, mobile starch extraction plant, rasper for starch extraction etc.

Eco-friendly innovations

Tropical tuber crops, which were once regarded as the sustenance crops of man , especially the resource poor are gradually changing their role in the new paradigm of development in India. In order to cope up with this emerging scenario, CTCRI has developed a plethora of technologies which can help retain tuber crops in the agricultural system of India and ultimately elevate the socio-economic status of the producers.

India produces about 1.26 million tones of commodity plastics per annum against a demand of 1.83 million tones. Agricultural and packaging sectors consume about one-half of the plastics produced. Due to the increased use of disposable plastics, their ultimate disposal is all the more difficult. In the look out for environmentally degradable polymers, CTCRI has developed a novel cassava based biodegradable plastic product incorporating cassava starch. The technology was commercialized in India through NRDC and transferred to four manufacturers in Haryana, Himachal Pradesh, Delhi and Karnataka.

Cassava is primarily an industrial raw material for the extraction of starch in Tamil Nadu and around 1100 starch factories are spread over the Salem belt. These factories have provided job security to about 5 lakh people of the State. Nevertheless, the effluent discharged into the nearby ponds and fields end up with high BOD, COD and cyanogens and thus pose a continuous threat to the flora and fauna. Many factories were at the verge of closing down due to the strict pollution control measures (enforced by the Government) to be adopted to resolve this problem. Realising the urgency of the situation, CTCRI has perfected a novel low cost effluent treatment technology which makes the effluent water safe for irrigation or aquaculture. The treatment system developed is environmentally safe as it involves only anaerobic treatment of such wastewater.

The quick perishability of cassava tubers demands its rapid processing into some dried form, to reduce the post harvest losses. Nevertheless, the sun dried chips, as is stored in the godowns, are susceptible to attack by a number of insect pests, which necessitates periodic insecticidal sprays to ward off the insects. CTCRI has developed an eco-friendly storage technology viz., cassava ensiling so that a product with good shelf life and quality can be obtained for feeding cattle especially the milch animals

NETWORKING CONCEPT & EPILOGUE

Tuber crops are poised to play a major role in the food and feed requirements of our country in the coming years. This group of crops offers a great promise in terms of export subject to production costs and export policies. Fulfilling this goal needs cost effective techniques in production and processing. To achieve this demand, a strategic tuber crops genetic resources management, production technologies, novel and quality of value added products appropriately backed by human resources developments activities for Scientists, extension personnel and the users system are needed.

International Collaboration

The CTCRI being the world leader on research on Tropical Root and Tuber Crops has established linkages with various International Organisations in furtherance of excellence in our research agenda; they are:

1. Centro International de Agriculture Tropical (CIAT), Cali, Colombia
2. International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria
3. International Potato Centre (CIP), Lima, Peru
4. Brazilian Agricultural Research Institute (EMBRAPA), Brazil
5. Asian Vegetable Research and Development Centre (AVRDC), Shanhua, Taiwan
6. International Laboratory for Tropical Agricultural Biotech (ILTAB), St. Louis, USA

There has been frequent exchanges of our Scientists visiting the above Institutes for Faculty Improvement, exchange of germplasm, advance studies/training on modern scientific methodology etc. Thanks to these collaborations, we have been steadily organising International Seminars/Conferences as well as Training Programmes to benefit, by and large, the developing countries. However, specific goal oriented network programmes are to be worked out for the enhancement of Tuber Crops Research and development.

Table 4. Current status of germplasm of tuber crops at CTCRI

Crop	CTCRI HQ	CTCRI RC	TOTAL
Cassava	1681	33	1714
Manihot sp (8 No.)	27	-	27
Sweet potato	934	243	1177
Ipomoea sp	13	78	91
Greater Yam	296	44	340
African Yam	258	-	258
Lesser Yam	114	-	114
Dioscorea sp	264	-	264
Taro	1063	120	1183
*Colocasia (*wild)	19	-	19
Xanthosoma sagittifolium	67	-	67
Elephant foot yam	110	32	142
Amorphophallus sp	28		28
Giant Taro	2		2
Swamp Taro	2		2
Chinese potato	87	1	88
Coleus sp	9	-	9
Costus	5	-	5
Curcuma	45	-	45
Canna	8	1	9
Arrow root	6	1	7
Yam bean	63	45	108
Alocasia	1	0	1
Vigna sp	1		1
Zingiber sp	5		5
Typhonium	5		5
Asparagus sp	6		6
Alpinia sp	*7*		*7*
Tacca sp	*2*		*2*
Other tuberizing sp	38	-	38
Total	**5166**	**598**	**5764**

National level

At national level the All India Coordinated Research Project on Tuber Crops has been initiated to generate location specific tuber crops technologies through a network involving coordinated centres located in 10 State Agricultural Universities and one each in ICAR Research Complex for North East Hill Region of India (Shillong) and the Central Agric. Research Institute, Port Blair, A.N. Islands. The CTCRI and its Regional Centre also serve as voluntary centres of the project. This approach has helped in generating a number of location specific technologies.

It is nice to conclude with a statement of Gelia T. Castillo that "while rice and wheat crops are grown on superior lands with irrigation or better moisture, secondary crops like root and tubers are grown in the upland or rainfed areas mainly by resource poor small farmers". Development of these crops is therefore, basic to poverty alleviation and equitable development of society. Therefore, it is hoped that the networking of Research & Development Organizations working on tuber crops will go a long way to play the role of poverty alleviation and utilize the available advanced technologies to upgrade/enhance the production and productivity of TRC.

Table 5. High yielding varieties released from CTCRI

Sl. No.	Variety	Average Yield ($t\ ha^{-1}$)	Special attributes
CASSAVA			
1	H-97	25-36	Drought tolerance
2	H-165	33-38	Popular in industrial belt, duration :8-9 months, Starch : 33-.38%.
3	H-226	30-35	Popular in industrial belt, Starch : 28-30%.
4	Sree Sahya	35-40	Hardy and highly resistant to drought
5	Sree Visakham	36-38	Rich in carotene
6	Sree Prakash	30-35	Early maturing (7-8 months) and shallow bulking
7	Sree Harsha	35-40	Triploid, high starch content (38-41%)
8	Sree Jaya	26-30	Early maturing (6-7months)
9	Sree Vijaya	25-28	Early maturing (6-7months)
10	Sree Rekha	45-48	Suited to both upland and low land cultivation
11	Sree Prabha	40-45	Suited to both upland and low land cultivation
SWEET POTATO			
1	H-41	20-25	Excellent cooking quality
2	H-42	22-25	Excellent cooking quality
3	Varsha	17-22	Drought tolerant, recommended for Konkan region of Maharashtra

4	Sree Nandini	20-25	Drought tolerant, Early maturing (100-105 days) Suitable for paddy fallows as a catch crop
5	Sree Vardhini	20-25	Early maturing (100-105 days), dual purpose variety
6	Sree Rethna	20-26	Early maturing (90-105 days) , excellent cooking quality,
7	Sree Bhadra	20-27	Early maturing (90 days) with excellent cooking quality, used as trap crop against root knot nematode
8	Gouri	19	A medium duration variety (110-120 days) with high carotene conten,can tolerate mid season drought
9	*Sankar*	14	A medium duration variety , excellent cooking quality
10	Sree Arun	20-28	Early maturing (90-100 days), spreading type, fusiform short/spherical tubers with pink skin and cream flesh
11	Sree Varun	20-28	Early maturing (90-100 days) spreading type, fusiform short/spherical tubers with cream skin and cream flesh
12	Sree Kanaka	12-15	Short duration hybrid rich in carotene (8.8-10 mg / 100g fresh tuber)
13	Kalinga	26-29	Open pollinated selection that matures in 105-110 days recommended for cultivation in Orissa state
14	Goutam	18-32	Clonal selection that matures in 105-110 days, suitable for upland and hilly areas in both Kharif/Rabi season
15	Kishan	16-26	Clonal selection with medium duration (110-120 days) and high dry matter and starch contents, suitable for upland and hilly areas in both Kharif/Rabi season
16	Sourin	16-32	Clonal selection that matures in 105-110 days, suitable for upland and hilly areas in both Kharif/Rabi season

YAMS

GREATER YAM

1	Sree Keerthi	25-30	Large sized conical tubers
2	Sree Roopa	25-30	Excellent cooking quality, digitate tubers
3	Sree Shilpa	28	Medium sized oval tubers , easy harvestability
4	Sree Karthika	30	High yielding selection with good cooking quality and keeping quality
5	Orissa Elite	22-25	Suitable for rainfed/ irrigated conditions of Orissa, matures in 180 days, tubers have white flesh and good cooking quality

	WHITE YAM		
6	Sree Priya	35-40	Drought tolerant, novel flavour, suitable for intercropping in mature coconut garden
7	Sree Subhra	35-40	Drought tolerant, novel flavour
8	Sree Dhanya	20	First dwarf bushy variety
LESSER YAM			
9	Sree Latha	25-30	High yield & wide adaptability
10	Sree Kala	20	Good tuber shape and excellent cooking quality
AROIDS TARO			
1	Sree Pallavi	15-18	A tall variety with large number of small sized tubers
2	Sree Rashmi	15-20	Taro selection that matures in 7 months, acrid free, good cooking quality.
3	Muktakesi		Taro variety tolerant to leaf blight
4	Sree Kiran	18	First taro hybrid from India, good cooking quality
5	Pani Saru-1	15	Clonal selection from variety Kantilo local, suitable for water logged/ submerged conditions of Orissa, duration 6-7 months
6	Pani Saru-2	13	Clonal selection from variety Vegunia local, suitable for water logged/ submerged conditions of Orissa
ELEPHANT FOOT YAM			
1	Sree Padma	40	High yield potential : 80.2 t ha^{-1}
CHINESE POTATO			
1	Sree Dhara	25	Excellent culinary quality, duration : 5months

ROLE OF FORESTRY RESEARCH IN POVERTY ALLEVIATION -TAMIL NADU

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INTRODUCTION

Forestry Sector in India is undergoing a continuous transformation since independence. Though the objective of the sector, which is primarily concerned with conservation of forests, remains stable and constant, the strategies adopted to achieve this, is undergoing continuous changes. From time to time, the values and importance attached to specific focal areas of Forestry activities at the international and national level have been shifting from production and post harvest technology to protection of biodiversity and poverty alleviation.

For the effective implementation of the National Forest Policy to its letter and spirit, the Tamil Nadu Forest Department had geared itself adequately by ensuring appropriate back up support through evolving problem solving, cost effective, adoptable, acceptable and location specific action research programmes. Such technical innovations have been dovetailed to the mega programme of the Tamil Nadu Government, namely Tamil Nadu Afforestation Programme and Tamil Nadu Wasteland Development Programme. Apart from enhancing the biomass productivity, these programmes ensure poverty alleviation and downstream employment generation. Ensurement of forward and backward linkages have added to the success of these programmes. This is done by bridging partnership of the Forest Department with the people living in the vicinity of Reserved Forests, marginal and sub marginal farmers living even in far-away lands, NGOs, self-help groups, wood based industries and rural artisans.

The structure of employment in Tamil Nadu has more or less mirrored the structural transformation that has taken place in the State's economy over the years. For, the number of persons employed in the primary sector has shown a decline while that in the secondary and tertiary sectors has gone up in the 1991-2001 period. Tamil Nadu's economy has undergone a major transformation over the last few decades, from being a primary producing economy to one dependent now on the services sector. The Primary sector's share of the Gross State domestic product has dropped from 43.5 per cent to about 17 per cent now, while the secondary sector's share increased from 20.3 per cent to about 33 per cent and that of the tertiary sector went up from 36 per cent to about 50 per cent now. According to a report on employment perspectives for Tamil Nadu, prepared by the Department of Evaluation and Applied Research, a State Government Department, primary sector employment has declined at an annual rate of 0.50% from 153.42 lakh in 1991 to 145.80 lakh in 2001. According to the evaluation study, primary sector employment, which accounted for a dominant share, 55-60% to the total employment had declined in 1999-2000 as compared to that in 1993-94. A host of factors have resulted in the number of persons employed in the agriculture sector drop, especially the increasing modernization of agricultural operations, which has reduced the need for a large number of workers.

Tamil Nadu, the southern state of India has a geographic area of 13 million hectares, which constitutes 3.96 % of the land area of the country. The total population of the state is 55.86 million (1991 census) accounting for 6.60% of the country's population. The recorded forest area is 2.26 million hectares, which makes 17.40% of the land area of the State. But the actual forest cover is only 1.71 million hectares, a mere 13.13 % of the land area. Not only that, half of this actual forest cover has a crown density of less than 0.4 (FSI 1999).

There are 15822 village in the State of which about 3000 are forest abutting. The total population of these villages is estimated to be 3.11 million. Though no separate consumption or income data are available, it is a known fact that these forest abutting communities are the poorest of the Poor. Because of remoteness, thin and scattered population, modem developments and amenities have not reached them.

Over 77% of the Tamil Nadu population, directly or indirectly, are indulging in agriculture more as a way of life than as an economic enterprise. Next to Rajasthan, Tamil Nadu is the driest state receiving lowest rainfall in India, average being 934 mm per annum. The total dependence of the majority of the agriculturist on the unpredictable and undependable monsoon rains result in the cultivation of cereals and pulses, many a time total wasteful expenditure and exercise.

Out of the 6.21 crores population of Tamil Nadu, 4 crores reside in the urban areas and 22 crores live in the rural areas (2001 census figure). Out of this population. 57 lakhs of people have been identified as cultivators. Out of the total area of about 80 lakh hectares, 30 lakh hectares are put into use for rainfed agriculture. The income generations from these marginal and sub marginal lands are getting reduced steadily and considerably year after year. This is because of the depletion in the soil fertility due to non-replenishment of organic manure to the soil. The average net profit per acre per year of these marginal and sub marginal farmers of Tamil Nadu with their rainfed agriculture is less than Rs.1000/ acre/year. Many times, because of the failing monsoons, they incur heavy losses. Agriculture has become a way of life than an economically viable venture. This has resulted in the younger generations not taking up agriculture as an enterprise and moving away to the cities and towns. It is significant to note that the number of towns has been increasing over the years - 434 in the year 1981 to 469 in the year 1991 and 832 in 2001. It is to be noted that the growth rate of the rural population has for the very first time shown a negative trend in the last decade (-5.20%). More and more rainfed agricultural lands are being left as fallows. This exodus has to be prevented. Because of these phenomena in Tamil Nadu, the rural resources are under utilized and the urban environs are over exploited.

Natural resources are being exploited by people recklessly. As the population grows, demand for energy increases, the forests and watersheds are often over exploited. Both the upland soils and the lowlands have become degraded leading to erosion loss of topsoil and thereby impoverishment of ecology and economy of the dependent people. Therefore, technological interventions are needed. Both large scale and small-scale changes are taking place in the eco-system and also in the quality of the life of the people due to the loss of biological wealth. Therefore, an appropriate forest strategy to cope with the problems of the people is needed.

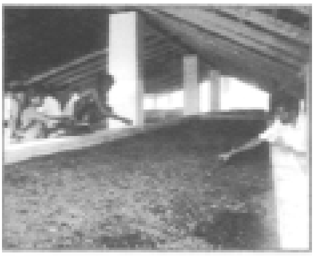
Forest Research in Tamil Nadu has been focused in the last five years so as to strengthen the conservation of the natural resources and at the same time addressed the issues of the rural poor. Research to strengthen bio-productivity, by strengthening tree cultivation practices in private lands has been the area of attention by the forest department. There have been many advances in forest management and practices due to the technological inputs, which have been utilized for bio-productivity enhancement and bio-diversity conservation, and thereby paving way for the improvement of the quality of the life of the rural people.

Technology intervention in forestry programmes

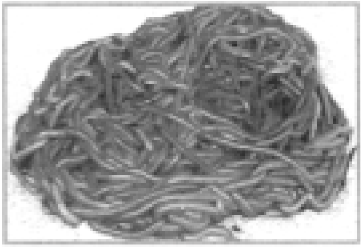
Various research projects are undertaken in the 66 Research centres, 6 modern nurseries located in 7 different agro climatic zones of Tamil Nadu to address the issues of rural development and poverty alleviation through forestry. Improving the forest cover, the quality of forest and doubling the tree cover are critical areas into which new technologies and new skills have been incorporated. The

Modern Nursery, Thoppur

Bacterial bio-fertilizers

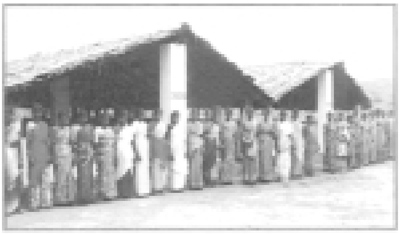


PRODUCTION OF
Vermicating



Vermiculture - Close up
(Perionyx excavatus)

VAM Production



Vermicomposting - Laborers - An eco-friendly employment generation activity experience gained by forestry research in various thrust area as listed below are put to advantageous use in bio- productivity enhancement, bio-diversity conservation thereby ensuring the rural upliftment.

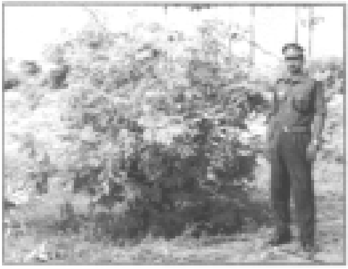
Tamil Nadu being a State deficit in water potential has utilised every drop of water available for agricultural, domestic and industrial needs. This State depends mostly on the northeast and southwest monsoon. The vagaries of nature causes enormous loss to the farmers. Therefore, it is imperative that the water holding capacity of the soil has to be increased to ensure high productivity. The indiscriminate uses of chemical fertilizers have deteriorated the soil texture and structure over the years. This has lead to the diminution in the population of the Rhizosphere microflora and fauna. Therefore, enhancement of bio productivity can made into reality only if this malady is remedied on priority basis.

During 1998-99, six modern nurseries were established by the Research wing of the Tamil Nadu Forest Department. In these modern nurseries, facilities for production of Vermicasting, VAM (Vesicular Arbuscular Mycorrhiza) and bacterial bio fertilizers like Azospirillum, Phosphobacteria, Rhizobium and Psudomonas etc. were created. During the last four years, more than 3000 tonnes of vermicasting, 800 tonnes of VAM and 500 tonnes of bacterial bio fertilizers have been produced in these modem nurseries. Till date more than 5 crore-tree seedlings raised by the Forest Department have been inoculated with this bio nutrients and bio fertilizers. Experiments were carried out to arrive at the optimum dosage of their combination for highest biomass production. This has resulted in cost-effective treatment models, which have increased the total bio mass of 6 months old seedlings of more than 30 species from 95 to 350% than the untreated ones.

These findings were immediately transferred to the nursery components of the two mega tree based programmes of Tamil Nadu namely Tamil Nadu Afforestation Programme and Comprehensive Wasteland Development Programme.

Identification, Isolation and Multiplication of high yielding plant propagules from the Natural Forests:

Tree growing proposition could be an economically viable one, only if superior varieties are planted. Trees have the greatest advantage of enduring the prolonged drought periods due to its deeper root system. Therefore, superior phenotypes of Non-wood Forest produce like Tamarind, Gallnut, Soap nut, Gooseberry and Neem were identified by undertaking thorough genetic combing. These has

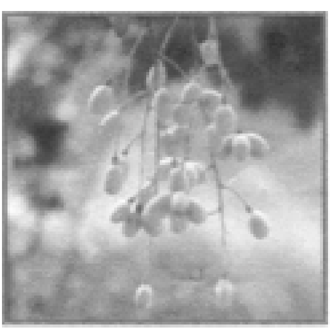


Two-Year-old Tamarind graft with fruits
On farm trial - Anthiyur

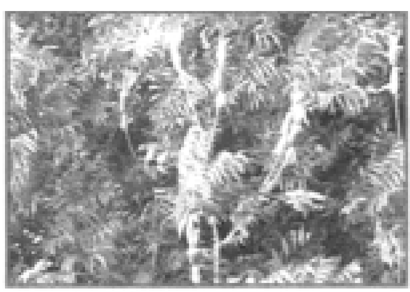
Emblica - Plus tree in fruits

Azadiracta indica

9000 ppm - Azadiractin
content plus tree rooted
cuttings (Bannari + tree No. 20)



Fruits of plus tree with
high azadiractin content



Air layering in plus tree

resulted in the isolation and production of more than 110 plus tree propagules of Tamarind yielding annually 800 to 1200 kg fruits. Vegetative propagation like air layering, grafting, rooting of sprigs etc. were standardized and about 300 malis were trained in the clonal multiplication technology. More than 150 mist tents have been erected all over the State and macro propagation is on in a big scale.

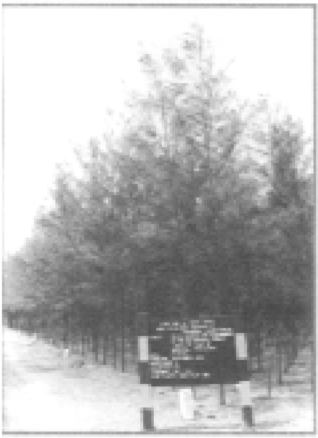
Similarly, high yielders in Soap nut, Gall nut, Gooseberry, Neem etc. have been multiplied and their performance have been evaluated under multi location trials spread all over the 7 agro climatic zones in Tamil Nadu. These trials have resulted in the identification of zones specific high yielders. These are multiplied and supplied to the farmers and also utilized in the planting programme of the Tamil Nadu Forest Department. So far, more than 10 lakh grafts of these superior yielders have been produced and utilized in the State in the past 2 years. The enhanced productivity of utilizable biomass from these high yielding plant propagule will accelerate the pace of income generation for the rural poor. Concomitantly down stream employment generation is also envisaged.

Hybrids and transgenic plants

Realizing the uniqueness of tree species as a cost-effective contrivance for sun energy harvesting, appropriate species, provenance and hybrids of very fast growing, less demanding varieties have been evolved by the Tamil Nadu Forest Department over the past two decades. To site one example, *Casuarina equisetifolia.* a species which is taken up for cultivation by the farmers in Tamil Nadu on a very large scale as block plantation at approximately 10000 ha. per year was concentrated upon for tree improvement from 1982-84 onwards. More than 120 superior phenotypes of female trees and 40 superior male trees were identified from among the cultivated population at selection intensity of one in 50,000. A clonal seed orchard was established during 1985. Continuous tree improvement programmes undertaken with these families have resulted in the production of intraspecific hybrids, which have exhibited 40% more yield than the normal cultivars. High quality seeds obtained from second-generation seed orchards established during 1999 - 2000 are being utilised for "ONFARM TRIALS' to demonstrate their efficiency. Superior clones from these progenies are being subjected to transformation into drought tolerant transgenic plants by incorporating 'Proline' producing genes by the Research wing under Collaborative Research with Madurai Kamaraj University.

Unlike *Casuarina equisetifolia*, *Casuarina junghuniana* is a species that can grow very fast even under rainfed conditions. Appropriate fast growing provenances of these species have been

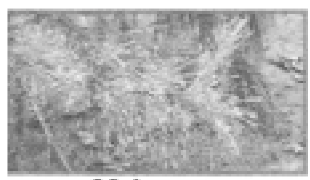
Casuarina equisetifolia - Intraspecific hybrid production
Neyveli, Tamil Nadu



Second generation clonal seed orch
Year of formation 2000-2001

Hexogen Orchard Design
Superior Male in the Centre

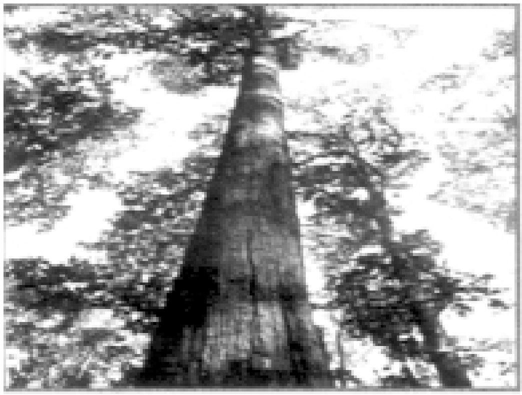
Ramet with cones



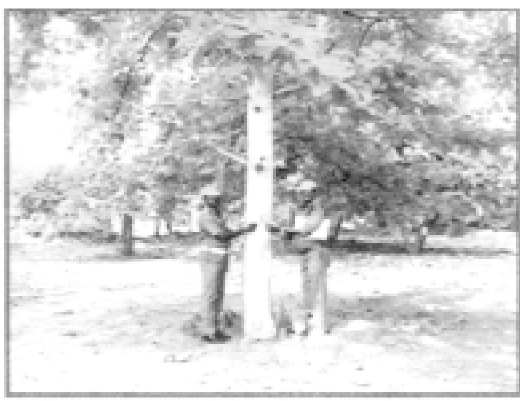
Male cones

identified under provenance trial experiments in the past two years. Fast growing phenotypes are vegetatively propagated for establishing clonal plantations. Similarly interspecific hybrids of *Eucalyptus tereticornis* x *Eucalyptus alba*, *Eucalyptus citridora* x *Eucalyptus toreliana* have been produced and the hetrotic vigour is captured by resorting to clonal propagation.

Farm grown Teak seed orchard progenies were screened and plus trees were identified from the 10 year old population which exhibited higher rate of growth with larger proportion of heartwood. These have been clonally multiplied and are being established as clonal banks in all the research centres. These are also planted in farm lands as demonstration plots.



Teak Plus tree

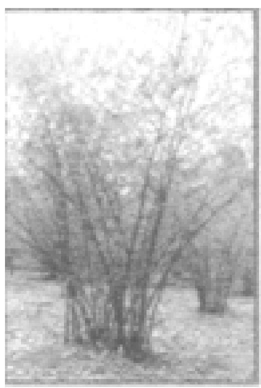


986 Teak-Clonal Seed Orchard- Neyveli

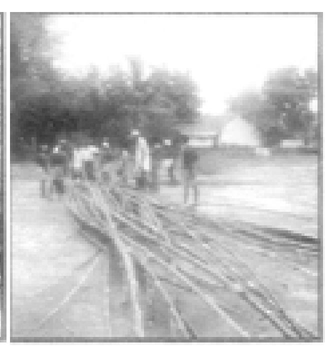
Silviculturally suitable, fast growing high yielding marketable tree species - "introduction to farmers"

The reluctance of the farmers in taking up of tree cultivation is due to its long gestation period between planting and harvesting. It was, therefore, aimed at introducing appropriate species and technique that could culminate harvestable, profitable biomass within 100 months after planting. Two bamboo varieties - *Bambusa arundinacea & Dendrocalamus strictus* - are natural to Tamil Nadu. The presence of thorns in *Bambusa arundinacea* and the lesser biomass production of *Dendrocalamus strictus* prohibit the adoption of these species by the farmers. Therefore, about 50 species of

Bamboo, out of the 139 found in India, were introduced during the year 2000 at various Forest Research field centres in Tamil Nadu and evaluated for their suitability and different agro climatic zones. Very positive results emanated from these trials indicating the profitability of cultivating species like *Bambusa nutans, Bambusa tulda*, *Bambusa polymorpha*, *Bambusa mukalba* and *Bambusa balcooa.* All these species are thornless and have great utility value and therefore, highly marketable. Large-scale vegetative propagation of these species are undertaken in all the research centres. They are of high utility value in basket making, mat, veneer, splints, screens, small construction etc. More over, Bamboos have got the capability to convert sun energy into bio mass much more rapidly within shorter span of time than any other tree species. Therefore, they are of great demand by the farmers. The harvested bamboos will certainly generate huge employment generation in the rural areas thereby accelerated the pace of poverty alleviation.



Bambusa nutans

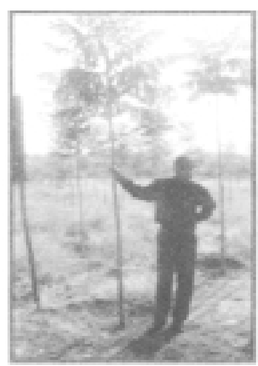


Bambusa balcooa

More than 15 lakh of people are employed in the match industries in Tamil Nadu and the industrialists are suffering due to the depletion of the raw materials. 90% of the total labourers involved in Match Industries of India are living in Tamil Nadu. *Ailanthus excelsa* is a very fast growing tree species found naturally occurring in the rainfed lands of Tamil Nadu. Since the Match industries require light coloured *Ailanthus excelsa* wood, very fast growing superior phenotypes with desirable characters have been identified and seedlings are raised. The farmers are supplied with the high yielding varieties of *Ailanthus*.

Ailanthus excelsa
Plus tree

Two year old *Simaruba glauca*
State Forestry Research Institute

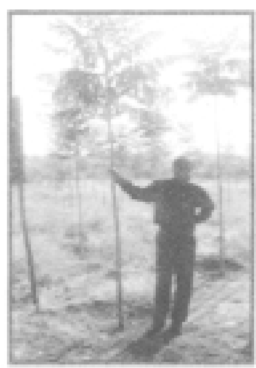


One year old
Kaya senegalensis

So far as Tamil Nadu is concerned, this species is a great boone to the marginal and sub marginal land holding persons as they exhibit fastest rate of growth, yielding upto 40 tonnes per acre per year. Income augmentation in these rural areas through such profitable sun light harvesting strategies are the need of the hour for the State of Tamil Nadu which is facing continuous depletion of irrigation water.

Ailanthus excelsa

Two year old *Simaruba glauca*
State Forestry Research Institute



One year old
Kaya senegalensis

Exotic species like *Simaruba glauca, Kaya senegalensis*, *Acacia elata* and *Swietenia macrophylla* have proved their potential to be a great asset for protective irrigated lands. Trials conducted out side the forest areas, in these rural landmass have resulted in identification of hither to unknown or under-exploited, cultivated tree species like *Acrocarpus fraxinifolious, Astonia scholarise. Albizia procera, Melia dubia, Anthocephalus cadamba* into limelight. Their rapid rates of growth, under the cost-effective profitable package of practice like one cu.m. pit saucer rim planting with bio nutrient and bio fertilizer inputs evolved by the Research wing holds great promise for a profitable tree husbandry proposition for the farmers. Since there is a total mismatch between the demand and supply of veneer, plywood, construction wood, match stick etc., these hold great potential to bridge the gap. Such recourse to enhance primary sector productivity will pave way for poverty alleviation and through down stream employment generation.

Forestry extension

All these cost effective, adoptable, acceptable location specific action research findings are demonstrated in the 19 forestry extension centres established in Tamil Nadu during the past four years.

Forestry Extension Centre

Training for farmers

Emblica-Demonstration Plot

Training to farmers, self-help group, publics and school children on Vermicompost and VAM production, Vegetative propagation like graft production, nursery technique etc. being given in these forestry extension centres. About 500 on farm trials with these superior tree varieties have been established to serve as Demonstration Plots all over the State in the past 3 years. This will help in the primary sector productivity enhancement and accelerate the pace of poverty alleviation. All the adoptable, profitable package of practice standardized by the Research wing is being transferred to the farmers through these extension centres.

Joint forest management (TAP)

The National Forest Policy of India has been revised in 1988 with the principal aim for environmental stability and ecological balance, which are vital for the sustenance of all life forms, human, animal and plant. In India, forests meet nearly 40 per cent of the energy needs of the country of which more than 80 per cent is utilized in the rural areas and about 30 per cent of the fodder needs of the cattle population. Forest products also play a very important role in the rural and tribal economy as many of the non-wood forest products (NWFP) provide sustenance to the rural poor. For landless families and marginal farmers forest related activities often represent the primary source of income. It is estimated that about 270 million tonnes of fuel wood, 280 million tonnes of fodder, over 12 million m^3 of timber and a large number of non-wood forest produce are removed from the forests annually. At a conservative level of pricing (Rs.500 or 10US$ per tonne of fuel/fodder) the value of these commodities will approximately aggregate to over Rs.3, 00,000 million or 6000 million US $.

Realizing the fact that there exists intricate, inter-dependence of forests and people, strategies were evolved to manage the forests with the participation of people.

Contribution of research to poverty alleviation oriented forestry programmes

In a developing country with high human and cattle population like India, 'applied research' could contribute immensely than 'fundamental research'. Specifically this is applicable to land and life based programmes like Forestry. Realizing the importance of such 'action research' findings in enhancing the quality of out put of Forestry Programmes, the following research interventions were implanted in the two mega programmes of the State of Tamil Nadu, namely- Tamil Nadu Afforestation Programme (TAP) and Tamil Nadu Wasteland Development Programme(TNWLDP).

Tamil Nadu afforestation programme

This programme is being implemented from 1998 onwards. About 1000 villages abutting the degraded reserve forests, situated mostly on the fringes of Eastern and Western Ghats were taken as focal points. About 300 ha. of micro watersheds of degraded forests adjoining each selected village are the treatment areas. In tune with the strategy of managing these forests on participatory basis with the people, microplans were prepared.

The entire treatment area was divided into three zones, the upper or steeper terrain as *Eco restoration zone,* the middle zone as *Asset creation zone* and the third one, as *Utility zone.*

Eco-restoration zone

Bio-diversity conservation and amplification are the twin objectives governing the treatments proposed for this zone. This could be achieved only by ensuring the happy life of 'Pollinators' and 'Seed dispersers'. Therefore, Silviculturally suitable species for those locations that could serve as ideal habitat for Bees, Butterflies, Bats and Birds were identified by the research wing of the Forest Department. Nursery techniques for raising many such uncommon species were standardised by the Research wing, from seed collection and processing till transplanting to the field and planting up. Many varieties of *Ficus* species, which serve as 'Keystone' species for habitat amelioration of the pollinators and seed disperses are being raised in millions in all the Research Modern Nurseries in the State. These are planted in these zones. Research is contributing not only in the selection of species but also in raising and supplying invigorated seedlings infused with bio-fertilizers.

Ficus religiosa

Ficus retusa

Ficus bengalensis

Asset Creation Zone

Though the primary objective of this project is Ensurement of ecosystem Services, only by meeting the fundamental needs of people this could be achieved. Therefore, the species that yield utilizable biomass of economic value like tree species yielding valuable timber resources are planted in this zone. Seedlings are raised from seeds collected from seed stands, seed production areas and seed from the "Forest Tree Seed Centre' maintained by the Deputy Conservator of Forests, Research wing. This centre handles seeds of over 120 species of plant varieties and annually 55 tonnes of seeds on an average are processed. Total annual stock is about 90 to 100 tonnes.

Utility zone

This zone, which is in close proximity to the human habitation, is dedicated for raising plants that are of direct consumptive utility value in the day- today life of villagers. Very high yielding plant propagules, fast growing superior phenotypes sourced from the research wing are utilized for planting. More than 350 indigenous medicinal plants have been assembled in the research centres and cultivation practice for the unknown varieties have been standardised. Medicinal plants suitable for the locality, which have market demand, are raised in this zone.

Joint farm management

The findings of research on the conditions required for maximizing growth, with bio-nutrient and bio-fertilizer inputs of economically important tree species are translated into practice on the farmlands of the peasants. Clones and grafts of valuable trees like Teak, Sissoo, Mahogany, Gallnut, Soapnut, Gooseberry, Neem, Tamarind and Bamboos are made available for planting as block planting or for planting on the field bunds.

Productive potential enhancement

All these seedlings raised under TAP, annually around 20 million, are inoculated with Vermicasting, VAM, Phosphobacteria, Azospirillum, Rhizobium etc. These inoculants not only enhanced the biomass to more than 100 to 350%, but also will be contributing to the proliferation of these beneficial microbes in the depleted forest soils. These sustainably contribute to the enhancement of the productive potential of the soils. Thus apart from bio-productivity enhancement is also ensured. These research interventions have resulted in mitigating loss of topsoil, increase in the organic content, water holding capacity, infiltration rate etc. Water harvesting structures like checkdams and percolation ponds created in the watersheds have resulted in raising of the water table in the wells of the farmlands. The availability of adequate water for irrigation had led to the increase in the cultivation of cash crops like paddy, banana, vegetables, etc. Lands that were left as permanent fallow so far, are being converted into cultivable lands due to increased water availability.

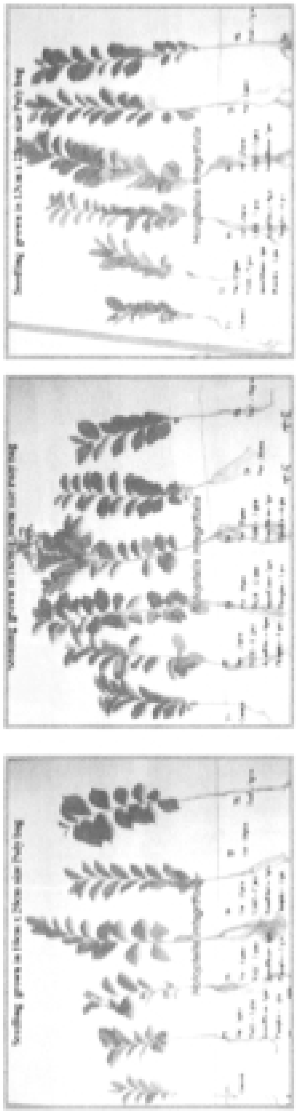
Tamil Nadu comprehensive wasteland development programme (TNCWLDP)

Another mega programme of the State of Tamil Nadu launched during the year 2002-2003, is Tamil Nadu Comprehensive Wasteland Development Programme, under which 60 watersheds in 10 Districts, covering an area of 50,000 ha are being taken up for development. About 54 lakhs numbers of agro forestry tree seedlings are raised by the Forest Department for this programme. All these seedlings are planted in the farmlands on their request and choice. Very high quality seeds from superior sources like Seed Production Areas or Seed Orchards or from selected phenotypically superior trees were collected by the Deputy Conservator of Forests (Genetics) of the Research wing were used for raising these seedlings.

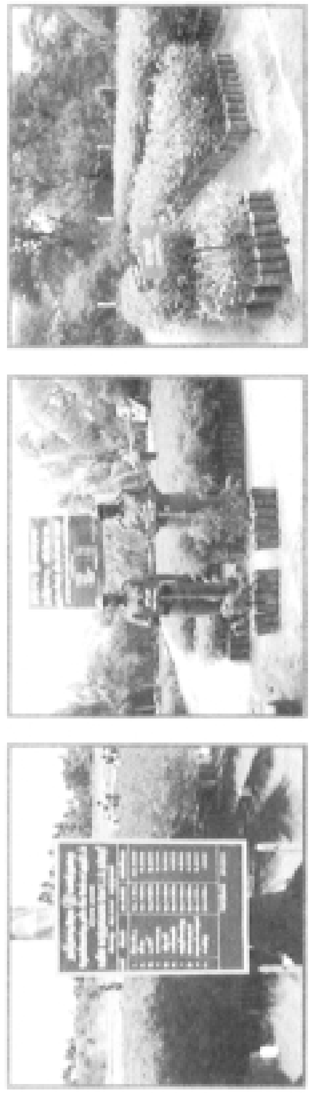
Seedlings raised under Tamil Nadu Comprehensive Waterland Development Programme

Detailed experimentation and trials with 30 species in different poly bag sizes with varying inputs of Vermicasting, VAM and Bacterial bio-fertilizers carried out by Tamil Nadu Forest Research wing, had resulted in identifying the most optimum mix for maximum biomass yield. This finding was translated into action by adopting it for the raising the 54-lakh seedlings. The entire nursery programme was implemented and monitored by the research wing. For the planting programme of Tamil Nadu Comprehensive Wasteland Development Project, 1340 tonnes of Vermicasting, 267 tonnes of VAM, 80 tonnes of Bacterial bio-fertilizers were produced by the Forest Department Research wing during 2002-2003.

The effect of this innovative strategy was evaluated by estimating the growth of treated and untreated six months old seedlings from all the nurseries. The results indicated that, compared to control, the treated seedlings have exhibited higher biomass from 95% to 350%, depending oh the species raised.



T4 Experiment seedlings have exhibited higher biomass



Apart from these, forest research in Tamil Nadu is engaged in Post Harvest Technology, processing and market research that are also contributing considerably to the alleviation of poverty of the people. Realizing the importance of research, training and extension in achieving the objectives of the National Forest Policy, more attention is paid to this sector in Tamil Nadu Forest Department.

EMERGING FOOD TECHNOLOGIES – A REVIEW OF MAJOR DEVELOPMENTS

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INTRODUCTION

Consumer demands for high-quality foods that are fresh-tasting and nutritious have created considerable interest in the development of new food-processing techniques. Traditional food-processing technologies such as freezing, canning, and drying rely on heating or cooling operations. Although these technologies have helped to ensure a high level of food safety, the heating and cooling of foods contributes to the degradation of various food quality attributes. The color, flavor, and texture of foods processed solely by heating may be irreversibly altered. To ameliorate the undesirable thermal effects on foods, considerable effort has been made in commercial and academic circles to develop nonthermal technologies that rely on techniques other than heating or cooling operations.

During the past two decades, numerous papers have been published in the literature that describe research using these emerging technologies (Barbosa-Canovas, *et al.,* 1998). Because these processing techniques have little or no thermal effects on foods, they are commonly called *nonthermal preservation technologies*. Among these emerging technologies, the most promising ones for food application are high-pressure processing, use of pulsed-electric fields, and application of pulsed light. This review provides a technical description of each of these technologies, along with a discussion of their applications in food processing.

High-pressure processing

High-pressure treatment of foods involves subjecting food materials to pressures as high as 9,000 times the atmospheric pressure. Pressure is applied uniformly throughout a food material, independent of its mass and time. Use of high pressure in food processing is an extension of a technology that is commonly employed in many other industrial processes, notably in the manufacturing of ceramics, diamonds, super-alloys, and sheet metal forming. Similarly, high isostatic pressures are routinely used in the manufacturing of polymeric compounds, such as for the synthesis of low-density polyethylene and in chemical reactors for the manufacturing of quartz crystals. Although commercial interest in the use of high-pressure technology in food processing has occurred only since the early 1990s, the effects of high pressure in inactivating microorganisms have been known for more than a century.

In 1899, one of the earliest investigations using high pressures in food processing involved the application of pressures in the range of 5,000 to 7,000 kg/cm^2 (see Table 1 for unit conversions) to reduce microbial levels in milk and meats (Hite, 1899). It was shown that a five- or six-log-cycle reduction in bacterial count was possible in milk when it was subjected to a high pressure of 6,800 kg/cm^2. Increased shelf life of meats was also observed when meat samples were pressurized to 5,400 kg/cm^2.

Table 1. Factors to convert units of pressure

Unit	atmosphere standard	MPa	bar	kg/cm^2	psi
atmosphere standard	1	0.101325	1.01325	1.0332	14.69594
MPa	9.8692	1	10	10.197	145.0377
bar	0.98692	0.1	1	1.0197	14.50377
kg/cm^2	0.9679	0.0981	0.9807	1	14.2236
psi	0.068046	0.006894	0.068947	0.0703	1

Around the turn of century, the effect of high pressure (6,000 kg/cm^2) on coagulation of egg albumin was observed. Other studies showed that high-pressure processing was beneficial in extending the shelf life of processed fruits. These early studies demonstrated that application of high pressure had effects similar to the use of high temperature on proteins and microbial population in foods.

Equipment Considerations

The key components of a high-pressure system are the pressure vessel, pressurizing system, and ancillary components.

Pressure Vessel

A high-pressure vessel, in which products under treatment are subjected to pressure, is the key component of this technology.

Pressure vessels are generally made of low-alloy steel and are routinely used in the ceramic and metal industries. However, in the case of food applications, a unique requirement for the high-pressure vessel is that it must undergo several thousand processing cycles per year to process large volumes of foods. The large number of required pressurized and depressurized cycles increases metal fatigue and reduces the life of the vessel. Furthermore, the vessel itself must be protected from any corrosion due either to the food material itself or to any liquids used for cleaning.

Pressurizing Systems

Two types of pressurization systems—indirect and direct—are commonly employed in the industry.

In an *indirect pressurization system*, the pressurizing medium (e.g., water) is first pumped through an intensifier, where its pressure is raised. The pressurized medium is then pumped to the pressure vessel. The intensifier is a high-pressure pump used to increase the pressure to desired levels. The intensifier is separate from the high-pressure vessel. This system requires high-pressure tubing and appropriate fittings to convey the pressurized medium to the pressure vessel.

In a *direct pressurization system*, the pressure intensifier is located within the pressure vessel. In this system, both pressure intensifier and the vessel are fabricated as a single unit, and the total size of the vessel can be quite large. A piston is used to deliver the high pressure to the product. This system requires heavy-duty seals that must withstand repeated opening and closure without leakage. A major limitation of this method is the need for efficient seals between the pressure vessel and the piston.

The isostatic pressure system, where products are uniformly treated to high pressure, may be operated under different temperature regimes. The cold isostatic system is commonly used in the plastic, metal, and ceramic industries. Pressures in the range of 500 to 600 MPa are applied using two techniques. In the *wet bag configuration*, which is more suitable for food processing, a mold is first filled with the material outside the pressure vessel. The filled mold is then moved into the pressure vessel containing a pressure medium. With cold isostatic pressure, water is used as the pressure medium. In the *dry bag configuration*, the mold is fixed in place within the pressure vessel. The material to be treated is filled into the mold. The mold remains separated from the pressure medium by an elastomer tool.

The *warm isostatic system* involves application of isostatic pressure at temperatures up to 200ºC. This system is more applicable when desirable chemical reactions must occur at high temperatures while the material is under high pressure.

Another method used in high-pressure technology is to pressurize the test material by heating a pressure medium that surrounds it. This method is based on the principle that liquids expand when they are heated. However, this procedure is suitable only when high temperatures can be used without damaging the material being processed.

In high-pressure processing, inert gases or water are the most commonly used pressure media. The relative uncompressibility of water compared with gases makes it the prefered pressure medium in many applications. The decrease in volume of water is about 5% when its pressure is increased from 0 to 4,000 kg/cm^2 at 22ºC. This volume reduction is much smaller compared with inert gases, where high-volume reductions can make operations more hazardous. When water is used as a pressure medium when subjecting food materials to high pressure, there is instantaneous and uniform transmission of the pressure throughout the product being treated. Typically, small amounts of oil may be added into the water for anticorrosive and lubricant purposes.

Modes of Operation

In a high-pressure process, the pressure vessel is filled with a food product and pressurized for a desired time, followed by depressurization.

The time required to pressurize the vessel is influenced by the compressibility of the pressure medium and the food material. If water is used as the pressure medium, for most food materials compressibility is similar to that of the pressure medium. Typically, the pressurization time of foods is independent of the amount of food placed inside the pressure vessel. However, if the food material contains any air, then the pressurization time is increased, because air is considerably more compressible than water. After pressurization, the food is kept under high pressure for the required process time, which may be for several minutes. Upon completion of the pressure exposure, depressurization can be done quite rapidly.

Batch Processing Mode

Operating high-pressure equipment as a batch process has several advantages. Different types of foods can be processed without cross-contamination, there is no need for clean-up between runs, the equipment is relatively simple, and there is no risk of large quantities of foods becoming contaminated in case of equipment malfunction. Several pressure vessels may be operated in a controlled sequence to minimize any time lag associated with the time required for pressurization of vessels.

Most of the high-pressure equipment used currently operates under batch mode. Because the pressurizing and depressurizing steps can be accomplished rapidly, the low efficiency associated with batch processing is therefore minimized. However, such rapid cycles also can cause metal fatigue and reduce the life of equipment. Above 4,000 kg/cm^2, the weight of equipment increases significantly, as does its cost.

Semicontinuous Processing Mode

Another approach to high-pressure treatment of liquid foods is the use of a semicontinuous processing mode (Moreau, 1995). This system involves a combination of multiple pressure vessels that are sequenced to provide a continuous flow. While one vessel is being pressurized, another may be in a decompression mode. This type of approach has been used commercially by companies such as the Wakayama plant in Japan, to treat tangerine juice, where three 50-liter pressure cells are sequenced to achieve a production rate of 4,000 liter per hour (Moreau, 1995). The pressure system, known as *ACB high-pressure liquid processor* (GEC Alsthom ACB, France), has a chamber with an internal volume of 4 liters. The compression process is done with water up to a maximum pressure of 400 MPa. Programmable pressure controllers are used to adjust pressurization and decompression rates. Appropriate temperature controls are used to maintain temperature from -20ºC to +80ºC. This unit has been used in selected processing steps in wine production. The reduction in cost of a semicontinuous process is about 27% over a batch process for 500-liter-per-hour production (Moreau, 1995).

Another continuous high-pressure system involves 5-m-long stainless-steel pipes that are wound like a coil with a pressure resistance of 700 MPa (Itoh, *et al.,* 1996). Each pipe has an internal volume of 10 ml. An air-driven hydraulic pump is used to introduce liquid product into the pipes. A plunger pump can deliver 800 MPa. With the outlet valve closed, the liquid is subjected to pressure. The coiled pipes are placed in thermostatically controlled water baths, where temperature is controlled between 5 and 80ºC. The outlet valve is gradually opened to release the pressurized product in a continuous manner.

Other innovations in high-pressure system design include the use of pulsating high pressures (Itoh, 1996). The pressure vessel is similar to those used in cold isostatic pressing. A unique feature in this new system is an air-driven pressure-increasing device that allows instantaneous change in pressure. Additionally, a pressure-reducing valve attached to the pressure vessel is useful in releasing pressurized water. By manipulating the pressure-reducing valve, desired pulsations are obtained. The pressure vessel is contained in a thermostatically controlled water bath. The investigators were able to achieve 500 MPa in 10 seconds. Reduced process times at high pressures were obtained when used in combination with higher temperatures. These studies emphasize the synergistic benefit of pressure and temperature in selected food applications.

The cost of high-pressure processing is dependent upon the combination of pressure, pressure hold time, and temperature at which the product is processed (Olsson, 1995). Therefore these variables must be carefully selected. The cost per unit of production is lower for a large production unit than when several small-size pressure units are used in parallel (Olsson, 1995). This cost saving is possible because the capital cost of manufacturing a large pressure unit is lower than several small units.

Examples of Industrial-Scale High-Pressure Systems

The following two examples of industrial equipment for high-pressure applications are provided for illustration purposes. High-pressure equipment, manufactured by ABB Pressure Systems AB, has been largely used for synthetic diamond manufacturing, sheet metal forming, and for the extrusion of metal. Equipment developed specifically for food processing includes the QUINTUS Food Press. The pressure vessel is prestressed using a spring steel wire and remains in a prestressed state even under pressure. A replaceable liner is inserted inside the cylinder for additional safety of operation. To keep the top and bottom closures safely in place, the press uses a retractable frame, fabricated of prestressed wire winding. The press is pressurized with an external pressure intensifier. Other designs involve a pump built into the press to obtain a wide range of pressure. A laboratory unit (QFP-6) has a capacity of 1.4 liters at pressures up to 900 MPa. As a total system, the QUINTUS Press may be incorporated in a bulk processing line, where the product is kept inside large bulk containers during processing and storage. As an alternative, food in retail-size packages, placed in a loading basket, may be processed under pressure and later transported directly for retail sales.

A pilot-size ultra-high-pressure food processor is manufactured by Flow International Corporation (Kent, Washington). This unit is developed for pumpable products. Under computer control, the food is pumped into the pressure vessel, the pressure is raised and held for the required time, and the food is discharged into filling containers. An ultra-high-pressure pump (FLOW WaterNifeâ) is used to pump the food into the chamber. In a multi-chamber system, the filling, pressurizing and discharging operations can be appropriately sequenced to achieve maximum production rates.

Commercial Applications of High-Pressure Technology in Food Processing

Some of the requirements for the suitability of a high-pressure system for food applications are as follows:

- Short cycle time for inactivating microorganisms and enzymes
- Safe to operate
- Easy to clean
- Accurate and reliable pressure control
- Low capital and operating costs.

Commercial application of high-pressure processing was first realized in Japan in 1992, when a Japanese company, Meidiya Foods, introduced jams processed with this new technology into the Japanese market. The products were well received by the consumers. Since then, other products processed with this technology in Japan have included fruit juices, ice cream, Japanese unrefined rice wine, and rice cakes containing herbs, such as *Yomogimochi* (Hayashi, *et al.,* 1992). These commercial applications have also spurred interest in conducting research on high-pressure processing. More than 70 food companies and governmental institutions in Japan had acquired laboratory-scale equipment for testing as of 1992 (Hayashi, *et al.,* 1992).

During the last decade, numerous publications have appeared in the literature that describe the influence of pressure on various constituents of foods such as spoilage microorganisms, food pathogens, enzymes, proteins, and lipids. A diverse range of foods have been subjected to high-pressure treatments, including fruit juices, jams, vegetables, milk, yogurt, cheese, fish, pork, and beef (Table 2). In contrast to thermal treatment, high-pressure processing does not break covalent bonds in foods, and as a result flavors are generally preserved. The effect of high pressures on enzymes is largely due to denaturation of proteins. The role of high-pressure processing on enzyme kinetics, other chemical reactions such as the Maillard reaction (which causes browning), and lipid oxidation (which leads to off-flavors in fat-containing foods) are the focus of current research.

Table 2. Some examples of products processed using high-pressure technology and changes in quality attributes other than microbial changes

Product	Process and Quality Attributes	Reference
Avocado Puree	Prevent discoloration. Inhibition of undesirable browning reactions in presence of low pH.	(8)
Banana Puree	Prevent discoloration. Reduction in Polyphenoloxidase activity when combined with blanching.	(8)
Black Beans	Cooking. Increased water absorption and reduced cooking time.	(8)
Cheese	Rennet coagulation. Reduction in rennet coagulation of milk.	(9)
Jam	Commercial Production (Meiji-ya, Japan). Improved retention of color and flavor of fresh fruit.	(10)
Meats	Thawing. Reduction in drip loss and minimal color change	(11)
Meats, tenderized	Commercial production (Fuji Chiku and Mutterham, Japan). Improved retention of sensory characteristics.	(10)
Orange juice, fresh-squeezed	Preservation. Retention of color and cloud stability during storage.	(8)
Pink grape fruit juice, fresh-squeezed	Preservation. Retention of color and cloud stability during storage.	(8)
Pork sausage	Manufacturing. Moister, denser, and more tender sausages with more retention of color than if heat treated.	(8)
Potato	Freezing. Reduction in freezing time in potato cylinders	(8)

Product	Process and Quality Attributes	Reference
Rice paste with herbs (Yomogimochi)	Commercial Production (Japan). More desirable sensory properties than if heat treated.	(7)
Soya proteins	Manufacturing. Less firm but more elastic and extensible gels. Improved preservation of color and initial aroma.	(12)
Surimi	Control of Enzyme activity. Enhanced activity of transglutaminase in surimi with increased gel strength	(8)
Surimi,Pacific Whiting	Gelation. Increased gel strength in surimi.	(8)
Tofu	Freezing. Production of small-size ice crystals.	(13)
Tomato juice	Juice production. Modification of physical and sensory characteristics deemed desirable.	(8)
Yogurt	Storage. Reduced syneresis.	(14)

Most studies indicate that the beneficial effects of high-pressure processing of foods are evident only when applied pressures are above 400 MPa. Vegetative organisms such as fungi and mold are inactivated by pressures between 400 and 600 MPa. The cell membranes of these organisms are damaged by high-pressure processing, and they cannot reproduce. Once damaged, the cells are unable to control the transport of water and ions across the membranes, leading to collapse of the cells. However, under favorable conditions, the cells may repair themselves; for example, recovery was observed after 60 days of storage at refrigerated temperatures (Nadathur, *et al.,* 1997). Much higher pressures, greater than 800 MPa, are required to inactivate bacterial spores and a pressure of 408 MPa for 2 minutes was sufficient to achieve a 6-log reduction of APC, yeast, and *E. coli* in apple juice (Ting, 1998).

Food materials may be subjected to high pressures either as packaged foods or they may be processed in bulk. The advantages and disadvantages of these procedures have been discussed in the literature (Deplace, 1995). When foods are first packaged and then pressurized, either as liquids or solids, there is no danger of post-processing contamination. However, packaged foods require more complex handling procedures. The filling efficiency in a pressure vessel is generally 50 to 70%, because of the geometrical shape of the packages. In addition, considerable time is required for loading, unloading, filling, and venting of the vessel. Common packaging materials used are EVOH and PVOH.

With bulk processing, the batch method is more suitable for pumpable foods, because the handling of these foods is simple. After processing, the product can be packaged using a variety of packaging materials such as glass or metal. The vessel is more fully utilized (up to 90% with food material), and minimum time is required for loading and unloading. Furthermore, the vessel does not require opening and closing. This method can also be made semicontinuous with the use of multiple pressure vessels operated in a desired sequence. Often there is a need for aseptic filling to avoid post-processing contamination, and all contact between food and equipment components must meet aseptic standards.

Another interesting application of high pressure is to store food materials at subfreezing temperatures under high pressure without actually freezing the food (Knorr, 1998). The freezing point of water decreases with increasing pressure. Thus, a food under pressure may be kept at subfreezing temperature in an unfrozen state, minimizing the deleterious effects of ice crystal formation on food quality.

Because high pressure is transmitted instantly throughout a food system, the size and geometry of the object being treated is not as critical as in the case of traditional thermal processing (Knorr, 1998). In high-pressure processing, the need for size reduction may be eliminated, thus minimizing losses of nutrients and the consequent environmental pollution. Similarly, high-pressure processing offers potential advantages due to low-temperature processing. A significant reduction in the leaching of cell constituents from potato cubes when blanched under pressure was achieved compared with traditional blanching (Estiaghi *et al.,* 1994). In high-pressure processing, the gelling phenomenon in proteins is different from that obtained with thermal treatment. This uniqueness provides new opportunities to create desired functionality of engineered foods. The increase of membrane permeability achieved with high pressure can be effectively used in controlling mass transfer in many food processes such as frying, blanching, and dehydration (Estiaghi *et al.,* 1994).

As seen in Table 2, applications of high pressure processing include increasing the shelf-life of foods and creating unique structural changes in foods that provide benefit for desired functions. Many of these changes influence the quality characteristics of foods. At present, there is a lack of sufficient data to describe completely the mechanisms and kinetics of reactions that influence the quality of foods when they are processed under high pressure. These are topics of current and future study.

Pulsed electric fields

Similar to high-pressure processing, the beneficial effects of pulsed electric fields on inactivating microbial levels in foods have been known for several decades. The pasteurizing effects of electric fields in foods were first observed in the early 1900s. According to Beattie and Lewis (Beattie and Lewis, 1924), in electrically treated milk supplied to the city of Liverpool in England, the bactericidal effects of the treatment were due not only to heat that was generated, but also to the electric field itself.

During the 1960s, procedures were developed to create pores in cell membranes by subjecting cells to high voltage. A natural pressure gradient exists across cellular membranes, so that when a cell is placed in an electric field, the transmembrane potential increases. If the applied electrical field is more than a certain critical value, then the cell wall ruptures. While the complete mechanism of cell wall breakdown in an electric field is not clearly understood, this observed phenomenon is used regularly in creating pores in a cell membrane. The technique is known as electroporation, and it has been used in the field of biotechnology to introduce foreign DNA into a cell.

In another application, cells are fused together when placed in an electric field. A process called electrofusion has been used in the food industry to convert nonflocculant brewer's yeast to flocculant yeast (Knorr *et al.,* 1994). It has been shown that when wheat dough is subjected to 50 kV for 20 minutes, there is a decreased water loss during baking and increased shelf-life of bread (Knorr *et al.,* 1994).

Technical Considerations

The main components of a pulsed electric field (PEF) system are the high-voltage generator, switch, capacitor, and electrodes. The microbial inactivation in foods due to an imposed electrical field depends on the length of time the field is applied and the number of pulses. Several technical issues that are important in the industrial application of PEF have been noted (Zhang *et al.,* 1995). These include :

- Determining the optimum electric field strength for inactivating bacteria
- Provision to cool the food material that heats up due to Joule heating effect

- Dielectric breakdown in foods
- Proper selection of power and flow rates
- Operational safety issues.

Pulse Generation

A food material contains ions that make it a good conductor of electricity. When a large flux of electrical current flows through a food material, a high-voltage pulsed electric field is generated within the food. The electric current is allowed to flow through the food object for a very short period of time, on the order of microseconds. Therefore, a capacitor is needed to generate pulses. The capacitor slowly charges and then quickly discharges its stored electrical energy.

Two types of pulses have been considered for PEF applications, namely exponential decay and square pulses. An electrical circuit may be used to generate an exponential decay pulse (Zhang *et al.,* 1995) or a square pulse. In square pulses, the voltage increases instantaneously to a peak value, where it is held for some time before decreasing to zero almost instantly. With exponential pulses, the long tail section of the pulse is not effective in killing bacteria. On the other hand, it generates excess heat. Square pulses can maintain their peak voltage for a longer time than exponential pulses, and they generate less heat. Although the generation of square pulses needs more complex circuits, it is preferred for its advantages in food applications.

Research shows that structural changes in cellular membranes caused by about 1 V cause irreversible loss of membrane function (Sale and Hamilton, 1967).

While PEF is desirable for microbial inactivation, it causes undesirable arcing or dielectric breakdown in a material. Arcing occurs when the applied field strength becomes equal to the dielectric strength of the material. When a liquid food is subjected to PEF, any presence of vapor bubbles causes arcing. Gases or vapors have a much lower dielectric strength than do pure liquids. Any roughness of electrode surface also causes dielectric breakdown of the food material. Zhang *et al.,*1995 recommend considerations of the following points to avoid arcing :

- Using electrodes that are smooth
- Carefully designed treatment chambers to provide uniform electric field strength

- Degassing
- Pressurizing the liquid in the treatment chamber to prevent bubble formation.

Design of PEF Treatment Cells

Several different designs of PEF treatment chambers have been investigated (Qin *et al.,* 1996). A static chamber was used by researchers at Washington State University. The disk-shaped electrodes (area 27 cm^2) are made of stainless steel polished to mirror-like surface, with a gap that could be set at either 9.5 or 5.1 mm. Electric field strengths of up to 70 kV/cm could be used. Electrodes contain built-in jackets that allow circulation of water to maintain low temperatures. A modified version of this static cell has been used for continuous application. To continuously pump a liquid food through the cell, baffled flow channels were added inside the treatment chamber. A pulse width of 2 to 15 microseconds with a repetition rate of 1 Hz has been tested, and the flow rate of the test liquid food through this cell was reported to be either 1,200 or 600 cm^3/min.

In studies conducted with PEF systems, it is recommended that high electric field and short time pulses be used to minimize heat generation due to Joule heating effect. Otherwise, the benefits of PEF are lost due to thermal degradation of the treated food. There are operational problems with the use of monopolar pulses (Zhang *et al.,* 1995). Because many constituents of a food material, such as electrolytes, protein, and living cells, have a net electric charge, they tend to accumulate on the charged electrode surfaces. A shielding layer is therefore created on the electrodes that makes the electric field nonuniform. The undesirable shielding layers are prevented when bipolar pulses are used (Zhang *et al.,* 1995).

Applications of PEF Treatment in Food Processing

Recently, a PEF unit for treatment of fresh orange juice at a pilot scale has been described (Qiu *et al.,* 1998). This system involved a continuous pilot-scale PEF unit integrated with an aseptic packaging machine. The investigators used a 40,000 V/17 MWp high-voltage pulse generator with a multiple state co-field PEF treatment chamber. The aseptic packaging machine was used to package PEF-treated food under either nitrogen or sterile air headspace. The pumping system (Moyno pump) was used to transport juice at a uniform rate from 75 to 200 liters per hour. The pulse generator had a 40-kV command charging power supply. For switching, they used a 0 kV/5 kA hollow anode thyratron. The maximum repetition rate of the pulse generator was set at 1,000

Hz. The network could be changed to generate different pulse shapes, namely, square wave, exponential decay wave, and an under-damped RLC waveform. They used a set of co-field tubular treatment chambers with cooling capabilities. The diameter of the treatment zone was 0.48 cm, and the separation between the electrodes was set at 0.48 cm. The system was operated at 30ºC, and the feed flowed through 12 PEF treatment chambers. A system flow rate of 75 liters per hour was obtained, with an average of 3.3 pulses delivered to the feed stream in each cell. The authors concluded that the PEF treatment inactivated 99.9% of microbial flora, with the square waves being most effective. Compared with heat pasteurization, the PEF-treated orange juice retained more vitamin C and flavor.

As seen in the preceding example, the goal of many studies using PEF treatments is to extend the shelf-life of foods by minimizing spoilage caused by microbial growth. In these studies,

Table 3. Examples of foods processed using pulsed-electric fields and change in their quality attributes other than microbial

Product	Process and Quality Attributes	Reference
Apple Juice, fresh and reconstituted	Pasteurization. No change in solids concentration, pH, and vitamin C. Loss of Calcium, magnesium, sodium and potassium. No sensory differences between processed and untreated juices.	(1)
Commercial cheese sauce, reformulated	Preservation. Better flavor and appearance than comparable products	(8)
Green Pea Soup	Cooking. No difference in sensory properties after 4 weeks storage at 4°C.	(1)
Liquid Whole Egg	Pasteurization. Prevention of coagulation, superior quality	(8)
Orange juice	Preservation at pilot-scale. Less than 6% flavor loss, negligible vitamin C and color change.	(8)
Orange juice, fresh-squeezed	Pasteurization. Minimal loss of flavor compounds, color and vitamin C.	(8)
Salsa	Preservation. Better flavor and appearance than comparable products	(8)
Spaghetti Sauce	Aseptic processing. Acceptable after 2 years and 80°F storage.	(8)

the rate of microbial growth is a key parameter that is compared between foods treated with PEF or traditional technologies.

Some illustrative examples of foods treated with PEF are shown in Table 3. These applications are still under development stage. Considerable more research is necessary to obtain data on the effects of PEF treatments on the sensory properties as well as nutritional content of foods.

Pulsed-light treatment

Pulsed-light treatment involves the use of a flash of high-intensity light for the purpose of killing microorganisms on the surface of food or packaging materials. This procedure, developed under the trade name PureBright (PurePulse Technologies, Inc., San Diego, California, USA), uses a light spectrum containing wavelengths from ultraviolet to near-infrared. The light spectrum generated with this equipment is similar to that of the sunlight reaching the earth's surface. The peak of intensity is in the blue-violet region, and the PureBright spectrum contains wavelengths in the 200 to 300 nm, not present in sunlight reaching the earth's surface. Sunlight, on the other hand, has more radiation in the infrared region than PureBright. The intensity of PureBright is 20,000 times that of sunlight measured at earth's surface. The intense flashes of light produced by PureBright system are used to destroy microorganisms.

Equipment

There are essentially two components of the pulsed-light system, the power unit and the lamp unit.

The power unit is used to generate high voltage. The resulting high-current pulses are then employed in the lamp. First the AC power is converted to high-voltage DC power, which is then used to charge a capacitor. After the capacitor is charged to certain voltage, a high-voltage switch discharges the capacitor into a lamp. The system is properly contained to protect personnel from high voltage. Cooling water is used to minimize any heating of the treated product.

The treatment unit has one or more inert gas lamps. When a high-current pulse is applied to the lamp, the gas in the lamp emits an intense pulse of light. The frequency of flashing, number of lamps, and flashing configuration depend on the treatment application.

Monitoring Controls

Monitoring of the lighting system is extremely important to ensure that the treatment area is properly treated. The PureBright system uses two types of diagnostic monitors, the lamp output (fluence) and the lamp current. Fluence is the measure of incident light energy per unit surface area (J/cm^2). The lamp fluence is measured to ensure that the lamp is producing sufficient ultraviolet fluence to inactivate microorganisms. This is accomplished with the use of a silicon photodiode that detects whether the lamp has the required output of ultraviolet light. A decreasing output would signal that the lamp needs replacement. This control is also necessary to shut down the operation in case the objects do not receive treatment above some predetermined threshold level.

A second monitoring control used in the PureBright system measures the lamp current for every flash. The current level is an indication of the intensity and spectrum of radiation. If the current level falls below a preselected threshold, the operation is shut down.

Operating Procedures

The PureBright system involves illuminating the desired treatment area with 0.1 to 3 J/cm^2 per flash, with total accumulated fluences of 0.1 to 12 J/cm^2. The flashes are applied at a rate of 0.5 to 10 Hertz, generally for a duration of several hundred microseconds. This type of system has been used for treating packaging materials.

Applications of Pulsed Light System in Food Processing

Results indicate that application of pulsed light can reduce up to 9 logs of vegetative microorganisms and more than 7 logs of bacterial spores on smooth, nonporous surfaces such as those of packaging materials. When the surfaces are more complex and porous, such as in case of food materials, then the microbial reduction is only 2 to 3 log cycles.

The pulsed light systems use only the surface of the product being treated. Any photoproducts produced due to this treatment are much fewer than those produced by thermal treatments, thus minimizing product degradation. Extension of shelf life of various foods such as bread, shrimp, and meats has been reported (26). Pulsed light is effective for treating water, because water is transparent and permits penetration of light. The reported costs of equipment amortization, lamp replacement, electricity, and maintenance indicate expenditures of only a few tenths of a cent (U.S.) per square foot of treated area (Dunn *et al.,* 1995).

Oscillating Magnetic Fields

Published studies in the literature show contradicting results on the inhibition of microorganisms when placed in oscillating magnetic fields (OMF). Some studies indicate that magnetic fields have an inhibitory effect on the microbial population, while others note no effect or in some cases even a stimulating effect. Mechanisms describing these observations are under scientific inquiry. In one study, foods with high electrical resistivity were placed within a magnetic coil in an apparatus and subjected to one or more pulses of OMF with an intensity of 2 to about 100 Tesla and a frequency of 5 to 500 kHz (Hofmann, 1985). It was observed that a single pulse of magnetic field generally decreased the microbial population by at least two orders of magnitude. OMF involves little thermal energy input, thus avoiding thermal denaturation of food constituents during treatment. However, more research is needed to understand the changes in microbial population and other constituents of foods when treated with OMF.

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POSTHARVEST TECHNOLOGY IN THE FOOD SYSTEM

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INTRODUCTION

Throughout the history of mankind, food security has been a challenging issue. Over the last century, the rising demand for food due to the increased population has been met by different measures to varying degrees of success. Larger areas of land have been brought under the plough in combination with increased productivity using high yielding varieties, increased inputs and better management techniques. Consolidation of the produce with postharvest management practices developed alongside, but at a slower pace than the thrust for production. Over the years, the decreasing marginal returns from the inputs of production have shifted the direction of food security towards postharvest practices. Better management, storage, preservation, product transformation and value addition have been increasingly under focus. The changing nature of global agriculture from subsistence, local market-oriented approach has also forced the players to pay more attention towards maximizing the returns through diversified products and practices. Throughout the world, the importance of postharvest technology is being realized more and more. The field has grown over the past few decades and the research and development efforts continue to shape the agri-business to the needs of the global market.

Historically, many fundamental postharvest practices have been practiced in different parts of the world. Form conversion of agricultural produce for longer storage and palatability is a common practice. However, the enormous potential of postharvest technology in agri-business is being realized only lately.

The 1990s were turbulent years in the recent history of mankind when the world changed radically over a short period of time. Economically, the dismantling of market barriers in many parts of the world due to either the weakening of the USSR or the relaxed communist policies of China, lead to the creation of a new environment that is dominated by capitalist forces. The cascading effects of this new global regime have been felt in almost all facets of life. New markets with enormous purchasing power opened up for private enterprise and reduced restrictions for movement of capital encouraged foreign investment worldwide. The vigorous pursuit of wealth since then has resulted in an economically stratified society. The broad spectrum of consumers has the über rich, highly discerning segment at one end and the economically deprived at the other, who have nothing to claim except human capital. In countries like India, there lies in-between a huge chunk of "middle class" – a vibrant component of the consumer profile that exerts a very powerful influence on the nation's economy, often steering to set new paths and destinations.

The sweeping economic changes have had their impact on the lifestyles and food habits of the people world-wide. The general trend is to desire for quick–to-prepare, ready-to-eat, healthy foods. As the income level rises, there is a tendency for the consumers to move away from staple foods and obtain the nutrients from wholesome or fresh products. Similarly, in the developed countries, people prefer the availability of exotic and seasonal agri-products throughout the year. Year-round demand for fresh produce is still evolving in the less developed and developing countries. Seasonal agri-produce is released into the domestic markets soon after harvest, causing gluts. Hence there are narrow but non-lucrative windows for marketing the produce locally.

In the face of such conditions, the producer has to look for alternative markets and marketing strategies. Traditional agricultural approaches are no longer sufficient or appropriate to perform satisfactorily in the business. Efficient postharvest management of the produce, processing and value addition are the means by which profitable solutions can be formulated.

The global perspective of postharvest technology can be considered for its different components – Research and Development, Education (awareness and adoption) and Institutional support (government policies). Of these, research and development has gained more attention over the recent past while the dissemination of the results among the beneficiaries is gaining ground slowly. Most developed nations are far ahead in the aspects of value addition compared to the less developed and developing countries. The governmental policies also mirror this state of affairs in different parts of the world. It is a perplexing paradox in some nations where it is hard to identify which should come first – governmental policy or field awareness.

Research & Development

Research in the area of postharvest technology has different priorities in different parts of the world. Significant work has been done and adopted by the producers in the US and Canada where the severe winters restrict the growing period. Due to the demanding climatic conditions, technological solutions have been developed to utilize the harvest throughout the year by the means of effective storage and transportation techniques.

Drying of grains is a common practice in the US and Canada. However, it is not very effectively utilized in Asian countries. The humid conditions often are not conducive to economical drying and loss of grains during storage is quite common. However, the efforts in the West to economize drying could hold promise to the Asian scenario. Use of heat pump dehumidifiers to recover the latent heat from dryer exhaust stream and hence reduce the energy cost is being pursued in many parts of North America. Heat pump dehumidifiers have been commercially employed for drying of various agri-food products in Europe. The same technology can be beneficially utilized in Asian countries for drying of grains with the enthalpy in the humid air. On the other hand, some of the traditional and indigenous techniques of the developing countries are being applied in North America. Use of particulate media for heat transfer in thermal processing is one of the finest examples. Which ever the technology, the emphasis is on effective utilization of the energy input by efficient heat and mass transfer as well as reduction and recuperation of waste heat. Western technologies try to be eco-friendly with less dependence on fossil fuels and reduced emissions. In the developing countries, the technologies need to be self-sustaining as well.

Form conversion is the major value addition in the sector of food grains. Drying, though a method of preservation could be considered as value addition from the perspective of the producer. Food grains are converted into flour, semi-processed products such as parboiled rice, and processed food products such as flakes, pasta and puffed rice. Western markets have developed over the years to support such agri-processing industry. A large proportion of the grain purchased and consumed in North America is in the form of processed foods. Conditions are developing in other parts of the world for similar systems and India is a good example. With less time available for food preparation, the consumers prefer to purchase semi-processed and processed foods including staple foods. This huge, promising and remunerative market needs to be tapped by the agri-processing industry.

Processing of fruits and vegetables is a weak area for most of the leading producers such as China and India, which along with Brazil account for almost 30% of world fruit production. Due to specialization in citrus fruits, Brazil do minates international trade in frozen orange juice concentrate. On the other hand, over half the vegetable and fruit consumption in developed countries is in the processed form, and the demand keeps increasing, especially for exotic or foreign foods. Hence there exists an enormous potential for the processing industry to perform well.

With global integration of the fruit and vegetable trade, the demand for year-round supply of seasonal perishable products is increasing. Significant technical expertise in postharvest technology is essential for exploiting the huge horti-produce markets opened up by the new trade agreements. Ability to store the produce longer and transport it over longer distances has been strengthened in many fruit exporting nations of the West. A continuous cold chain coupled with modified and controlled atmosphere storage techniques has enabled the producers and marketers to increase the storage life of products from two weeks to eight months for different products. The R & D efforts in these parts are focused on reducing the energy, material and handling costs to make the business more profitable.

However, in many tropical countries, cold chains for horticultural products are patchy, if not non-existent. India, for instance, has a well developed cold chain system for milk but not for agri-products in spite of being one of the major producers of fruits and vegetables in the world. The market for the products has been mostly local with a large percentage being lost or wasted. Energy and capital costs are the major constraints for establishing an efficient cold chain. The solutions in these parts of the world have to come from innovative and indigenous methods. For instance, evaporative cooling based storage chambers could be used in tropical countries for precooling on field, which is the first link in a cold chain. The rapid removal of field heat itself can extend the life of the product significantly and is a simple but effective value addition process.

Many years of research have gone in to the development of controlled and modified atmosphere storage techniques and the success is being enjoyed by many producers in countries like the US, Canada, Australia and New Zealand. These techniques are still being tried out in the labs of many other parts of the world. The research is being carried out using membranes and diffusion channel assisted storage for different exotic products. However, there is a different dimension to research in this area. Having discovered the advantages of the techniques, the next step is to search for similar materials that are cheaper and more easily accessible. Selection of the material, study of its properties and subsequently, its suitability for use in storage are to be explored. Even in the West, where membranes are used for large scale storage, the quest is for a design where the material could be used for small packages, even individual units, and recycled economically.

Most of the R & D efforts in future will have to be carried out in the light of the advances in biotechnology. Genetic and biotechnological manipulations can be used to develop products with desirable characteristics. High quality, longer storage life, delayed ripening, a chemical profile that suits processing, resistance to diseases and spoilage etc. are some of the postharvest related changes that could be brought about by the application of biotechnology. Modifications can be done to control undesirable physiological processes such as chilling injury to mangoes or browning of fruits as well as ensure a closer match between product and processing requirements, such as the development of characteristics in wheat more suited to manufacture of pasta.

Education and Institutional Support

The burning importance of postharvest management and food processing for value addition is yet to be realized by many of the potential beneficiaries. In case of India, after years of success in increasing production during the Green Revolution, the gains are being consolidated slowly. Yet, the awareness of fundamental postharvest management principles is lacking in the general farming community. The agents of change, the government departments as well as the agricultural universities are not geared to move in this direction and the required changes are coming about gradually. The benefits of value addition and food processing are also not well impressed upon the domestic enterprises. Hence, most of the large units that are involved in this sector are multinational firms with large capital absorbing capacities.

Human resource development at all levels is one of the key approaches to bringing about satisfactory consolidation of food security. Beginning from the curricula in the universities right up to training the staff in government departments, the importance of postharvest management needs to be inculcated for effective results on the field.

Integration of postharvest principles in educational curricula, training of university staff at all levels in research, teaching and extension, Agricultural Extension activities, farmer and industrial entrepreneur training programs as well as consumer education is essential for broader realization of food security. Management Institutes also need to address the issue by inculcating the subject in their curricula.

The wheels can be put in motion only by institutional support. Government policies and support are essential for the benefits to influence the national economy. Similarly, the financial institutions also need to support the cause by adopting policies sympathetic to the human enterprise. Some of the steps taken by the Government of India in this direction are very encouraging. Quality and safety are the key areas that need regulation, especially in the export market. Policy guidelines and regulatory mechanisms have to evolve to respond to the global situation.

Levels of Food Security

The problem of hunger and nutritional security can be visualized at different levels in scale, each varying not only in the magnitude but also in the factors influencing the management. At the bottom, the problem appears at the household level in both rural and urban areas. Food is grown by individual farmers mostly for sale and partly for consumption by themselves. Moving up, the problem appears at the village level, wherein community action becomes necessary to tackle the operational challenges. The next dimension is a slightly complex one, involving densely populated urban centres linked with rural production areas for their food supply. And finally, the problem appears at the national level where the solutions are linked to government policies and macroeconomic factors.

Household food security

Prolonged storage of cereals, grains and horticultural crops for subsistence consumption is the main challenge at the household level. In case of subsistence farming, all or most of the produce has to be stored till the next season as well as a buffer stock needs to be maintained for emergency situations. With commercial farming, a part of the stock is needed for consumption at home. In the latter case, small farmers are under pressure to market a major share of their produce in order to meet their economic commitments and often, a lower grade of the produce is retained for self, thus increasing the risk of spoilage of the food stock.

Indigenous storage methods have been followed by people in different parts of the world to store food products. Most of these techniques are disappearing over time; it is a matter of great concern as not many of the indigenous technology practices have been scientifically studied and documented. These techniques need to be evaluated in the light of the current understanding of modern storage principles and refined, if necessary. Underground storage of tubers and grains in sealed chambers, a storage technique based on modified atmosphere, can be traced back to the early pyramids in Egypt. Well sealed underground pits are still used in parts of India for storage of grains. Standardization of the techniques aided by scientific studies and their documentation is required to popularize their widespread adoption. Traditional and indigenous material such as earthen pots, rattan baskets, plant leaves and coconut fibre used in storage structures have favourable aeration properties that need to be scientifically described and standardized. Similarly, the shapes of some of the indigenous containers need to be modified to suit modern transport and storage requirements. Simple and inexpensive devices to reduce pest infestation have been developed in some parts of the world and these are found to be more effective at the household storage level. The devices exploit the physiological and behavioural features of the pests to contain them in reusable traps. Along with physical methods, biochemical control of pests with the application of biological extracts is also being studied. Use of active components from neem is one good example. There are various other underutilized plant material that could be safely mixed as well as separated from grains for pest control and subsequent consumption. These are used as powders, tubers, tablets and extracts. Physical methods of control such as storage under layers of sand, coating of pulses with soil, oil etc. have also been developed for pest control.

Food processing and preservation on a small scale in the form of drying and osmotic treatments are well placed for household nutritional security. Preservation of excess perishable produce by drying is a well known technique. However, the use of dried products in the diet may not have been traditionally established and hence not followed in some societies. In these cases, utilization of the excess food as well as the easily available energy resources should be encouraged by introducing the novel products for consumption. Converting roots, tubers, cereals and pulses into flour is another common food processing operation on a small scale. In some parts of the world, further processing to produce dry ready to eat bread (eg. Sorghum breads in South India) is also practiced with great success. Fortification of such flours or breads with other ingredients such as minor millets, vegetables and herbs could be effective in enhancing the nutritional status of the food by providing micronutrients.

Village Level

Use of mechanical equipment for postharvest operations is not an economically viable option for small-scale, household level, even though there are some health benefits in the form of reduced drudgery and better quality of food produced. In developing countries, strategies that involve community and cooperative action have been successful to a large extent in fighting economical and social problems. Ensuring food sufficiency at village level requires dealing with the combined resources at that level to ensure the supply. Use of mechanized equipment, refrigerated storage, improved transportation containers etc. for storage and processing of the produce can be implemented by communities for efficient use of the local production. One of the major problems in South Asia is the harvest of the late crop during rains when the relative humidity is high. Mold-induced spoilage and loss in quality is a serious problem with rice, sorghum and green gram in parts of India, Philippines and Vietnam. Harvesting of grains at physiological maturity and subsequent artificial drying using heat pump dehumidifiers is a solution that requires high initial investment for individual producers for modest land holdings. Community and cooperative ownership would be helpful in solving the problem of high initial investment as well as the operating expenses, besides making the exercise economically feasible. Application of low-cost technologies such as solar drying, underground and cellar storage can also be practiced at this level more effectively with sharing of resources. Some aspects of food safety such as hygienic processing can be better practiced at a village level. Use of closed cabinet solar dryers, storage of unthreshed grain in improved storage structures to protect them from pests, use of mechanical threshers and decorticators, graders, attrition mills to produce flour etc. are some of the postharvest operations that become more economically viable in such cases.

The Urban market and its supply network

Throughout the world, rapid urbanization has lead to the development of dynamic relationships between the urban, peri-urban and rural areas. Urbanization has created a wider consumer spectrum that adds to the complexity of food requirements. On one hand there is a teeming mass of urban poor who live under very challenging conditions, barely able to sustain their livelihood, and then on the other, there is a miniscule percentage of discerning consumers who demand a wide range of characteristics in their food. In between, there is a fast growing middle class that has created demand for ready-to-eat and convenience foods that are also nutritious and healthy.

There is no doubt that urbanization has encouraged the growth of food processing and value addition and hence, a wide range of postharvest technology practices in agriculture. However, the cascading effect of such development on the rural poor has not been as expected. Most of the major food processing units are situated in the urban areas, a trend that has contributed to the growth of the cities. Even though the rural agricultural sector has supplied the raw materials, it has not benefited much from the value addition industry. Unless the rural population is actively involved and is benefited directly from the processing operations, the imbalance in food sufficiency will continue to grow. Partial value addition such as grading operations, conversion of grain to flour, preparation of semi-processed material (eg. Dough for bread making, cut vegetables, fruit pulp), packaging of minimally processed horticultural products etc., should be located closer to the production areas in order to provide employment and access to food, required to achieve food sufficiency. Lack of infrastructural facilities such as electrical power, water supply and technical support services are often the drawbacks that shift the location of the industries to the urban fringe. In places such as India, there is a growing awareness among the people about income-generating opportunities in food processing sector that is being translated into small-scale industrial operations. However, village-based processing activities need good HRD programs to support effective management and marketing.

Transportation and handling losses are enormous (20-45%) in the horticultural products supplied to the urban market from rural areas. Often, these losses could be reduced to a large extent by spreading awareness among the workers who handle the material at different stages of transit (Fig. 1). Proper packaging of the material, loading, stacking in the vehicle, use of good cover and insulation in the vehicles used for transportation, gentler unloading and heaping at the market and use of shades could result in appreciable reclamation of the produce that is otherwise rejected due to physical damage. Human resource development is a very essential factor in achieving food sufficiency through postharvest management, and education of the workers at different levels of the food supply chain is a tool to work in that direction. Concepts such as rapid precooling soon after the harvest, gentler handling of the produce, use of appropriate containers for transportation, shade and film covers to reduce water loss etc. should be understood and followed by the producer. Periodic cleaning of storage structures and containers to prevent incipient contamination during off season is a healthy practice for ensuring food safety and reduction of pest-related losses.

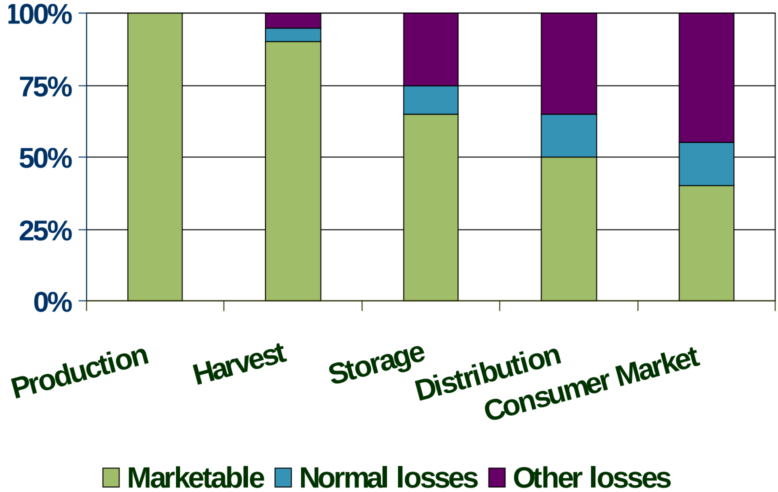

Figure 1. Typical postharvest losses

National Level

The last two decades have seen enormous changes in the world political order. The stable but apocalyptic calm that existed under two distinct blocs have given way to a rather chaotic but optimistic uncertainty that is passing around the globe. The greater shift towards free market has brought a mixed bag of results. However, the role of governments and their policies are extremely important in the fight against hunger. While the macroeconomic policies influence the quantity of food availability, the social policies affect the distribution among the needy.

Growing world trade in food grains has influenced the diet and food demand in developing countries. During 1995-97, almost 9% of the cereal consumption in the developing countries was obtained from food imports or aid. However, there is a growing realization that traditional crops that are well suited to the tough growing conditions can play a defensive role in the fight against hunger. In many parts of Asia and Africa, research into the innovative use of traditional food products from Sorghum, millets, yam, sweet potato and cassava has shown that these products can contribute handsomely to nutritional security. These products can help achieve sustainable livelihoods through household food security by improved home-based processing and storage practices. Traditional foods also add nutrients as well as variety to the diet and have the potential to be ideal convenience foods for lower income groups of urban populace. But increasing imports of staple foods due to globalization and international trade have seriously affected the chances for traditional foods. The traditional foods will have to compete with the imports which set the price ceiling. Only foods that have unique characteristics will enjoy support in a supply-demand equilibrated market.

Maintenance of buffer stocks and public distribution systems are two common characteristics among the developing nations. Despite the garb of free market economies, farmer subsidies continue to be issued in almost all parts of the world in one form or the other. In case of countries with different degrees of socialistic leanings, the public distribution systems continue to make food available to the needy millions at affordable prices due to government intervention. However, the food collection and storage systems of almost all of these countries suffer from poor postharvest technology management. Recently, it was reported that more than 233 million people in India suffer from hunger even though the country has been maintaining impressive buffer stocks for over two and a half decades. The lack of efficient storage, monitoring and decision making systems in the postharvest sector lead to the wastage of a large percentage of the food grains grown in the country. National governments are in a very strong position to adopt modern postharvest storage and management technologies to consolidate the food production and ensure food sufficiency. The awareness and implementation will provide a major boost to the efforts being put in at the lower levels.

Post-harvest handling of horticultural products

Proper storage is an important part of the marketing and distribution of horticultural commodities. The storage of produce has two main objectives: 1) to provide short-term storage to balance the daily fluctuations of supply and demand, and 2) to provide long-term storage to extend the marketing season. Three factors involved in the deterioration of perishable commodities must be controlled to meet these objectives. The natural rate of respiration must be reduced as much as possible by controlling temperature and, for many commodities that respond positively to low O_2 and/or high CO_2, the composition of the storage atmosphere. Moisture loss should also be minimized, and pathogenic micro-organisms not be permitted to proliferate. Storage facilities may also be used for special treatments, such as the curing of potatoes or the de-greening of oranges prior to shipment.

There are many technologies available to create and maintain optimal temperature, relative humidity and atmospheric composition for harvested horticultural products. This is partly due to the differences in recommended storage conditions over the range of products that are marketed as fresh, a partial list of which is given in Table 1. The choice of system is therefore a function of the range and type of products to be stored in a given facility, the volume handled and a number of other factors that will be explained in the major sections of this chapter: pre-cooling, cooling and refrigeration, and modification of atmospheric composition.

BACKGROUND

Temperature

Temperature is the single most important factor affecting the deterioration rate of harvested commodities [Kader, 1992]. The rate of deterioration is proportional to the respiration rate of the commodity, and the respiration rate is temperature-dependent. For each 10ºC reduction in temperature, the respiration rate of a wide range of produce can be reduced by a factor of 2 to 4 [Wills *et al.,* 1998]. Moreover, the activity of post-harvest pathogens and insects is also suppressed by low temperatures. Therefore, cooling and refrigeration are important for preserving the quality of fresh fruits and vegetables and in extending their storage lives.

The ideal storage temperature varies from product to product, and the temperature maintained in the storage area should be within 1ºC of that level [Wills *et al.,* 1998]. Lower temperatures may cause chilling injury and higher ones will reduce the storage life of the product. The refrigeration unit must be able to handle the maximum refrigeration load that is expected. If the load is too great for the refrigeration unit then the temperature will rise. There should also be sufficient air circulation to keep the product at a uniform temperature and to prevent condensation, thus, uniformity of airflow around all of the produce is an important design consideration. Flow rates of 0.06 to 0.12 m^3/min of air per metric ton of product are generally adequate [Wills *et al.,* 1998].

Temperature may be controlled by placing thermostats in positions that represent the effective cooling temperature. They should not be placed near sources of heat or cold, such as doors, exterior walls, or air discharge areas of the cooling unit.

The timing, degree and type of cooling that can be used depend on the commodity to be stored and its end use since there are important differences in composition and physiology among the fruit and vegetables species used as foods. For example, leafy vegetables are cooled soon after harvest to maintain turgor, whereas tubers (potatoes, yams, sweet potatoes) are not. Potatoes, for instance, are held at 15 to 25ºC for up to 15 days to permit suberization [Dennis, 1984]. Many commodities are susceptible to chilling injury (eg. banana, cranberry, cucumber, green pepper and tomato), whereas others are sensitive to high CO_2 levels (pear, lettuce). Chilling injury can result in several sources of postharvest losses, including: surface lesions, water-soaking of tissues, internal discoloration, breakdown of tissues, failure to ripen normally, accelerated senescence, greater susceptibility to decay, and compositional changes [Morris, 1982]. Tropical and subtropical fruits are more likely to experience chilling injury than temperate climate produce.

Relative Humidity

Relative humidity is another important factor for the long-term storage of perishable commodities. Low relative humidity will allow excessive moisture loss from the produce, resulting in quality loss. The recommended humidity level for the storage of fresh fruits and vegetables is commodity specific, but the levels are generally in the range of 85% to 95%. Wilting and shrivelling are likely to occur in most vegetable crops when stored at low humidity. However, relative humidity close to 100% can be ideal for the growth of micro-organisms and can cause surface cracking in some produce [Wills *et al.,* 1998].

Atmospheric Composition

The deterioration of harvested produce can further be reduced by limiting the available oxygen in the storage atmosphere, usually combined with higher carbon dioxide levels (Fig. 2). This can be done by active means (controlled atmosphere storage, or CA), or by passive means (modified atmosphere storage, or MA). It is generally accepted that limiting the O_2 supply reduces the respiration rate by approximately 50% at temperatures of 20 to 25ºC [Raghavan *et al.,* 1996]. If the product is refrigerated, the additional reduction due to low temperature is approximately 24%. These are equivalent to storage life increases of 100% and 33%, respectively under the two temperature regimes [Raghavan *et al.,* 1996]. Higher CO_2 concentrations in the storage enclosure can also inhibit the respiration mechanism, however some commodities are sensitive to higher-than-ambient CO_2 concentrations and can develop off-odours, discolouration and other disorders [Raghavan *et al.,* 1996]. Therefore the type of system used to provide optimal conditions is dependent on the commodity. Finally, the control of ethylene (C_2H_4), a plant growth regulator involved in ripening and senescence, is an important consideration in the storage of certain commodities.

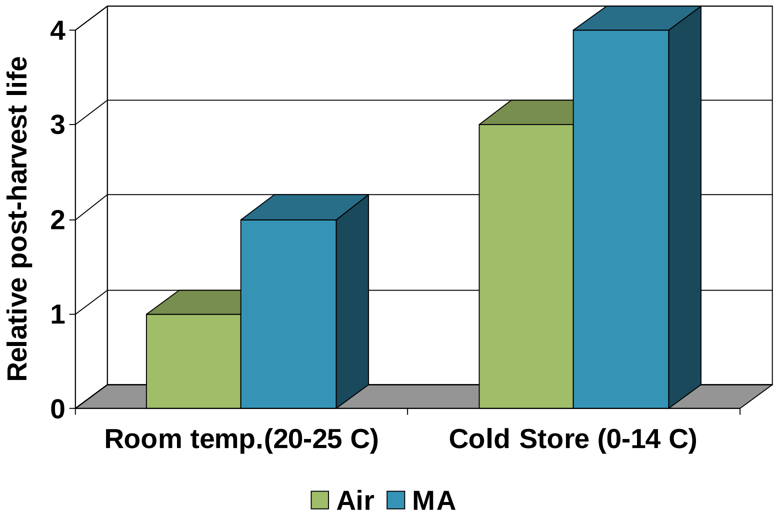

Figure 2. Advantage of modified atmosphere storage

PRE-COOLING

Cooling is the process of removing heat. The rate of cooling of a product is often referred to its 1/2 cooling rate. The 1/2 cooling rate is the time required to reduce the difference between the mean temperature of the product and the temperature of the cooling medium by one-half. It is expressed as a constant for a particular set of precooling conditions. Reduction of the temperature difference by 7/8 is usually three times that referred to as the 1/2 cooling rate, and is often used as a commercial standard for the total time of cooling.

The sooner produce is cooled down, the better its chances at a relatively long storage life. Some fresh fruits and vegetables may deteriorate as much in one hour at 26ºC as in one week at 1ºC [Boa and Lindsay, 1976], particularly if they have naturally high respiration rates. The distinction between pre-cooling and cooling is that pre-cooling refers to any method of removing field heat more rapidly than if the produce were simply placed in a storage chamber set at the desired temperature and allowed to cool.

Pre-cooling can significantly extend the storage life of fresh fruits and vegetables, particularly when large quantities of produce harvested in warm temperatures are involved. In many situations, the bulk could take several days to cool down to the final storage temperature if alternative means are not used.

Hydrocooling

Hydrocooling is the cooling of produce with cold water. This method is very effective for a wide range of products. Some hydrocooling facilities can handle up to 30 000 crates per day during the peak season [Ashrae, 1986]. One of the advantages of hydrocooling over other methods is that the commodity does not lose moisture during the process [Sargent *et al.,* 1991]. There are two methods of hydrocooling : 1) immersion in a cold water bath, and 2) shower cooling [Wills *et al.,* 1998]. Immersion systems are continuous flow and are most useful for products that have a higher density than water and therefore remain submerged [Thompson, 1995]. Lower density produce such as cucumbers, squashes, and tomatoes is cooled by flotation in circulating water. However, when the produce is immersed in cool water, the air contained inside some commodities decreases in volume, creating a suction pressure which may facilitate the entry of pathogens into the tissues. It is therefore important to ensure that the circulating water is and remains clean.

Shower coolers involve overhead spraying of the produce with cold water and may be batch or continuous (Fig. 3). The water is either pumped onto an overhead perforated pan and allowed to drip on to the produce or it is showered through spray nozzles. When water is applied from overhead, the distance the water falls before hitting the produce should be kept below 15 to 20 cm [Thompson, 1995]. Drop heights that exceed this range can damage some produce.

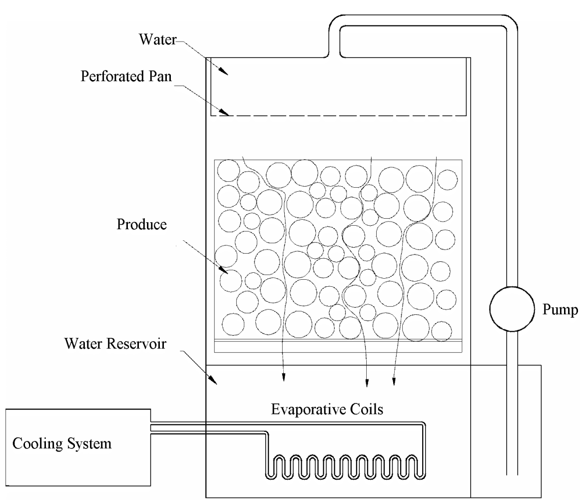

Figure 3. A typical showering hydrocooler

In a batch operation, palletised containers are placed in a room and water is sprayed from the top. For shallow product depth, the water should be provided at a rate of 280 to 490 L/min per m^2 (litres per minute per meter squared) [Thompson, 1995]. The water is collected in drains on the floor or in an underfloor reservoir, cooled and then sprayed on the produce again. This cycle continues until the precooling is finished. If this is done in a refrigerated room, the produce may be stored for a short time in the same room after the precooling operation [Ashrae, 1986].

In a continuous flow shower system, the produce is transported on a conveyor. The time that the produce spends in the hydrocooler can be adjusted by changing the conveyor speed. Water is sprayed on the produce from overhead.

The water must be sanitised, especially if it is reused. It should be taken from a clean source, either a well or a domestic supply [Thompson, 1995] and should be disinfected by adding chlorine to the extent that the free chlorine level is 100 to 150 ppm [Sargent *et al.,* 1991]. The water should be drained out of the hydrocooler at least daily and the system sanitised. Extremely dirty products should be washed before hydrocooling to decrease the amount of dirt that enters the system.

Water used for hydrocooling is generally kept between 0 and 0.5ºC using mechanical refrigeration [Thompson, 1995]. Produce that is sensitive to chilling injury may be cooled in water at 0ºC as long as the cooling time is limited [Thompson, 1995]. Ice is often used to assist the mechanical refrigeration system [Wills *et al.,* 1998] and is usually added to a water tank to cool the water or is used in an ice-accumulator refrigeration system. Financial costs for energy can be reduced by building the ice supply during off-peak hours and using the ice for cooling when the energy costs are high.

Hydrocooling is suitable for bulk or packaged produce. It is commonly used for melons, root vegetables, stem vegetables and many types of tree fruits [Thompson, 1995]. Commodities that are hydrocooled must be tolerant to contact with water and to the levels of chlorine in the sanitised water. Commodities such as grapes and most berries must be ventilated after hydrocooling to remove surface water which can otherwise encourage decay [Thompson, 1995].

Contact-icing

One of the oldest and simplest cooling methods is contact-icing, a method which is well-suited to produce that is tolerant to long periods of cold (0ºC) wet conditions [Wills *et al.,* 1998]. This involves filling packed containers or pallets with ice or covering pallets with ice. The contact between ice and produce causes rapid cooling. In general, reduction of product temperature from 35ºC to 2ºC requires a mass of ice equal to 38% of the product weight [Hardenburg *et al.,* 1986].

There are several different methods of filling the containers with ice. Individual package top icing is the simplest method. Ice is shoveled, raked or blown on top of the product in the container. Cooling by this method is rather slow since the ice is only in contact with the top layer [Sargent *et al.,* 1991]. It is not efficient for large operations due to the amount of labour involved in opening the containers, adding the ice and then closing the containers. The coating of ice may block vent spaces, thereby restricting air movement and leaving the centre of the load warm [Sargent *et al.,* 1991]. Individual package top icing should be used only after precooling and prior to shipping, to assist in cooling and in maintaining high relative humidity [Sargent *et al.,* 1991].

An improvement to top icing is pallet box icing by layer. This method of icing is more labour intensive than top icing but the cooling is faster and more uniform [Sargent *et al.,* 1991]. Crushed ice and produce is alternately layered in the pallet box. Thus, the produce is better surrounded by ice and cools faster.

Liquid-icing provides much faster cooling than individual package top icing. A slurry of cold water and ice is either drenched over the pallet of produce or is pumped into the containers through the hand holds (Fig. 4.). The water slurry causes the produce to float until the water drains out the bottom of the container. As the water drains out, ice is distributed throughout the container. This method creates very good contact between the ice and the product, resulting in good heat removal. The cold water of the slurry has a substantial effect on the cooling of the product. It has been shown that the cold water can contribute up to 40% of the cooling effect on broccoli [Boyette and Estes, 1992].

A greater financial investment is required for liquid-icing than for the other methods of contact-icing. Equipment includes an ice crusher, a slurry tank with mixer, a pump and delivery hoses. With the manual equipment, two workers can liquid-ice a 30-container pallet in 5 minutes [Boyette and Estes, 1992]. Automated systems exist which can process five times more produce within the same time, but they are expensive and require power. Recently, smaller scale systems have been developed to process 200 containers per hour with power requirements of only one fifth of that required by automated systems [Vigneault *et al.,* 1995].

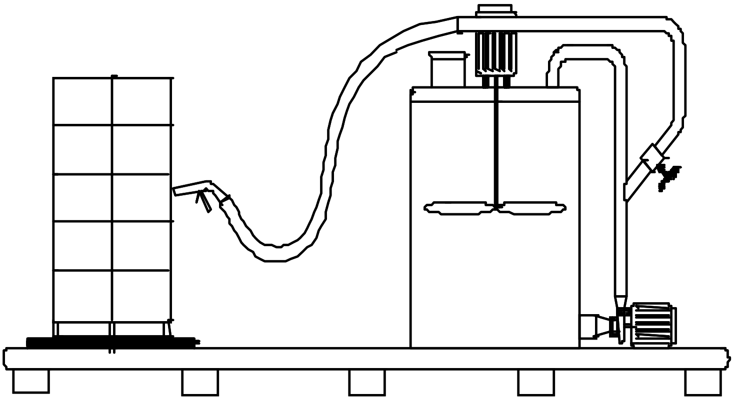

Figure 4. Injection of liquid ice in palletized containers

Careful container selection is necessary if contact-icing is to be used. The containers must be water resistant and large enough to accommodate the amount of ice required to cool the product. Waxed fibreboard cartons are acceptable for contact icing since they have few openings and provide some insulation from the surrounding environment, however, they do not retain their strength over long periods of time when wet [Boyette and Estes, 1992]. Reusable plastic containers were specially designed for uniform ice distribution, ice retention, and resistance under very wet conditions [Emond and Vigneault, 1998].

The ice that is to be used for any type of ice cooling should be no larger than 9.5 mm so that the ice particles can fill the voids between the produce [Boyette and Estes, 1992]. Small particles of ice are less likely to damage the produce than larger ones. Furthermore, ice particle sizes ranging from 4.5 to 5.1 mm used for liquid-ice systems provide the most uniform ice distribution and greater icing efficiency regardless of container type [Vigneault *et al.,* 1995]. The equilibrium temperature of a slurry of melting ice and water is 0ºC [Gast and Flores, 1991] and 335 kJ (316.8 Btu) of heat are required to melt 1 kg (2.2 lbs) of ice.

Vacuum Cooling

Vacuum cooling is one of the most rapid cooling methods. This method is suitable for produce that have large surface area to mass ratios and easily release water. Commodities such as lettuce, sweet corn, celery, green beans and mushrooms can be cooled in 20 to 30 minutes. Vacuum cooling is recommended for leafy vegetables such as lettuce since the overlapping leaves create insulating air pockets that reduce the efficiency of other cooling methods. The main drawback of vacuum cooling is limited capacity due to space and vacuum requirements. Vacuum cooler capacities range from 4 to 20 pallets per batch [Wills *et al.,* 1998].

Produce is placed in an air tight chamber and the pressure in the chamber is decreased to the point that water boils at the desired cooling temperature. For example, a pressure of 0.610 kPa (4.6 mm Hg) permits water to boil at 0ºC [ASHRAE, 1986]. Since the energy needed for the phase change of water from liquid to vapour comes from the sensible heat of the produce, the produce will cool close to the boiling temperature in a very short time. The evaporation of water also causes a weight loss in the produce. Generally, each 1% reduction in the weight of the produce due to moisture loss results in a temperature decrease of 6ºC. Since this can have detrimental effects on product quality, the product can be wetted before vacuum cooling [ASHRAE, 1986] or sprayed with a fine mist during cooling [Wills *et al.,* 1998].

Forced-air Cooling

Forced-air cooling is a method of precooling that can be used on a wide range of produce. It can cool produce four to ten times faster than room cooling [Mitchell *et al.,* 1972] and gives a more uniform temperature distribution in the pallet (Fig 5.). This method works well for small-scale operations due to its cost effectiveness, compared to hydrocooling or vacuum cooling, and its high cooling rate [Fraser, 1991]. Cold air is forced through the product, rather than just surrounding the produce containers as is done in room cooling. Fans are used to create a static pressure difference across the two sides of the product containers. This results in the air being pulled through the containers, thus removing the warm air around the produce by convection. The static pressure that is created across the produce containers is in the range of 3 to 25 mm of water gauge, with a typical value of 12 mm [Fraser, 1991]. An air flow rate of 0.5 to 3 litres of air per second per kilogram (L/s per kg) of warm produce is needed for adequate heat removal [Fraser, 1991].

The position of containers must be such that the vents which are in adjacent containers are lined up in the direction of flow. These vents should be evenly distributed on the containers to allow for even air distribution throughout the produce [Fraser, 1991]. It is recommended that the total area of these vents be at least 5 to 10 % of the surface area of the sides of the container [Fraser and MacKinnon, 1992] and that the produce inside the containers not be wrapped so that optimal heat transfer conditions can be achieved [Ryall and Pentzer, 1974]. It should be noted that increasing the amount of vent surface on a container by over 6% of the side surface results in a decrease in the strength of the container. Reusable plastic containers allow up to 40% of the side surface of the containers to be used as vents. However, an opening percentage of 25% seems to be the optimum, taking into account cooling efficiency and physical support the container provides to the produce [Emond and Vifneault, 1998].

Forced-air cooling is very attractive to small operations that harvest many types of produce, as it is suitable for a wide range of produce. It is believed that forced-air cooling can dry out some products, such as lettuce, spinach, mushrooms and peaches. However, forced-air cooling of these products can be successful if the cooling is rapid and the relative humidity of the air is kept high [Fraser, 1991].

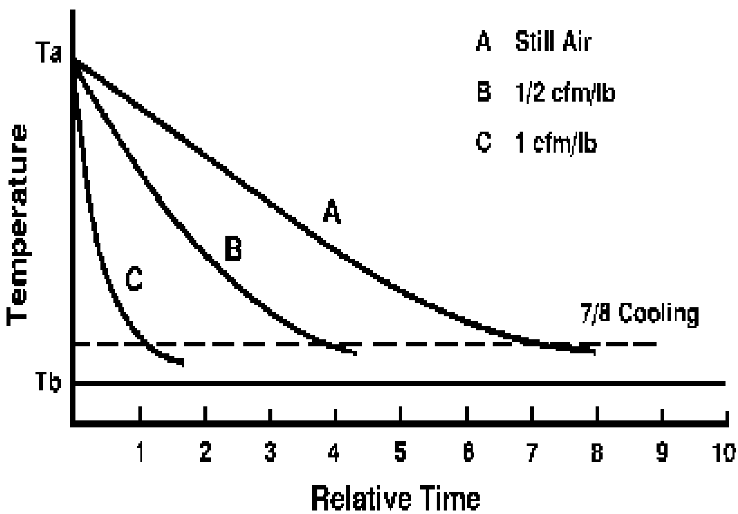

Figure 5. Temperature in forced-air cooling

Forced-air tunnel systems are the most used form of forced-air cooling. Two rows of palletized containers are placed parallel to each other with a space between them. The aisle formed is covered on the top, along with one end to create a tunnel. A fan is placed at the free end to pull the air out of the air plenum tunnel, creating a static pressure difference across the containers. The cooled air around the outside of the pallets is pulled through the produce and into the plenum by the pressure difference. The costs associated with this type of forced-air system are minimal. The fan may be a portable unit that returns the air to the room or a permanent fan that directs the air back directly to the cooling coils.

Cold wall cooling systems are a more complex form of forced-air cooling, but are very flexible with regard to the time that different types of produce require for adequate cooling. The main constraint is that pallets need to be moved as soon as they are cooled in order to prevent dehydration of the contents. A false wall is constructed, creating a permanent air plenum between the real wall and the false wall. This plenum is equipped with exhaust fans that circulate air across the cooling coils. Air inlets are located on the false wall but are not opened until a pallet load is placed up against the wall. Dampers control the air inlets so that they remain closed until a pallet load or a stack is placed up against the false wall.

Serpentine cooling is a modification of the standard cold wall cooling method and it is used for cooling pallet bins. Although the bins must have bottom ventilation, side ventilation is not necessary [Wills *et al.,* 1998]. Several rows of bins are pushed up against the false wall, each row having several layers. The number of rows that can be used is dependent on the desired cooling speed and the flow rate that is available. The openings on the pallet bins for the forklift are used as air supply and return plenums. Every second layer of the forklift openings that are facing the cold room are covered to prevent air from entering. Likewise, every second layer facing the false wall is covered. The coverings of the forklift openings are staggered, so that a layer which is covered facing the room is not covered facing the wall. When the fans are turned on, the fans pull air from the forklift openings that are against the false wall, causing a static pressure difference. Cold room air is forced into the forklift openings. The air then travels up or down through the produce to a forklift opening which returns it to the air plenum. This system has a few advantages over regular cold wall cooling. It provides very quick cooling because the air travels through a very shallow layer of produce, the rows are not limited in height [Wills *et al.,* 1998], and large volumes of produce may be cooled at one time.

COOLING AND REFRIGERATION

Room Cooling

Room cooling is one of the most widely used forms of cooling, primarily because the room in which the produce is cooled also serves for storage, thus reducing overall handling requirements and costs. Since room cooling is quite slow compared to the methods described in the previous section, it has not been categorized as a pre-cooling technique. It is not recommended for crops that have high respiration rates or are harvested in the warmer months, since significant quality deterioration may take place during the cooling period.

Produce that is room cooled must be tolerant to slow heat removal, as heat transfer is by conduction through the container walls rather than by convection. In general, crops that are harvested in the cool season or have low base respiration rates are suitable for this method. The time to cool the produce to the recommended storage temperature may range from a few hours to several days.

Field containers filled with fresh produce are placed into a refrigerated room. Cold air from evaporators near the ceiling travels across the top and between containers before returning to the evaporator. An air flow of at least 1 to 2 m/s is needed to remove field heat effectively [Wills *et al.,* 1998] and this should be reduced to 0.05 to 0.1 m/s for subsequent storage to prevent excessive moisture loss thereafter [Mitchell *et al.,* 1972]. Space should be left between all bins and the bins should be oriented so that the openings for forklifts run in the same direction as the air flow.

The type of packaging has an effect on how quickly the produce will cool. Cooling time can be reduced by providing ventilation in the containers. For example, a side venting area of 5% on boxes can reduce the cooling time by 25% compared to similar containers that are not vented [Mitchell *et al.,* 1972]. However, the addition of venting to containers decreases their stacking strength, depending on the size and location of the vents. Using 5 % venting area will reduce the fibreboard container strength by 2-3 % as long as the vents are not situated in the corners [Mitchell *et al.,* 1972]. It is more efficient to use a few large vents than numerous small vents [Mitchell *et al.,* 1972]. Plastic containers do not have this disadvantage of lost strength and can be designed to support the load of produce with up to 25% of the container surface area dedicated to venting [Emond and Vigneault, 1998].

Mechanical Refrigeration

The vapour-recompression cycle is the most commonly used form of mechanical refrigeration. Four major components are required: an expansion valve, an evaporator, a compressor and a condenser. High pressure refrigerant passes through an expansion valve where it is suddenly reduced in pressure. This results in 'flashing', a term used for a sudden drop in temperature caused by a sudden pressure drop. The flashed refrigerant should be at a lower temperature than the desired storage temperature, since it must be able to absorb heat from the storage room as it passes through the evaporator coils. The evaporator is a series of coils that are designed to promote heat transfer from the storage area to the refrigerant in the coils. The evaporation temperature of the refrigerant should also be below the desired storage temperature for maximum cooling capacity, due to the latent heat of vaporization. The refrigerant vaporizes as it collects heat during its flow through the evaporator, providing the cooling effect in the storage room. The vaporized refrigerant is then recompressed and its temperature increases. The high pressure vapour thus enters the condensation coils at a vapour temperature higher than ambient temperature. As heat is transferred from the hot vapour to the air outside the storage room, the vapour condenses back into a high pressure liquid. This high pressure liquid enters the expansion valve and the cycle is repeated.

The expansion valve plays a major role in the vapour-recompression cycle, as it is used to control the amount of refrigerant that enters the evaporation coils and in smaller systems controls the pressure of the refrigerant. The valve aperture may be controlled manually or automatically by temperature or pressure sensors. There are many different types of expansion valves but the two most often used are capillary tubes and thermostatic expansion valves [Wills *et al.,* 1998].

The evaporator is responsible for allowing heat to vaporize the refrigerant. The two designs most often used in storage systems for fruits and vegetables are the bare-pipe and the finned-tube evaporators. The bare-pipe evaporators are the simplest form and are easy to clean and defrost. The finned-tube evaporators have fins to increase the surface area of the evaporator and thus provide a higher heat transfer rate. Evaporators are also classified as direct-expansion or flooded types. In direct-expansion evaporators, there is no recirculation of the refrigerant in the coils before returning to the compressor. The flooded type re-circulate any liquid refrigerant in the coils until it vaporises before returning it to the compressor.

Evaporative Cooling

In some parts of the world, the climate is suitable for the use of evaporative cooling to provide some or all of the necessary refrigeration for cooling or storage. Evaporative cooling is a very economical and energy efficient technique. For evaporative cooling to be effective, the air used should have a relative humidity lower than 65% [Gast and Flores, 1991]. An airstream is passed through a water spray or a membrane that is saturated with water. Due to the low relative humidity of the air passing through a zone of high moisture, the air acquires more water vapour. The added water vapour must evaporate from the surface of the membrane or from the spray, which requires energy. This energy comes from the water and the air stream, resulting in a reduced temperature of both. Theoretically, the lowest temperature that can be obtained from a single stage evaporative cooler is the wet bulb temperature of the incoming air. Evaporative coolers can be designed to be 85 to 90 % effective, or in some cases even more [ASHRAE, 1984]. A multiple-stage evaporator can be used to obtain temperatures that are below the wet bulb temperature of the incoming air. In a two stage system, water is cooled to the wet bulb temperature of the air using an evaporative system. This water is then used in a water-to-air heat exchanger to reduce the temperature of the outside air without adding moisture to it. The dry bulb and wet bulb temperatures of the outside air subsequently decreases. The cool air can be passed through an evaporative cooler for further cooling if desired, down to its wet bulb temperature. The theoretical minimum temperature that can be obtained from a multiple-stage evaporator is the dew point temperature of the air [Wills *et al.,* 1998].

CO_2 Cooling

Liquid CO_2 is a refrigerant that requires relatively low equipment investment with high cooling capacity; however operating costs are higher than for conventional vapour-recompression refrigeration systems. The latent heat of CO_2 (2068 kPa and -17ºC) is 265.2 kJ/kg [Gamache and Desilets, 1987], at which point the CO_2 vapour is at a temperature of about -78.9ºC. It will absorb more heat as it increases in temperature. The specific heat of the CO_2 vapour is 0.804 kJ/kgºC. If the vapour temperature increased to 0ºC, an additional 65.53 kJ/kg of heat would be extracted from the surrounding environment, bringing the total to 328.6 kJ/kg of heat removed.

ALTERNATIVE METHODS

Nighttime Cooling

In some parts of the world there is a large diurnal temperature swing and, where the nighttime temperature is low enough, outside air may be used as a source of refrigeration. Natural ventilation during the night is usually sufficient if the outside temperature is below the required range for 5 to 7 hours each day [Wills, R. *et al.,* 1998]. In such climates it is advantageous to harvest the product when its temperature is lowest (early in the morning or at night), thus reducing the refrigeration load.

Well Water

Groundwater temperature usually does not vary by more than 1ºC during the year for any given location [Braud, 1979] if taken at a depth at which soil temperature is nearly constant. This depth varies with geographical region and can range from 2 to 9 m [1985]. The water can be used as a heat sink to cool produce if circulated through some type of heat exchanger.

MODIFICATION OF ATMOSPHERIC COMPOSITION

Controlled Atmosphere (CA) Storage

CA storage implies precise control of the gas concentrations inside the storage room. Modification of atmospheric gas levels may reduce the respiration rate of fresh produce, as well as control the level of ethylene (C_2H_4) and thus retard ripening. The gas concentrations of ambient air are 78.08% N_2, 20.95% O_2, and 0.03% CO_2 [Wills *et al.,* 1998]. In most CA storage systems, the O_2 level is decreased and/or the CO_2 level is increased. Either of these will generally cause a decrease in product respiration rate. Different types of produce respond differently to these two gases, and thus the proper atmosphere for a given commodity should be predetermined experimentally. In some cases, ideal concentrations of these gases for long-term storage of one commodity may prove harmful to another. For example, cauliflower stored in 10% CO_2 at 5ºC will be injured after a week in storage, whereas broccoli in the very same environment would remain in excellent condition [Ryall and Pentzer, 1974]. Some recommendations of the proper storage requirements are given in Table 1.

TABLE 1 Recommended precooling methods and storage conditions for various fruits and vegetables

Produce	Precooling Method[a]	Storage Conditions
Apples	RC, FA, HC	0 to 5ºC, 1-3% O_2, 1-5% CO_2
Asparagus	HC, PI	0 to 2ºC, 95 to 100% RH
Apricots	RC, FA	0 to 5ºC, 95% RH, 2 to 3% O_2, 2 to 3% CO_2
Artichokes	HC, FA, PI	to 5ºC, 90-95% RH, 2-3% O_2, 2 to 3% CO_2
Banana	no precooling	5ºC, 90-95 % RH,2 to 5% O_2, 2 to 5% CO_2

Beans, snap	RC, FA, HC	8ºC, 2 to 3% O_2, 4 to 7% CO_2
Beets	RC	0 to 4ºC, 95% RH
Blueberry	FA	1º C (1-4ºC), 90% RH
Broccoli	FA, HC, PI, LI	0ºC (0-5ºC), 90-95% RH, 1-3% O_2, 5-10% CO_2
Brussels Sprouts	FA, HC, PI	0ºC, 95-100
Cabbage	RC, FA	0º, 92% RH
Cantaloupes	HC, FA, PI	2-5ºC, 95% RH
Cauliflower	HC, VC	0ºC, 95-98% RH
Carrots	RC, PI	0 to 2ºC, 95% RH
Chinese Cabbage	RC, FA, HC	0ºC, 95-100% RH
Celery	FA, HC, VC, WV	-5ºC, 90-95% RH, 2-4% O_2, 3-5% CO_2
Cucumbers	RC, FA	10-13ºC, 50-55% RH
Eggplant	RC, FA	8-12ºC, 90-95% RH
Figs	RC, FA, HC	0-5ºC, 5-10% O_2, 15-20% CO_2
Garlic	RC	0ºC
Grapes	FA	-1 to 0ºC, 85% RH
Kiwifruit	FA, RC, HC	-0.5 to 0ºC, 90-95% RH,1-2% O_2, 3-5% CO_2
Leeks	HC, PI	0ºC, 95-100% RH
Lettuce	HC, PI, VC	0ºC, 95+% RH
Longan	RC	4-6ºC, 90-95% RH, MA packing 3-5%O_2, 5%CO_2
Lychee	RC	4-6ºC, 90-95% RH, MA packing 2-3%O_2, 5%CO_2
Mango	no precooling	10-13ºC, 90-95% RH, 3-5%O_2, 5-8%CO_2
Mushrooms	FA, VC	0ºC (0-5ºC), normal O_2, 10-25% CO_2
Nectarines	FA, HC	-0.5-0ºC, 90-95% RH
Okra	RC, FA	7-12ºC, 90-95% RH, normal O_2, 4-10% CO_2
Onions	No precooling	0ºC, 75% RH
Peaches	FA, HC	-1 to 0ºC, 85% RH
Pears	FA, RC, HC	-1.5 to -0.5ºC, 90-95% RH
Peas, green	FA, HC	0ºC, 95-98% RH
Peas, southern	FA, HC	4-5ºC, 95% RH
Peppers, chili (dry)	RC, FA, VC	0-10ºC, 32-50% RH
Peppers, sweet	RC, FA, VC	7-13ºC, 45-55% RH
Pineapple	no precooling	7-13ºC, 85-90% RH, 3-5% O_2, 5-8% CO_2

Plums	FA, HC	-0.5-0ºC, 90-95% RH
Potatoes	RC, FA	3-10ºC, 90% RH
Pumpkins	No precooling	10-13ºC, 70% RH
Radish	PI	0ºC, 90-95% RH, 1-2% O_2, 2-3% CO_2
Raspberries	FA	0 to 0.5ºC, 90% to 95% RH
Rutabagas	RC	0ºC, 98-100% RH
Spinach	HC, VC, PI	0ºC, 95-100% RH
Squash, summer	RC, FA	5-10ºC, 95% RH
Squash, winter	No precooling	10ºC, 50-70% RH
Strawberries	RC, FA	0ºC, 95% RH, 5 to 10% O_2, 15 to 20% CO_2
Sweet Cherry	RC, FA, HC	0-5ºC, 3-10% O_2, 10-15 %CO_2
Sweet Corn	HC, VC, LI	0ºC, 95% RH
Sweet Potatoes	No precooling	10-15ºC, 85% RH
Tamarillos	RC, FA	3-4ºC, 85-95% RH
Tomatoes	RC, FA	12ºC (12-20ºC), 3-5% O_2, 0-3% CO_2
Turnip	RC, HC, VC, P	I0ºC, 95% RH
Watermelons	No precooling	4-10ºC, 80-85% RH

The choice of CA system to use depends primarily on the gas composition that is desired, and the rate at which it is to be achieved. The standard free volume (SFV) is the ratio of the volume of air to the volume of commodity. The SFV in typical warehouses range from 1.5 to 3.0 and is a function of the stacking arrangement, room geometry, commodity shape and density, and the method of packing, either in bulk or crate [Raghavan *et al.,* 1996]. CA rooms with a higher SFV result in more stable gas composition with time but also requires more intervention to modify the gas composition. For example, a storage room with a SFV of 3.0 requires approximately twice as much time to reach its equilibrium gas composition than a room with a SFV of 1.5, since twice as much O_2 must be removed by the respiration of the produce or by the control system.

Generally, the largest benefits of CA storage come from the rate of decrease in the O_2 level. Rooms that require very low O_2 levels, 1 to 2%, or that require a very fast pull-down should have a very efficient CA system and a low SFV. The system must also take into consideration the level of CO_2. High levels of CO_2 can cause damage to some types of fruits and vegetables. For example, it has been shown that some apple cultivars may be damaged by 3% CO_2, while lettuce cannot tolerate any CO_2 [Lidster *et al.,* 1990].

Methods of CO_2 scrubbing therefore need to be considered when designing CA storage for produce that are susceptible to CO_2 injury. Finally, attention should be given to the control of C_2H_4 levels in the storage room if the produce is susceptible to hastened ripening from increased C_2H_4 concentrations. Thus, there are three main control systems that may be used to obtain the desired gas concentrations: 1) O_2 control systems, 2) CO_2 control systems, and 3) C_2H_4 control systems.

O_2 Control Systems

If product respiration does not decrease the O_2 level quickly enough, one of four active methods may be used: 1) external burners, 2) liquid or gaseous nitrogen (N_2), 3) gas separator systems, or 4) hypobaric storage. External burners use the combustion of propane or natural gas to remove O_2 from air that enters into the storage room. The combustion process produces a mixture of CO_2 and water vapour, and usually requires a CO_2 scrubber to prevent high accumulations of the gas. The air should be cooled after combustion and before it is injected into the room. Open flame or catalytic burners may be used. The open flame burner has the disadvantage of not permitting air recirculation due to the risk of extinguishing the flame by the O_2-depleted recirculating air stream. Catalytic burners are therefore preferred. Furthermore, catalytic burners provide more complete combustion and can bring O_2 levels down to 3%. Catalytic burners are more expensive to install if used in a recirculating system but this is compensated quickly by lower operating costs. Overall, external burners are inexpensive, but may be safety hazards if they use highly flammable fuels.

Flushing with liquid or gaseous N_2 is an effective rapid O_2 pull-down technique. The amount of N_2 needed to reduce the O_2 level is a function of the desired O_2 level and the SFV. Usually, liquid N_2 is injected into the room through spray headers which atomize the N_2 into a fine mist. It is best to have the spray headers placed in front of the evaporator fans. This method also assists in refrigerating the room due to the latent heat of evaporation of the liquid N_2; however, this advantage may be offset by the cost of insulating the N_2 supply lines. This method should not be used on unpacked produce since freeze-burning may occur, and adequate venting should be used to prevent over-pressurization of the room [Singh and Heldman, 1993]. Nevertheless, liquid N_2 can create appropriate CA conditions very rapidly with a purge rate of up to 35 m^3/h [Singh and Heldman, 1993].

Gas separator systems may also be used for O_2 control. The different gas separator systems are: 1) pressure swing absorption

(PSA), 2) hollow fibre membrane separators (HFMS), and 3) high temperature ammonia cracking (HTAC). PSA systems are used to generate a stream of air that is very high in N_2 and low in O_2. This system compresses dry air and forces it through a bed of pelletized carbon material (molecular sieve) which absorbs O_2 and yields an N_2-enriched stream [Singh and Heldman, 1993]. The bed pressure is typically 830 kPa (120 psi) [Singh and Heldman, 1993]. The purity of the N_2 stream can range from 90 to 99.9%, depending on factors such as the pressure, temperature and the air flow rate. After a few minutes of operation the molecular sieve becomes saturated with O_2. The O_2 may be removed by decreasing the pressure and venting the sieve [Singh and Heldman, 1993]. Two molecular sieves are usually connected in parallel so that the operation can be continuous, one being regenerated while the other is depleting O_2 from the supply stream. PSA systems can provide rates of 105 to 385 m^3/h at 98% purity with compressors ranging from 30 to 112 kW, respectively [Singh and Heldman, 1993]. The initial cost of the system is fairly high, and the system requires regular inspections.

HFMS works on the principle that some gases can diffuse through membranes at higher rates than others. In the case of air, CO_2 and O_2 have much higher permeation rates than N_2. In HFMS, compressed hot air is forced into a hollow fibre membrane chamber. The O_2 and CO_2 quickly pass through the membrane and are vented to the ambient air. The concentration of N_2 increases, since N_2 does not pass through the membrane as quickly. The stream leaving the chamber is nearly pure N_2 and is fed to the storage room. The purity of the output may be changed by modifying the rate at which the N_2 stream leaves the chamber [28]. For CA storage, the aim is to produce an airstream of 97 to 99% N_2 [Singh and Heldman, 1993]. The initial cost and the cost of replacement of an HFMS is very high, but maintenance costs are lower than for a PSA system. This method may also be used for scrubbing by recirculating air from the CA rooms [Singh and Heldman, 1993] since water vapour and CO_2 permeate through the membrane walls.

Ammonia cracking is another type of O_2 control system. High temperature anhydrous ammonia (NH_3) gas is reacted with air brought from the CA room. The reaction involves the splitting of the NH_3 into hydrogen and inert N_2 gas. The hydrogen then reacts with the O_2 present in the air to form water vapour. The air returning to the room consists of N_2 and water vapour, but is free of CO_2, carbon monoxide (CO), and hydrocarbons. The returning air stream is cooled before it returns to the room. The operating costs are high and the use of ammonia gas can be extremely dangerous since the gas is toxic at concentrations of 0.5% by volume in air. In addition to these disadvantages, processes of ammonia manufacture require a lot of fossil fuel energy simply to combine the inert atmospheric N_2 with hydrogen in the first place.

Hypobaric storage involves storing the produce at reduced pressure, usually between 10 and 80 mm of mercury. The air in the reinforced, airtight refrigerated room is continually removed by a vacuum pump [Raghavan and Gariepy, 1984]. When the pressure in the room reaches the desired level, air is allowed to enter the room at a rate that will create one to four air changes per hour [Raghavan and Gariepy, 1984]. This system provides relatively easy manipulation of O_2 concentration and relative humidity. CO_2, C_2H_4 and other volatile gases of metabolism are also removed, making it possible to store commodities together that are otherwise not normally compatible in storage [Raghavan and Gariepy, 1984]. The costs associated with providing a room with acceptable structural strength for the required vacuum is very high. It is also difficult to permit accumulation of CO_2 to levels that would be beneficial to product quality. Finally, hypobaric storage can affect the flavour of the produce and can cause unsatisfactory ripening after storage.

Carbon Dioxide (CO_2) Control Systems

There are five commercially available scrubbing systems for the removal of excess CO_2. These are based on: 1) caustic soda, 2) hydrated lime, 3) water, 4) activated charcoal, and 5) molecular sieves. The level of CO_2 in the room is controlled by adjusting the gas or liquid flow rate through the scrubber. The atmospheric composition of the room should be measured to determine the flow rate required.

Caustic soda (NaOH) dissolved in water can be used to remove CO_2 from the air of the storage room by circulating it in open tubes. The amount of CO_2 removed can be adjusted by changing the duration the caustic soda solution is exposed to the room's atmosphere. The use of caustic soda has been largely discontinued due to its corrosiveness and the potential danger in handling.

The hydrated lime ($CA(OH)_2$) scrubber is one of the simplest and most effective systems for controlling the level of CO_2. Hydrated lime is placed in an insulated and airtight box outside the storage room to which it is connected by two pipes. One pipe is an inlet which allows air from the storage room to enter the box containing the lime. The other pipe is a return through which CO_2-depleted air is brought back to the CA room.

The box is usually large enough to contain sufficient lime to last the entire storage period. The lime should be placed on a pallet with a 10 cm space between layers of 25 kg bags to allow for good air circulation. The effectiveness may be further increased by having the bags only partially filled due to the fact that less than 2% of the lime in a 25 kg bag is consumed due to the hardening of the outer layer. The amount of lime required depends on the amount of produce in the storage room, the respiration rate and the rate of CO_2 addition to the room. Some O_2 scrubbers produce CO_2 as a by-product, which must also be removed by the lime. A 25 kg bag of lime has a volume of approximately 0.1 m^3 [Bartsch and Blanpied, 1984] and roughly 10 bags would be needed for every 19 tonnes (1000 bushels) of fruit, while about 40 bags are needed for 100 tonnes of vegetables [20]. The hydrated lime and the CO_2 react in a 1:1 ratio to form limestone ($CaCO_3$) and water. The lime that is to be used can be agricultural or chemical hydrated lime as long as it is fresh, high in calcium and is fine enough to pass through a 100 mesh sieve [Bartsch and Blanpied, 1984].

Water CO_2 scrubbers use the inside to outside differential pressures of CO_2 to remove it from the CA room. A brine solution is pumped or sprayed over the evaporator coils in the CA room. As the brine is exposed to the atmosphere in the CA room it absorbs CO_2, since the CO_2 partial pressure is very low in the incoming water and very high in the atmosphere of the CA room. The brine solution is collected in the room and allowed to travel into a reservoir located outside of the room. Here the brine solution is pumped to aerators where the CO_2 is dissipated to the air due to a differential pressure between the CO_2 in water and that in air. Water scrubbers have some disadvantages that have made their popularity decline. Small amounts of O_2 are added to the room since there is a higher partial pressure of O_2 in the incoming water solution than there is in the CA room [Bartsch and Blanpied, 1984]. This addition of O_2 makes the control of the atmosphere more difficult, especially if the room is not already perfectly airtight.

Activated charcoal and molecular sieves scrubbers are based on the adsorption of CO_2. They consist of a unit filled with an adsorbent material, two blowers, and four solenoid valves dedicated to a control unit. Air from the CA room is blown through the absorbing unit, and the CO_2-depleted stream is then directed back to the CA room. The adsorbent loses its ability to trap CO_2 due to saturation of active sites, and thus after some time must be reactivated. This is done by purging the adsorbent with ambient air. The control unit, generally based on timers, shuts off the valves that are connected to the CA room and opens other valves to force outside air through the absorbent material to remove the CO_2 (reactivation process). Molecular sieves should be heated during the reactivation phase to enhance the rate of CO_2 removal [Bartsch and Blanpied, 1984]. Since purging with ambient air can add O_2 back into the CA room, the absorbing unit is often purged with pure N_2.

C_2H_4 Control Systems

C_2H_4 will induce ripening in many fruits and can also cause some physiological disorders in vegetables [Ryall and Pentzer, 1974]. The amount of C_2H_4 produced by the commodity can be reduced by decreasing the surrounding O_2 level and increasing the CO_2 level [Ryall and Pentzer, 1974]. Low temperature levels, 0 to 4.4ºC, can prevent the production or inhibit the action of C_2H_4 [Ryall and Pentzer, 1974]. Nonetheless, C_2H_4 levels less than 1 ppm can produce physiological responses in many fruits and vegetables. For example, kiwi fruit may be affected by C_2H_4 concentrations as low as 0.1 ppm [Bishop, 1990]. Therefore, removal of C_2H_4 from the storage environment is important. It should be mentioned that C_2H_4 sensitive commodities should not be stored near or with commodities that produce high levels of it, such as climacteric fruit (e.g. apple). Most of the C_2H_4 may be removed if N_2 generators or gas flushing methods are used. This may be acceptable for types of produce that have low C_2H_4 production rates, but other control systems are often required for commodities that have high C_2H_4 production rates. Commercial C_2H_4 scrubbers include: 1) the heated catalyst scrubber, 2) C_2H_4-absorbing beads, and 3) ozone.

A heated catalyst can be used to maintain relatively low levels of C_2H_4. Air from the CA room is forced through ceramic packings, which are used as heat exchangers, and contacts a heated catalyst. The catalyst is electrically heated and the high temperature promotes the oxidation of C_2H_4 to CO_2 and water vapour. Up to 87% of the C_2H_4 can be removed from the air in one pass through the catalyst. The system is set up so that flow reversal through the ceramic packings occurs at timed intervals. The energy requirements for heating the air and then cooling it after breakdown of C_2H_4 are the main disadvantages of the heated catalyst approach.

C_2H_4-absorbing beads are small spherical particles of aluminum silicate impregnated with potassium permanganate ($KMnO_4$). The beads are placed in a sealed unit and air from the CA room is circulated through the unit. The C_2H_4 reacts with the $KMnO_4$, changing the colour of the beads from purple to brown as they become saturated with C_2H_4. Once saturated, the beads must be replaced. The cost of the bead system is similar to that of the heated catalyst [Thompson and Reid, 1989], and is a function of the required rate of C_2H_4 removal. For long-term storage of a product that has a high C_2H_4 production rate, it is less costly to use a heated catalyst. On the other hand, if the production rate of C_2H_4 is low, it is cheaper to use a $KMnO_4$ scrubber [Thompson and Reid, 1989].

Some research has been done on the use of ultraviolet (UV) radiation as a means to remove C_2H_4. UV light reacts with O_2 to form ozone (O_3), which has the ability to destroy C_2H_4 [Thompson and Reid, 1989]. The reaction rate between O_3 and C_2H_4 is very slow, therefore a fairly large reactor is needed for efficient removal [Thompson and Reid, 1989].

Modified Atmosphere (MA) Storage

MA storage differs from CA storage in that the atmospheric composition is not actively controlled. Most MA systems use semi-permeable membranes to regulate gas exchange between the MA and the ambient air. The composition of the air changes due to the respiratory action of the produce and the permeability characteristics of the membrane used (Fig. 6). For example, silicone membranes allow the gases to diffuse at different rates, which are determined by the chemical and physical characteristics of the gases [Gariepy *et al.,* 1986]. Other important factors in the amount of gas diffusing through the membrane include temperature, membrane surface area, permeability of the membrane, and the gas partial pressure difference across the membrane. Generally the membranes are more permeable to CO_2 than they are to O_2. Therefore, the concentration of CO_2 increases and the concentration of the O_2 decreases, as O_2 is consumed and CO_2 is released as a by-product during respiration of the produce. Although MA storage does not achieve the same degree of atmospheric control as does the CA approach, it is less expensive [Mannapperuma *et al.,* 1989]. The membranes can be made of polymeric films or wax, or may be edible coatings of individual fruits. MA storage is often a better approach for short-term storage of small quantities of produce than is CA storage [Mannapperuma *et al.,* 1989], and this is often used in association with packaging.

The time it takes for the gas composition to stabilize to quasi-steady-state is an important factor in MA storage. The stabilization period is a function of the designed gas composition, commodity respiration, relative stacking volume, and air tightness of the system. The time required to reach the stable gas levels may be in the order of days to weeks. If the stabilization period is too long, the product may deteriorate more than desired. In this situation, it may be advantageous to use a rapid O_2 pull-down method for the initial modification of the atmosphere.

MA storage systems are widely used in European countries, whereas they are only beginning to be popular in North America [Gariepy *et al.,* 1986]. Several silicone membrane-based systems have been conceived since the early 1970's, with the most popular being the Marcellin system. This system consists of a series of silicone rubber bags that are connected in parallel. Air from the storage room is circulated through the exchanger, resulting in an exchange of gases as they diffuse through the silicone rubber bags. The amount of diffusion taking place can be changed by changing the number of bags that are being used. The maintenance of 5% CO_2 and 3% O_2 requires 50 m^2 of silicone membrane for every 100 tons of fruit at a bulk density of 200 to 250 kg/m^3 [Raghavan and Gariepy, 1984].

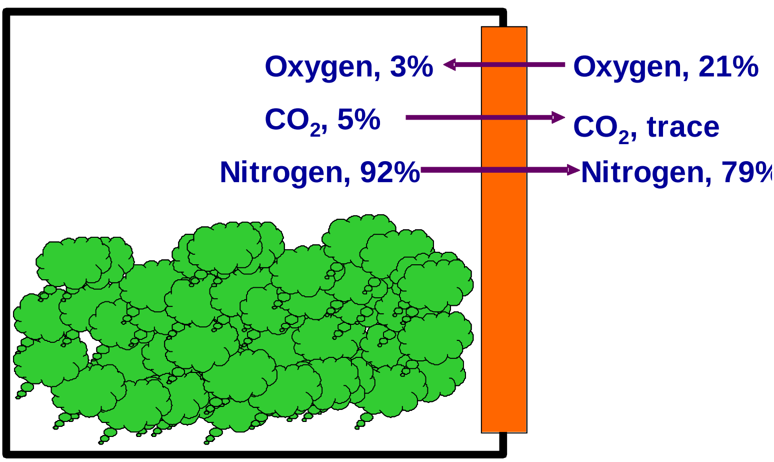

Figure 6. Typical gas exchange in membrane storage

A pallet MA package system also exists and has been used successfully for fruits and vegetables during transportation and storage. It requires little initial investment and involves wrapping individual pallets of produce with a polyethylene wrap of a thickness of 80 to 150 ìm. An area of the polyethylene wrap is replaced by a silicone membrane window, which allows for gas exchange. Calibrated orifices are also used to allow for pressure regulation within the pallet package. This system has a lot of flexibility, as the produce may be moved from place to place while still under modified conditions, though extra care must be taken to avoid damaging the packages. The produce can be stored under optimal atmospheric composition without any modifications to pre-existing buildings or investment into expensive equipment to change the air composition. This system allows for easy management of produce, small quantities of produce may be marketed without disturbing the atmospheric composition of all the pallets as would occur when a sealed room is opened. However, there are a couple of disadvantages to the system: the space required to store the produce is greater due to the need to provide adequate ventilation around all the pallets; and the time and material required to wrap the pallets and install the correct size of membrane add to the storage cost of the produce.

Some produce may be packaged in permeable film wraps or bags. These wraps or films allow the passage of gases at different rates, much in the same manner as other MA storage techniques. These films have been tested on many commodities, such as apples, avocados, kiwifruits, peaches, and tomatoes [Gariepy *et al.,* 1986]. However there are situations where damage can occur to the produce due to a very high CO_2 or very low O_2 concentration [Watkins and Thompson, 1992]. A solution to this problem is the addition of micro-perforations to the polyethylene bags.

CONCLUSION

The deteriorating environment due to the short sighted development approaches has forced us to rethink the path along which the world is moving. Many exciting developments are taking place in different parts of the world that may influence the life on earth. Ensuring food security to the teeming billions of human beings is a daunting task that needs effective management of resources.

The global picture of postharvest technology presents a striking contrast between the developed and the developing nations. It also presents the enormous opportunities that can be used beneficially for ensuring a better life in both parts. It is a challenge that needs to be taken up by the professionals to influence the key players and bring to fruition the numerous possibilities.

The solutions to the problem of food sufficiency need to be multidimensional and approaches are required at all levels of the issue. Starting from increasing the awareness about the problems and the available opportunities for solving them at the fundamental level in households, governments have to work their way upwards till their policies and support programmes are synchronized to deal with the issue at the national level. Efficient use of the resources for production and consolidation can be achieved by a concerted effort, both by the producers and the different levels of consumers. Sufficient efforts have been put into the fundamental research and by passing on the knowledge to the potential beneficiaries, the scientific community also gets an opportunity to find new areas for applied research.

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CONVERSION OF BIOFUELS TO A HIGH-GRADE POWER UTILIZATION*

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INTRODUCTION

One of the vital forms of life and human development and progress is practically associated with the utilization of the available energy resources in our everyday endeavours and activities. The generation of energy in the form of electric power and its coverage is often taken as a measure of the advancement and well being of a nation. The per capita energy consumption and realization of the energy demands of a society have therefore been detrimental for economic growth and prosperity. Hitherto, non-renewable energy sources based on fossil fuels such as oil, natural gas and coal have dominated the energy supply and demand for the technological and industrial development. However, owing to the adverse environmental repercussions caused by these energy sources in the form of green-house gases and global warming with long-term effect on human health, agriculture, forest and natural ecosystems, alternative energy sources that to replace on a global scale are sought. Not only the recent price hike of oil and similar reserves and the impact this might have on the economies of the developed and developing countries, but also the ever-depleting reserves of these supplies are of concern for switching to sustainable and renewable energy sources. Though controversial depending on how the global energy reserve for each type of fossil fuel is made, the fossil fuels as a group and given the current consumption rate are likely to last for less than 100 years (Chadwick and Lindman). This is a rough figure and subject to a wide range of uncertainty mainly due to factors affected by a) world and regional forecasts of economic development; b) correlation of economic growth with energy consumption; c) physical, economic, environmental and geopolitical constraints applying to energy production and consumption; d) future prices of different sources of energy; e) future availability of different sources of energy and the appropriate technologies developed for their use; f) public awareness and acceptance of the energy sources and the conservation measures (Lindström, 1988).

Fig. 1 shows a chart representing the main fuels of the world's total primary energy supply during the year 2000. Fossil fuels account for almost 80% of the world's energy consumption and supply, while renewables were mainly composed of 11.0% combustible renewables, 2.3% hydro and 0.5% others (geothermal, wind, solar and tide). The combustible renewables or biofuels derived from plant matter in the form of wood, crop and forestry residues and energy crops, biogas, municipal and industrial wastes, though showed an upsurge in energy utilization for the last 30 years through combustion, have the potential in providing much more share in energy supply by replacing fossil fuels. The environmental advantages are profound due to the fact that biofuels in a biocycle for energy production do not introduce extra carbon or are not net contributors of CO2 into the atmosphere, as does the combustion of fossil fuels. Secondly, energy harnessed this way and with proper policies brought in, the price tag for energy production may significantly be reduced compared with today's price for fossil fuels. In addition to the merits above, biofuel harvesting gives job opportunities extending to the village level, thus benefiting the majority of the people in most countries of the world.

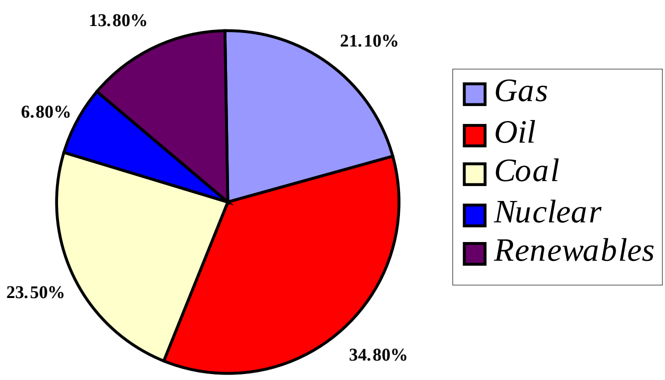

Fig. 1. Fuel shares of world total primary energy supply under year 2000. (source IEA's fact sheet Nov. 2002).

The conversion of biofuels to useful electricity either has to take place by means of thermochemical processes in engines and gas turbines or by electrochemical processes in a fuel cell. The primary advantages of both systems are that the plant sizes for both processes can be made flexible either as small or large units as well as they can be installed both in isolated places or remote areas away from the national or regional grid system for electric delivery. However, fuel cells due to the non-limitation by the Carnot cycle, which is the case in combustion engines, permit high efficiency of the amount of electricity generated for a given input of biofuel compared to corresponding power plants using combustion engines.

Energy conversion by fuel cells

Energy conversion in fuel cells is straightforward and simple compared to the sequences of chemical and mechanical steps in heat engines. A fuel cell is an electrochemical device, which unlike the conventional galvanic cell directly converts the chemical energy from a continuous flow of a fuel into electricity. In the fuel cell, oxidation of fuel (hydrogen) takes place at the anode while reduction of the oxidant (oxygen) proceeds at the cathode. The theoretical energy conversion efficiency ç (equation 1) is given by the ratio of the Gibb's free energy (ÄG) of the cell reaction shown in equation 2) to the reaction enthalpy change at the standard state ÄH°:

$$\eta = \frac{\Delta G^o}{\Delta H^o} \qquad 1)$$

$$H2 + \frac{1}{2}\ O2 \rightarrow H2O + \text{Electricity} + \text{Heat} \qquad 2)$$

Depending on the enthalpy of reaction at 298 K and the product water either being liquid or gas, the theoretical conversion efficiency for a fuel cell is 94.6% based on lower heating value (LHV)* or 83.2% on high heating value (HHV)*.

Moreover, a fuel cell runs quietly and instantly with no moving parts. It generates sustainable energy with no pollutants except harmless water as a product. Co-generation of power in conjunction with the heat developed during the reaction further increases the overall efficiency of the fuel cell to a significant level. Being efficient for direct fuel conversion and having no emissions, fuel cells are to become the next generation of power sources to be applied in broad spectra of installations ranging from stationary power plants for uninterruptible power supply (UPS) and backup, transportation for small and heavy-duty propulsion to small portable electronic devices.

The performance of the fuel cell electrodes mainly depends on the requirements of the materials used for both the cathodes and anodes used to carry out the electrochemical reactions. The stability

*ΔH^o =242kJ/mol & ΔG^o=229 kJ/mol for LHV gaseous product) or ΔH^o =285 kJ/mol & ΔG^o=237 kJ/mol (aqueous product)

and activity of the electrocatalysts to increase the rate of reactions and the electronic properties as well as the morphological factors are very important in order to realize high current densities at substantial voltages. Porous structure of the electrodes is needed in order to allow the gases to diffuse and react on the reaction sites within the bounds of the three-phase interface of gas, solid and electrolyte. Gas diffusion and ion conduction is of great concern in the design of the electrodes (Contreras *et al.,* 1999). The electrolyte, which allows ions or protons to be transported to or from the electrodes has to be stable in the fuel cell environment or does not corrode the materials used for the construction of the fuel cell parts. The nomenclature of fuel cells depends on the type of electrolyte or can be referred to as low, medium or high temperature fuel cells according to the temperature range in which they are operated. Alkaline (AFC) and polymer electrolyte (PEFC) are typically low temperature, phosphoric acid (PAFC) medium temperature, while molten carbonate (MCFC) and solid oxide (SOFC) are high temperature devices. The product gas, water is depleted from the cell either on the anode or cathode depending on the flow or direction of the ions or protons as depicted in the schematic Fig.2 for all the types of fuel cells.

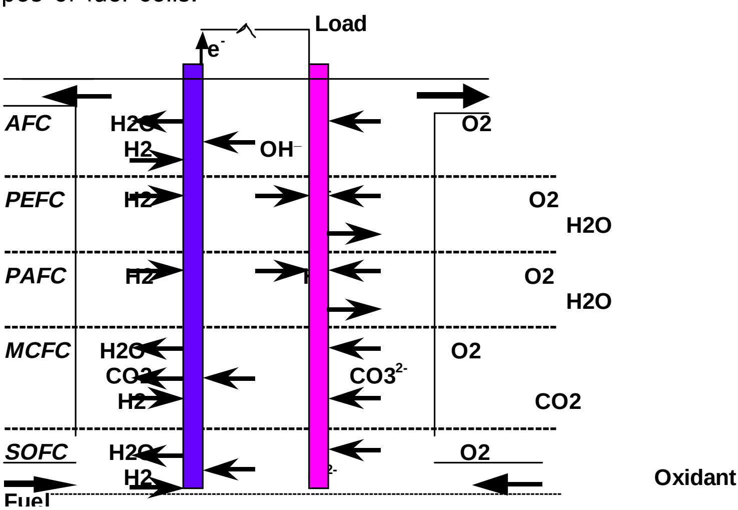

Fig. 2. Main types of fuel cells with directions of the flow of reactants, product water and ions/protons

Cells are configured in modules and are stacked together either in series (bipolar) or in parallel (monopolar) connections so that desired units of different sizes are designed. Existing state-of-the-art of fuel cells, though in small scale have started to make market entries for demonstrations either for power supply by the power supplying utilities, for tractions by the car industries or for portable electronic device applications. Long-term projections and strategies are formulated to introduce fuel cells as viable and sustainable commercial products in the coming years. In this demonstration stage, fuel cells are produced of varying sizes (<50W-5MW) for demonstration purposes to gain experience, public awareness, market-readiness and assessment of the characteristic qualities in terms of performance, durability and reliability. Thus, R&D on materials is carried out in many labs to cut the current price per kW product in order to materialize wide-scale applications.

Hydrogen is one of the most promising energy carriers for the future. Owing to its abundance bound in the form of compounds, such as water, plants and animals, it is estimated that over 75% of the mass of universe is composed of it (Barreto *et al.,* 2003). Introduction of hydrogen would mean in the mid- to long-term, facilitation and transition from non-renewable hydrocarbon energy resources to the use of renewable sources, which could play an essential role in the "decarbonisation" of the energy system, contributing to substantial decrease in the emission of greenhouse gases. Thus, the available resources of hydrogen from renewables with its combustion product in the form of water makes it strategically important in the pursuit of environmental benign, cleaner and sustainable energy system (Kiros *et al.,* 1999). The future technology roadmap for the production of hydrogen from water through electrolysis or photoelectrolysis and from biofuels is therefore, an essential challenge for the realization of the "green energy"

Biofuel feeding presents an attractive option for high-grade power utilization by connecting to a fuel processor whereas hydrogen enrichment occurs in a series of chemical reactors to be oxidised at the anode. It is a technological challenge to pass the producer gas after gasification or biogas through beds of steam reformers, shift reactors, oxidation steps and gas cleanup to obtain the fuel qualities to generate electricity. Department of Bio Energy, College of Agricultural Engineering, Tamil Nadu Agricultural University (TNAU) as one of the participants in the joint ICAR-SAREC programme (1990-1997) of the Stand Alone Fuel Cell Power Plants for Rural Electrification in India, was one of the major contributors for the realization of the project objectives in a biofuel-fuel cell application. A fuel processor unit in combination with an alkaline fuel, the first of its kind was demonstrated at the Asian Seminar on Fuel Cell Technology, Coimbatore and organised by TNAU during 25-26 April 1996 (Samapthrajan and Ramanathan, 1997). Feedstocks, pertaining to biofuels, such as agro-residues, wood charcoal, wood species and biogas were used for the production of hydrogen and other process gases with subsequent shift conversions and removal in well-defined tasks and activities [Jain *et al*., (1996), Myren (1996), Ramanathan *et al.,* (1996), Naumann and Myren (1995), Jain (1997)]. Furthermore, a fuel cell lab, equipped with modern equipment has been installed in TNAU in order to carry out R&D of excellence on fuel cells and related issues of fuel treatment and enrichment.

Fuel Processor, Gas Cleaning and Fuel Cell Module Test

The fuel processor unit for biogas, tested at KTH and PAU (Punjab Agricultural University) constitutes a steam reformer for conversion of methane into hydrogen in a nickel catalyst bed and a high and low temperature shift reactors, which are common for both biogas and producer gas for the generation of hydrogen rich gas. Prior adsorption of hydrogen sulphide or sulphide compounds is necessary in order to limit the poisoning effect on the catalysts, which thereby decreases the conversion or selectivity for the reactions. Fig. 3 shows a schematic flow sheet of the set-up with common reactors and reactant feed for the fuel processing of biogas and gasifier with subsequent clean-up of the of the steam-reformed methane and producer gas as well as the AFC generator as demonstrated in TNAU and KTH.

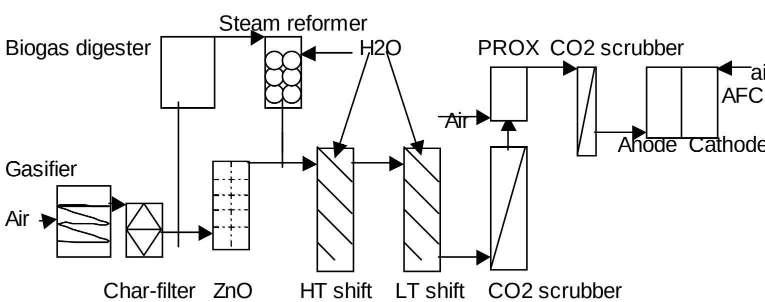

Fig. 3. Flow sheet diagram of the fuel processor and gas cleanup with the AFC generator

The gas compositions after the various steps of reactions in the fuel processor with or without gas cleanups and different feedstocks are shown in Table 1. The variation of the gas compositions is mainly dependent on the fixed carbon of the biomass species, airflow rate and operating temperature for the gasifier or on the steam to carbon ratio, space velocity and temperature for the steam reformer.

Table 1. Gas compositions for biofuels with or without fuel processor or gas removal in the respective process steps for different feedstocks

Feedstock	H2	CO	CH4	CO2	N2
Biogas in[1]	0.9	-	60.3	38.0	<1.0
Biogas after treatment[1]	70.85	0.85	0.24	28.91	
Biogas in[2]	60		40		
Biogas after treatment[2]	70.6	0.2	0.3	28.9	
Wood charcoal after gasifier[2]	3-6	15-21	1	8-12	65-70
Wood charcoal[2]	20-30	90 ppm		0-15 ppm	70-80
Leucaena Leucocephala wood[3]	16.4	20.4	2.0	11.0	52.2
Wood[4]	39.3	NA	2.5	NA	57.5
Maize cob charcoal[5]	6-8	1-2	1-2	8-9	79-84
Coconut shell charcoal[5]	3-7	1	2-4	8-10	78-86
Groundnut shell charcoal[5]	7-10	2-4	2	2-3	81-87
Bagasse charcoal[5]	6-8	1-2	2-4	6-10	76-85
Acacia nilotica charcoal[5]	4-5	3-4	1-2	8-16	73-84
Casuarina Equsettifolia charcoal[5]	3-5	6-12	1-3	7-11	69-83
Prosopis juliflora charcoal[5]	3-5	5-8	2-4	6-8	75-84
Pine charcoal[5]	5-9	8-15	3-4	6-15	57-78
Pine charcoal[6]	20-28	4-10 ppm	NA	0.06-0.1	72-80

NA-non-available 1. At PAU after LT shift reactor without the steps of PROX and CO2 scrubber; 2. At KTH; 3. At PAU gasifier without shift reactors; 4. At PAU after shift reactors; 5. At TNAU with / without shift reactors and gas removal.

After a series of steps where CO and steam are converted in shift reactors into hydrogen, the rest CO is oxidized in a preferential oxidation reactor (PROX) to ppm levels and the CO2 removed in a soda lime bed, the hydrogen is fed to the anode, while air or oxygen is supplied to the cathode of the fuel cell. An Elenco module with a nominal power output of 320 W was a circulating 6.9 M KOH as electrolyte at 65^{o}C was used for the assessment of the fuel cell performance. Groundnut shell, bagasse and maize cob charcoals as shown in table 1 are suitable feedstocks as their biochars contain high concentrations of hydrogen as well as lower CO content compared with the other wood species. The charcoal consumption rate of the gasifier varied between 0.14 and 0.16 kg h^{-1} with gas production rates of 0.35 to 0.58 Nm^3 h^{-1} depending on the type of the feedstocks.

Reformed hydrogen/pristine hydrogen gas and air/oxygen were fed to the fuel cell module in order to substantiate the power output and open cell voltages (OCV) for respective gas combinations. Table 2 summarises the type of gases, OCV, current loads, voltages, total power outputs and the percentages of power developed as compared to the nominal power of the fuel cell.

Table 2. Characteristics of the fuel cell with different gas inlets to the anode and cathode

Type of gases	OCV (V)	Current (A)	Voltage (V)	P (W)	%
O2/H2	5.75	60	4.89	293.4	91.7
Air/ H2	5.63	60	4.85	291.0	90.9
Air/P-gas	5.60	60	4.83	289.8	90.6

P-gas-hydrogen from a producer gas

The main discrepancy in the power output compared to pure hydrogen and oxygen lies in the electrode kinetics of the catalysts, where the presence of nitrogen (79%) in air decreases the available reaction sites for the oxygen molecules to a significant level. Furthermore, the flow rate of air has to be raised in order to meet the required stoichiometric amount of oxygen to carry out the cathodic reaction. The studies on the integrated biofuel to fuel cell clearly show the verification of the system and the possibility of decentralised power production. Another interesting aspect of biofuel to fuel cells is the current ongoing project of Bio-FC, a Swedish-Asian Research Partnership Programme, funded by SIDA-VR (Swedish research Council), which entails a study of producer gas in combination with LTSOFC (Low temperature solid oxide fuel cell). This project is particularly interesting in that the gas cleanup is not necessary. Gases, for example CO2 is either inert or diluent in the fuel cell and the CO may serve as a fuel together with hydrogen. Here too, the indelible experiences in gasification, tar removal, electrode preparation, test assembly and analyses of TNAU researchers are of utmost importance for the project.

CONCLUSION

Conversion of biofuels as renewable energy sources to high-grade power utilization is imminent in order to meet the energy requirements and needs of the future. The extensive exploitation and use of fossil fuels with ever dwindling reserves followed by environmental degradation have to pave way for the replacement by sustainable development with the environmentally friendly biofuel and hydrogen economy. Fuel cells for conversion of fuels with high-energy efficiency have shown to be one of the realistic options towards this end. TNAU as one of the partners in our joint projects has shown the competencies in fulfilling and accomplishing the tasks for research, development and technical demonstration by supplementing the knowledge-base gathered over the years. TNAU as one of the leading institutions of India not only works on education and close exchange of ideas and results with the society and collaboration with other Universities and Institutes in India and other countries but also contributes to the betterment of the environment through research, development and introduction of renewable energy production by wind, solar, gasification of biomass, esterification of oil seeds, etc.

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EMERGING POST HARVEST TECHNOLOGIES AND VALU E ADDITION IN RICE

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India has achieved an enviable position among the countries of the world due to its surplus food production, within a short time from the status of a food importing country. This is due to the great efforts of the Scientists, extension personnel and the farmers. As the production technology is an interdisciplinary approach, the post production technology or post harvest technology is also equally interdisciplinary in nature including the disciplines of Entomology, Engineering, Microbiology, Biochemistry, Economics, Food Science and Extension. Out of 120 million tonnes of paddy produced in India every year, nearly 60-70 percent is utilised within the country and considerable quantity is exported to other countries. As the people have become quality conscious, production of quality rice has become inevitable. The significant role played by the production agencies in making the country secure in food should be matched by the post production agencies to avoid the losses in quantity and quality and ensure the nutritional security as well.

Harvest, drying and storage of paddy

The appropriate stage of harvest in paddy has a tremendous influence on the field yield of paddy and the yield of raw rice. Rice is mostly preferred in the form of head rice or whole kernel. The delayed harvest in paddy crop leads to the formation of cracked kernels or sun checks. The preferred stage of harvest is when a few grains in the lower part of the panicle are green and the approximate moisture content of grains are 20-22 per cent. At a very late stage of harvest more and more of multiple transverse cracks and irregular cracks are found in the kernels. The improper use of threshers for paddy also lead to breakage and damage to paddy grains affecting the yield and quality of rice to a great extent. Cracks or fissures are the single largest source of breakage during milling. The harvested paddy at 20-22 per cent moisture content has to be reduced to 13-14 per cent gradually keeping in mind that it should be handled as a grain and not as a seed. Improper drying either manually in yard or mechanically in driers lead to heavy breakage, reducing the rice out turn and the market value. Thus, a potential yield of 72 per cent rice from 100 kg of paddy is seldom achieved in our country, even in modern rice mills. The storage of paddy is normally done for a period of six months to one year.

However, paddy stored for more than a year and upto three years are considered to be valuable, especially in case of Basmati. If the moisture content of stored paddy is above 14 per cent or if the ambient humidity is more than 70 per cent, the grains get heated up, germinate and become discoloured. They are also infected with microbes, leading to caking up of grains and production of aflatoxin. When the grain is infested with insects, even slight nibbling by the larvae weakens the rice kernel, resulting in more brokens.

Parboiling and milling of paddy

The paddy is soaked in water for hydration, steamed for thermal treatment to obtain gelatinization and then dried. Thus parboiling hardens the grain and the cracks or sunchecks in the kernel are fused due to which the milling quality is improved yielding 2 per cent more of rice out turn. This is the major advantage in parboiled rice, apart from some of the nutritional improvement. Hence, one fifth of the world paddy production and 50 per cent in India is estimated to be parboiled. There are number of technologies to produce the parboiled rice of desired quality from thousands of paddy varieties available from various parts of the country. Some of the examples are cold soaking method, hot soaking method, single steamed parboiled rice, double steamed parboiled rice, pressure steamed parboiled rice, white core parboiled rice, fully gelatinized rice, “Sela Rice”, Golden rice, cured or steamed rice and so on. Since millions of paddy grains are obtained from the primary tillers and subsequent tillers of the paddy plant, the maturity vary from grain to grain and in turn the behaviour of grains for various processing treatments. All these variations should be taken into account and produce the rice of nearly uniform quality.

Milling of paddy is the mechanical removal of husk to yield brown rice and in turn polish the brown rice to remove some amount of bran and yield milled rice. This can be done by hand pounding or using a huller with metal shaft or by rubber rolls followed by friction or emery polishers. The extent of polish given to brown rice is generally 5-6 per cent so that the rice is nutritious and safe for insect free storage, as brown rice is highly susceptible to insects. However, in the commercial market, rice is polished even 8-10 per cent to make it white and shiny in appearance which reduce the outturn and nutritional quality. The polish should be in two or three passes with a bran removal of 2-3 per cent in each pass. The initial polish can be given by an abrasive polisher and the final one with a friction polisher. Silky rice can be produced by humidified polisher or water mist polisher. Grading and removal of discoloured rice can be done by using a colour sorter.

Value addition in rice

The processing at every stage after harvest of paddy leads to value addition such as conversion into rice and upto final produce ready for consumption. The major quantity of paddy after primary processing is consumed as whole kernel and the remaining quantity is either used after secondary or tertiary processing into products like expanded rice, flaked rice, popped rice, quick cooking rice, fermented products, noodles, infant foods and extruded products.

In India there are about 1,40,000 rice mills, out of which nearly one lakh are traditional and 40,000 are modern rice mills. About 60 per cent of the paddy produced is milled in modern mills and the traditional mills process about 30 percent of the production. The traditional huller mills either process 5-10 tonnes per day or on custom basis. The cost of a huller mill may be Rs.50,000 – Rs.60,000 and that of a minimum capacity modern rice mill (300-400kg/h) may be Rs.1 lakh. Nowadays, there is an increasing demand for minimally processed rice, equivalent to hand pounded rice. Irrespective of the type or quality of rice, from any variety of paddy including basmati / aromatic superfine varieties can be processed in any milling machinery, provided the processing technology is adopted properly and the man behind the machine is capable of.

Expanded rice is a value added product from paddy, involving cumbersome steps. This is a cottage industry processing about 100 kg paddy / day by sand roasting, the preconditioned rice as a fully gelatinized one. However, higher capacity units are prevalent in West Bengal and Gujrat. In West Bengal, the modern rice mills produce pressure paraboiled rice in large quantity and such rice is used in higher capacity sand roasters to produce expanded rice. All paddy varieties are not suitable for expanded rice and some of the preferred varieties are Intan, Bhavani, Jaya, IR 64, ADT 38, Co 37 and so on. In general 100 kg of paddy may yield 60 kg of expanded rice, but the expansion in volume of rice may be about 10 times.

Similarly, flaked rice is another value added product, involving the expertise of technologists and use of machineries like edge runners or flaking machines. Commercial flaked rice units processing 10-20 tonnes per day are common in Gujarat and Karnataka. Some of the best suited varieties of paddy for flaked rice are IR 8, Gujri, CO 43 and TRY 1. Thin, medium and thick types of flaked rice are produced and the out turn varies from 65-70 per cent. Popped rice is yet another value added product prepared from raw paddy. However, the production of popped rice is comparatively less and mostly used in religious ceremonies. Quick cooking rice a precooked and gelatinized product and its cooking time is 7-10 minutes compared to 20-25 minutes for raw rice. Similar to wheat vermicelli, rice vermicelli can also be prepared and used for various food preparations. Weaning foods, using rice flakes as the ideal base material and fortifying with protein, minerals and vitamins are some of the value added products of rice meant for the use of specific target groups. The fermented products of rice like Idli and Dosa are quite popular and widely used. The instant Idli mix without the need for wet grinding has become quite convenient for the city dwellers. In the recent past, the production of high volume, crispy products prepared by extrusion of rice alone or in combination with other foods grains as snack foods has become a tremendous success in value addition of rice. The cumbersome process, the need for specific variety of paddy and the quality of rice as whole kernels are dispensed with, for preparation of a product similar to expanded rice by the use of extruders.

Apart from the rice, its byproducts like brokens and rice bran are profitably utilized for production of alcohol and extraction of bran oil respectively.

NUMBER OF RICE MILLS AS ON 01.01.2002

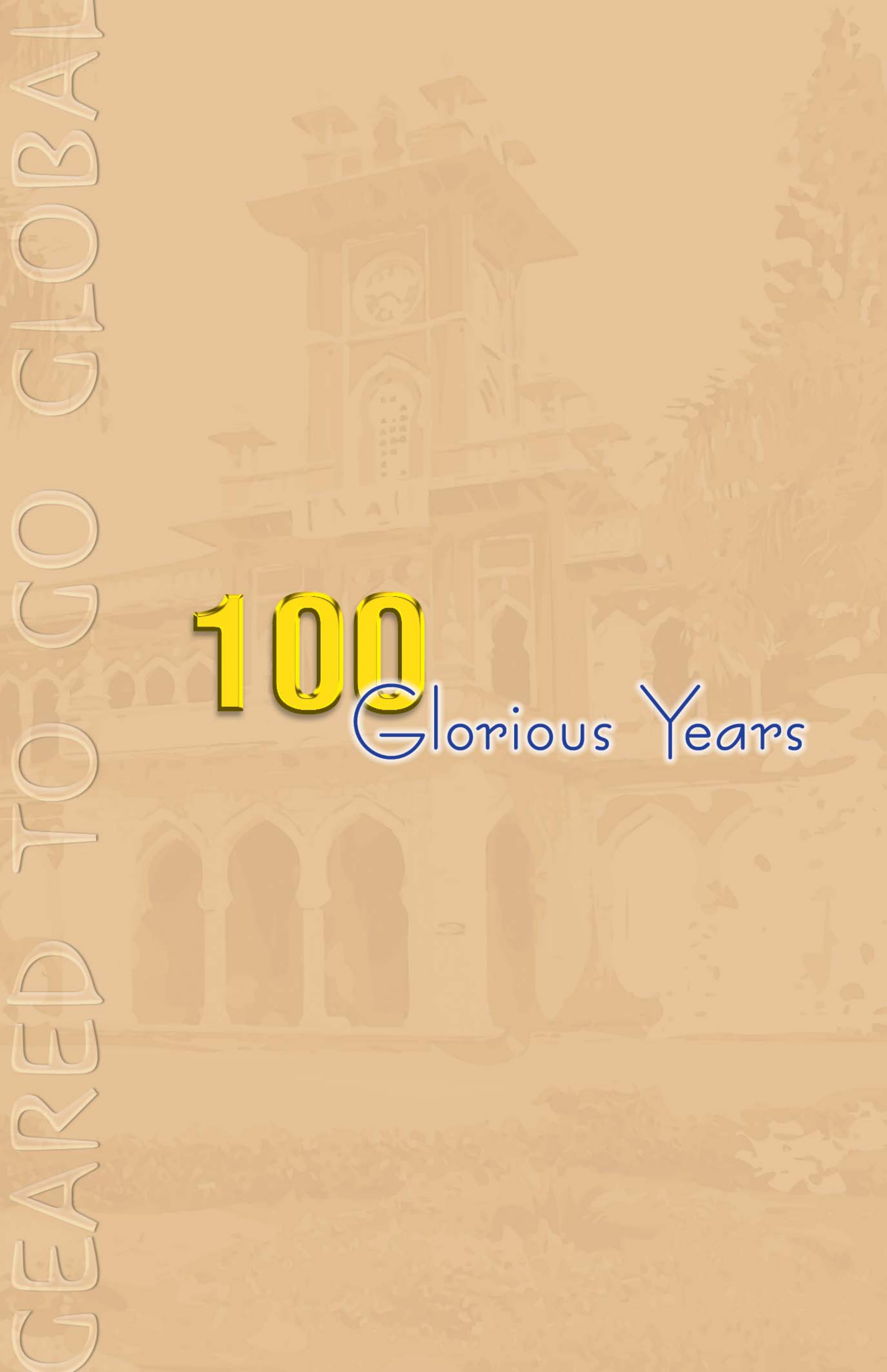
S. No.	Name of State	Hulles	Shelles	Hullers Shelles	Modern Rice Mills	Total
1.	Andhra Pradesh	4609	1776	2364	12995	21744
2.	Assam	431	14	2133	242	2820
3.	Bihar	4749	63	9	51	4872
4.	Gujarat	1890	159	67	1045	3161
5.	Haryana	807	-	-	990	1797
6.	Himachal Pradesh	890	1	3	222	1116
7.	Jammu & Kashmir	-	-	-	-	-
8.	Karnataka	9131	462	1103	3674	14370
9.	Kerala	13664	-	13	2533	16210
10.	Madhya Pradesh	3918	201	262	1761	6142
11.	Maharashtra	8199	273	541	1759	10772
12.	Manipur	838	-	-	660	1498
13.	Meghalaya	252	-	8	-	260
14.	Nagaland	-	-	-	-	-
15.	Orissa	6398	125	289	552	7364
16.	Punjab	4416	442	-	1965	6823
17.	Rajasthan	152	2	6	193	353
18.	Sikkim	17	-	-	-	17
19.	Tamil Nadu	13684	448	1324	3922	19378
20.	Tripura	1030	6	8	1	1045
21.	Uttar Pradesh	5707	562	150	145	7834
22.	West Bengal	9554	3	72	926	10555
23.	Andaman & Nicobar	116	-	-	-	116
24.	Arunachal Pradesh	1	-	-	-	1
25.	Chandigarh	16	-	-	11	27
26.	Dadra & Nagar Haveli	8	1	-	-	9
27.	Delhi	2	-	-	27	29
28.	Goa	670	-	25	56	751
29.	Mizoram	-	-	-	-	-
30.	Pondicherry	138	-	8	88	234
31.	Lakshadweep	-	-	-	-	-
	TOTAL	**91287**	**4538**	**8385**	**35088**	**139298**

List of Rice Mill Machinery Manufacturers

M/s.Mill more Engg. Pvt Ltd 289, Old Mahabalipuram Road Sholinganallur, Chennai 600 119	M/s.Jayalakshmi Engineering Works 12-B, Big Mill Street Tiruvarur 610 001
M/s Damu Agencies Shop No.6, Ishwar Trade Centre Opp Dr. Nanjappe Road Church Grey Town, Coimbatore - 641 018	M/s Zaccaria Rice Milling Machinery and Grain Drying Systems RUA LARANJAL, 180-C, Posta/54-CEP 13484-016
M/s.Bulher (India) Pvt Ltd 13D, KIADB Industrial Area Attibele – 562 107 Bangalore	M/s Satake Corporation 11th Floor, Dr. Gopal Das Bhavan Bharakhamba Road New Delhi - 110 00
Sri New Tech Milling Plot No: 41, Ekambara Naicker Indl. Estate Alapakkam, Porur Chennai 600 116	M/s.Sahara Milling System Pvt.Ltd. 9, Sardar Colony Main Road Ekkaduthangal Chennai 600 097
M/s.Millstroes (Madras) Pvt Ltd Mew No. 236-A,Angappa Naicker Street, PO Box No. 4 Chennai 600 001	M/s.Agro Mech Engineers 374, Patil Road Coimbatore 641 009
M/s.Binny Engineering Limited Meenambakkam Post Box No. 8677 Chennai 600 114	M/s.Photons 19, Rajeshwari Nagar Thanjavur 613 005
M/s.Perfect Equipments No.7, Multi Industrial Estate Gerugambakkam Chennai 602 101	M/s.Samdan Industrial S-8, Sidco Industrial Estate Nanjikkottai Road Thanjavur 613 006
M/s.Southern Milling Systems 479, Bangalore High way Nazarathpet, Poonamalle Chennai 600 103	M/s. G.G.Dandekar Machine Works Ltd Dandekarwadi Bhiwandi 421 302 Thane Dist. (M.S.)

Milling capacity and approximate cost **Year : 2000**

Description	1t/h	2t/h	3t/h of paddy capacity
Paddy cleaner	2 HP	2 HP	2HP
RR sheller with husk aspirator	7.5HP	10HP	10HP
Paddy separator	2 HP	2 HP	2 HP
Primary polisher	15 HP	25 HP	2 Nos-25 HP x 2
Final polisher	10 HP	20 HP	20 HP
Aspirator cum sieve	2 HP	3 HP	3 HP
Double elevators	3 Nos-1 HP x 3	3 Nos-1 HP x 3	3 Nos-1HP x 3
Bran separator	1 No-2 HP	3 HP	5 HP
Mill cost	Rs.5,25,000/-	Rs. 6,00,000/-	Rs. 7,00,000/-
Electricals cost cable, control panel, etc.	Rs.3,00,000/- (50HP)	(95 HP) - 4,00,000/-	100 HP- 5,00,000/-
Space required for milling	11x7x7m height	11x7x7m height	11x7x7m height
Recommended size of building	25x12x7m height	25x12x7m height	25x12x7m height
	(82'x40'x23')		
Land Rs.25/- sq.ft.	1,00,000/-		
Building Rs.300/- sq.ft.	10,00,000/-		
Total cost	**20,00,000/-**	**23,00,000/-**	**25,00,000/-**



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