TNAU-IFPRI Collaborative Research Project
on

Methane Reduction in Rice Farming Systems in Tamil Nadu

Training Manual

Centre for Agricultural and Rural Development Studies (CARDS)
Tamil Nadu Agricultural University, Coimbatore
&
International Food Policy Research Institute (IFPRI)
Washington DC, USA

2025

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Foreword

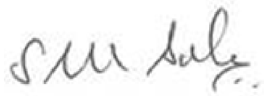
Under the Paris Agreement, countries have committed to reduce greenhouse gas emissions through their Nationally Determined Contributions (NDCs). One major and hazardous greenhouse gas is methane, which is significantly more potent than carbon dioxide. The agriculture sector is an important source of methane emissions in developing countries, particularly from paddy rice cultivation. Thus, addressing methane emissions in developing countries through technological innovations in rice production systems is a timely and prudent climate intervention.

India is highly vulnerable to the effects of climate change but is also among one of the major emitters of methane especially from its large agriculture sector. Rice is a major staple food in India. Grown in flooded fields, called paddies, rice cultivation creates ideal anaerobic conditions for bacteria that emit methane. Methane emission is higher in southern and eastern parts of India, including the state of Tamil Nadu, due to expansive flooded rice cultivation.

In this regard, the International Food Policy Research Institute (IFPRI) in collaboration with Tamil Nadu State Agricultural University (TNAU) and other partners is implementing a Global Methane Hub (GMH) funded project which aims to strengthen the capacity of local, institutional, and innovation systems for achieving the climate goals through methane emission reduction technologies in the rice production systems. A pilot program is being implemented in 20 local administrative units (Panchayats) in the state of Tamil Nadu, India. The long-term goal is to scale this program in an additional 200 panchayats in Tamil Nadu and other rice-growing states in India.

The project recognizes that agriculture extension systems are pivotal to improving farmers' knowledge and enhancing the adoption of sustainable and resilient practices. Extension systems provide farmers with proper guidance and training to enhance agricultural production/productivity, access the markets, connect with local climate change actors, and monitor and evaluate the impact of adopted strategies. This training manual has been developed as part of the effort to strengthen the capacity of extension system professionals to support farmers on implementing climate resilient methane reduction technologies. Using the manual, training workshops will be conducted for local extension professionals on the i) impact of rice production on climate change; ii) available methane reduction technologies, iii) methane measurement and analysis; iv) empowering rural women to support climate action.

On behalf of IFPRI and TNAU, we thank GMH for the support of funding and all our collaborators and partners for their contributions to this important and timely work.



Suresh Babu,

Head, Capacity Strengthening, IFPRI

About the Scheme

The Research Project on Methane Reduction in Rice Farming Systems in Tamil Nadu is a strategic initiative aimed at addressing the critical challenge of methane emissions from rice cultivation. It is a joint effort between the Tamil Nadu Agricultural University (TNAU) and the International Food Policy Research Institute (IFPRI), with contributions from leading experts in various fields. The project focuses on strengthening local, institutional and innovation systems to achieve climate goals through the adoption of methane emission reduction technologies in rice production systems.

The core activities under this project include conducting a baseline survey to assess the current status of farmers' adoption of sustainable practices. To enhance capacity-building, the project will implement field demonstrations, Farmer Field Schools (FFS), and training programs for Farmers, Agricultural Extension Officers and Panchayat Officials. Additionally, Primary and Secondary data will be collected to evaluate the impact of climate-resilient agricultural practices on yield, profitability and environmental sustainability. By integrating scientific research with community-driven initiatives, the scheme aims to foster a sustainable and climate-smart rice farming system in Tamil Nadu.

Importance of the Scheme

Rice farming is a major contributor to methane emissions, posing a challenge to climate change mitigation. The TNAU - IFPRI Collaborative Research Project will address by promoting low - emission rice farming techniques to reduce methane emissions, improve resource use efficiency and enhance farmers' resilience to climate variability.

A key focus of the project is knowledge dissemination and farmer empowerment through training programs and field demonstrations, ensuring widespread adoption of climate-resilient practices. By integrating training with data-driven impact assessments, the project strengthens farmers' capacity and provides valuable insights for policymakers in developing climate - smart agricultural policies.

Aligned with National and Global climate goals, this initiative supports sustainable development, food security and environmental conservation. The adoption of methane reduction technologies will enhance productivity, improve farm incomes and strengthen climate adaptation strategies, making this project a model for scaling up sustainable rice farming across India.

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An Overview of Rice Cultivation

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Rice (*Oryza sativa L.*) is the main source of food for more than half the world's population and its cultivation secures a livelihood for more than two billion people. It is the largest consumed cereal catering to the needs of about 70 percent of the world population and about 90 percent of the Asian population. It is grown by more than 200 million small rice farmers with landholdings of less than one hectare. The introduction of high-yielding varieties, fertilizers, pesticides and irrigation has improved rice yields significantly and expanded the area in which rice is cultivated. However, in the last 20 years, the rice yield and the area under rice have stagnated. The two most significant reasons for this stagnation are the lack of adequate water for irrigation and the increased costs of cultivation. It is estimated that India will need to produce more rice if it is to meet the growing demand, likely to be 130 million tonnes of milled rice in 2030. Since there is not much scope to increase the area of rice cultivation (due to urbanisation and severe water constraints), the additional production will have to come from less land, less water and less human labour. It is estimated that to produce one kilogram of rice requires 3,000-5,000 litres of water. About two or three times more water is needed for rice cultivation than other irrigated crops. Evidence shows that the irrigated rice receives 34-43 per cent of the world's irrigation water.

India ranks first in total area under rice cultivation of 47.82 million hectares but ranks second in total rice production of 137.83 million tonnes. As of Tamil Nadu is concerned, during the 2022-2023 season, the area under rice cultivation was recorded at approximately 2.1 million hectares, constituting 34.48% of the gross cropped area, with a production of 7.5 million tonnes.

Rice plays a major role in the Indian economy and ninety per cent of the rice produced is consumed within the country. In the year 2022-23 India exports 4561.21 thousand tonnes of basmati rice to other countries, worth of Rs.38525.37 crores, 17792.14 thousand tonnes of rice (non basmati) worth of Rs.51096.73 crores and imported non basmati rice variety for Rs.43.99 crores (6.71 thousand tonnes). Rice provides about 30% of total calories in the Indian diet. Growth in population and economic prosperity are the two driving forces for increasing rice demand in India. Given that the country still has about 37 per cent of its population below the poverty line the growth in rice production and productivity is critical to the wellbeing of millions of consumers as well as producers.

1.1. Trend in Area, Production and Productivity

1.1.1 Rice Production in India

In India, rice is cultivated under diverse soil and climatic conditions, but its productivity remains low compared to many other rice-producing nations worldwide. One of the major constraints to to increasing productivity is that about 90% of the cultivated land is owned by marginal, small, and medium farmers, limiting access to advanced technologies, mechanization, and efficient resource management.

An analysis of long-term trends in rice cultivation (1950-51 to 2023-24) reveals significant changes in both cultivated area and production levels. A visual representation (Fig. 1) highlights how rice production has increased substantially, even though the expansion in cultivated areas has been relatively moderate. This suggests that improvements in productivity have been the key driver of enhanced production, largely influenced by technological advancements, policy interventions, and modern farming practices.

Rice production in India has experienced a significant upward trajectory, increasing from 20.58 million tonnes in 1950-51 to 137.83 million tonnes in 2023-24. This growth can be attributed to advancements in agricultural practices, the introduction of high-yielding varieties during the Green Revolution, improved irrigation facilities, and widespread adoption of modern agronomic techniques. Over the same period, the area under rice cultivation has expanded from 30.81 million hectares to 47.82 million hectares, but this increase is considerably lower compared to the rise in production, indicating a significant boost in productivity per unit area.

A closer look at the trends reveals a widening gap between production and cultivated area, reinforcing the fact that yield improvements, rather than land expansion have fueled production growth. This shift has been driven by mechanization, precision agriculture, better nutrient management, and climate-smart farming techniques.

Given the limited scope for further land expansion, future increases in rice production must rely on enhancing productivity through innovative approaches. Strategies such as precision farming, climate-resilient varieties, water-efficient irrigation methods, and digital agriculture solutions will play a crucial role in ensuring sustainable rice production and food security in India.

Top 3 Districts in Rice Cultivation in Tamil Nadu (2023 - 24)

Tiruvarur – 2.24 lakh ha

Thanjavur – 2.09 lakh ha

Tiruvannamalai – 1.84 lakh ha

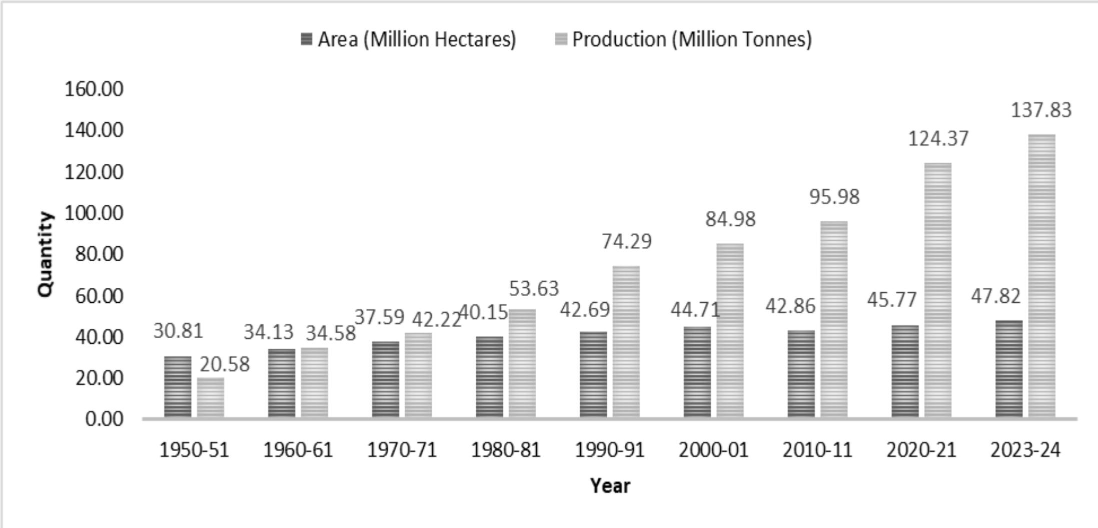


Fig 1. Area and Production of Rice in India

1.1.2 Rice Production in Tamil Nadu

Rice cultivation in Tamil Nadu plays a significant role in the state's agricultural sector, contributing notably to India's overall rice production. As per the 4th Advance Estimates for 2021-22, Tamil Nadu has a total rice cultivation area of 2.21 million hectares, accounting for 4.76% of the total 46.38 million hectares under rice cultivation in India. Despite ranking 10th in terms of area, the state has achieved higher productivity, producing 8.07 million tonnes of rice, which is 6.19% of India's total rice production of 130.29 million tonnes, positioning Tamil Nadu as a key contributor at the national level. This highlights the state's efficient agricultural practices, irrigation facilities, and adoption of high-yielding varieties, ensuring higher output despite a relatively smaller cultivated area.

The region's rice cultivation adheres to Kar / Kuruvai / Sornavari (April-July), Samba / Thaladi / Pishanam (Aug-Nov), and Navarai / Kodai (Dec-Mar) make up the three-season pattern. Rice accounted for a sizeable portion of the state's agricultural landscape in 2022–2023, making up 34.5% of the entire gross cultivated area.

Table 1. Last 5 years Rice Area in Tamil Nadu

(in 000' ha)

Season	2023-24	2022-23	2021-22	2020-21	2019-20
Kar/Kuruvai/Sornavari	435	421	413	307	2065
Samba/Thaladi/Pishanam	1290	1407	1449	1318	1360
Navarai/Kodai	375	330	354	410	339
Total Rice	2101	2158	2217	2036	1907

Table 2. Last 5 years Rice Production in Tamil Nadu

(in 000' tonnes)

Season	2023-24	2022-23	2021-22	2020-21	2019-20
Kar/Kuruvai/Sornavari	1557	1620	1690	1339	847
Samba/Thaladi/Pishanam	4031	4622	4801	3849	4954
Navarai/Kodai	1439	1313	1414	1693	1463
Total Rice	7048	7556	7906	6881	7265

Table 3. Last 5 years Rice Yield Rate in Tamil Nadu

(in kg/ha)

Season	2023-24	2022-23	2021-22	2020-21	2019-20
Kar/Kuruvai/Sornavari	3617	3848	4085	4359	4104
Samba/Thaladi/Pishanam	3124	3284	3313	2920	3641
Navarai/Kodai	3839	3975	3994	4120	4303
Total Rice	3354	3500	3566	3380	3809

Table 4. Area of Rice in Tamil Nadu During the year 2023-24

District	Area (in Ha)			
	Kar / Kuruvai / Sornavari	Samba / Thaladi / Pishanam	Navarai / Kodai	Total Area
Thanjavur	78447	117231	14054	209732
Tiruvarur	70192	144689	9431	224312
Tiruvannamalai	40835	75979	68111	184925
Cuddalore	38441	93230	11082	142753
Ramanathapuram	0	139667	480	140147
Mayiladuthurai	38446	68983	88	107517
Villupuram	10316	57528	24314	92158
Tiruvallur	25153	50845	27650	103648
Pudukkottai	8043	82460	5407	95910
Nagapattinam	24862	64685	160	89707
Sivagangai	1088	76147	2049	79284
Tiruchirapalli	6198	31866	6466	44530
Kallakurichi	9766	36467	11870	58103
Madurai	1482	19151	20208	40841

Chengalpattu	12206	16592	29572	58370
Kancheepuram	11636	13749	28856	54241
Ranipet	16069	13365	20290	49724
Tenkasi	3535	21474	16762	41771
Tirunelveli	2606	18403	17639	38648
Erode	4516	15122	4429	24067
Krishnagiri	4991	15035	9157	29183
Virudhunagar	1142	23827	6155	31124
Dharmapuri	1025	17841	3555	22421
Ariyalur	4823	17890	124	22837
Salem	487	12058	3352	15897
Karur	3	8182	620	8805
Dindigul	1669	5829	6170	13668
Theni	5357	5206	2879	13442
Thoothukudi	1066	1505	11196	13767
Kanniyakumari	5490	5702	26	11218
Namakkal	755	3955	899	5579
Tiruppur	809	4284	3054	8147
Vellore	2661	2644	4748	10053
Tirupathur	1592	4742	1292	7626
Perambalur	220	3869	2814	6903
Coimbatore	60	211	94	365
Chennai	8	72	15	95
The Nilgiris	0	78	0	78

Table 5. Production of Rice in Tamil Nadu During the year 2023-24

District	Production (in tonnes)			
	Kar /Kuruvai / Sornavari	Samba / Thaladi / Pishanam	Navarai /Kodai	Total Production
Thanjavur	297255	378272	46622	722149
Tiruvarur	198972	425836	36168	660976
Tiruvannamalai	167913	275163	275379	718455
Cuddalore	148686	295889	44503	489078
Tiruvallur	99926	143294	105595	348815
Villupuram	40079	219320	80404	339803
Pudukkottai	35505	238648	18475	292628

Mayiladuthurai	132806	186237	336	319379
Nagapattinam	62282	179948	616	242846
Tiruchirapalli	22743	123691	24339	170773
Chengalpattu	51446	62145	111888	225479
Kallakurichi	35482	140745	46426	222653
Madurai	5362	76508	72787	154657
Sivagangai	3937	173269	7867	185073
Kancheepuram	44649	47671	137165	229485
Ranipet	67880	51499	76956	196335
Tirunelveli	10060	82865	77367	170292
Tenkasi	12253	75724	55920	143897
Krishnagiri	21469	66271	40323	128063
Erode	16336	62538	17003	95877
Dharmapuri	3708	74129	14833	92670
Ramanathapuram	0	285991	1841	287832
Ariyalur	14258	67819	477	82554
Salem	1762	52159	13694	67615
Virudhunagar	4131	65539	18525	88195
Karur	11	27404	2382	29797
Dindigul	6038	23249	20160	49447
Namakkal	2731	15963	3451	22145
Thoothukudi	3856	2659	29913	36428
Theni	23639	23040	11053	57732
Tiruppur	2928	20338	11720	34986
Tirupathur	5757	19081	4959	29797
Kanniyakumari	22523	22448	101	45072
Vellore	9625	8260	19259	37144
Perambalur	794	16629	10801	28224
Coimbatore	216	659	360	1235
Chennai	28	219	58	305
The Nilgiris	0	244	0	244

(Note: All the season, area, production, productivity of Tamil Nadu data are taken from Season and Crop Report 2023-24)

1.2 Climate Change and Rice Production

Climate change and its impacts have received much attention from policy makers and others in recent decades. It is understood that climate change increases risk, particularly for those who rely on weather patterns, agriculture, water, and other natural resources for their livelihoods. It is found that an increase in temperature in India could reduce farm net revenues by 9- 25 Percent. The changes in temperature, radiation, rainfall and carbon dioxide levels can affect the yield of rice through their direct effect as well as indirect effects such as weather-induced changes in incidence of pests and diseases, and the requirement or availability of water for irrigation

An analysis of the historical trends in the yield of the rice crop in the Indo–Gangetic plains has shown that rice yields during the last three decades are showing a declining trend and this may be partly related to the gradual change in weather conditions in the last two decades. The simulation analysis indicated that irrigated rice is likely to lose yields of up to 23 percent in Upper the Ganga Basin. Climate change is likely to reduce the yields of rice productivity in 16 major agriculture intensive states of India. It is also found that productivity of rice has declined by 41 per cent with 40°C increase in temperature in Tamil Nadu. And also rice cultivable land has declined due to scarcity of inputs and scanty rainfall in Tamil Nadu (India). An increase in minimum temperature of up to 10°C causes a decrease in the yield of rice by 3% in Punjab (India). Change in temperature up to 50°C lead to a continuous decline in the yield of rice and every one degree increment in temperature will leads to a 6 per cent decline in the yield of rice in Kerala. Rice production may decline by 31per cent in 2080 due to climate change in Bihar.

Grain yield of rice, for example, declined by 10 per cent for each 1 °C increase in temperature above 32 °C. The climate change impact on the productivity of rice in Punjab (India) has shown that with all other climatic variables remaining constant, temperature increase of 1°C, 2°C and 3°C, would reduce the grain yield of rice by 5.4 percent, 7.4 percent and 25.1 percent respectively.

Given the significant impact of climate change on rice production, it is imperative to adopt suitable climate-resilient technologies to sustain and enhance rice yields. Rising temperatures, erratic rainfall patterns, and increased vulnerability to pests and diseases necessitate the implementation of adaptive strategies such as stress-tolerant rice varieties, improved water management practices, precision farming techniques, and integrated pest management. This training manual provides a comprehensive guide to climate-resilient technologies specifically designed for rice cultivation, equipping farmers and stakeholders with the necessary knowledge to mitigate climate risks and ensure sustainable productivity in the face of changing environmental conditions.

Climate Resilient Technologies 2

2.1. Direct Seeded Rice

Rice, a semi-aquatic crop, is primarily grown using transplanted or direct-seeded systems. The transplanted system, though effective, is resource-intensive, requiring more water, contributing to methane emissions, and increasing labour demand. In contrast, Direct Seeded Rice (DSR) improves water and nitrogen efficiency, reduces greenhouse gas emissions, and lowers labour needs, making it a more sustainable alternative. Once common before the Green Revolution, DSR is regaining popularity due to its water and labour-saving benefits.

DSR helps farmers adapt to climate challenges by reducing water use and offering flexible planting methods. It enables early crop establishment, lowering the risk of late-season drought and minimizing irrigation costs while preserving soil structure rotation to prevent resistance. However, DSR faces challenges such as severe weed infestations, requiring proper herbicide management and crop rotation to prevent resistance. Limited farmers knowledge about herbicide use and DSR techniques can hinder effective sowing and crop establishment. Early sowing (May-June) may also complicate harvesting due to heavy rains, while fragmented landholdings and water shortages further challenge adoption.

DSR involves direct seeding into fields with retained crop residues using advanced machinery, reducing the need for rice straw burning and associated air pollution. It lowers greenhouse gas emissions, reduces physical strain on female labourers, and cuts cultivation costs by Rs. 5000-6000 per hectare.

Developing a resource-efficient and sustainable rice cultivation system is crucial for addressing climate change and emerging risks. DSR presents a viable alternative, ensuring higher yields with less labour while optimizing water use in an environmentally friendly manner.

Direct Seeded Rice (DSR) is a cultivation method where rice seeds are directly sown into the main field instead of transplanting seedlings from a nursery. This can be done by planting pre-germinated seeds in puddled soil (wet direct seeding) or in a well-prepared, non-puddled seedbed (dry direct seeding). A major challenge, especially in dry DSR, is weed infestation, which can cause yield losses of up to 85% if not effectively managed. Seed priming with water and potassium chloride (KCl) has shown potential in enhancing crop establishment.

a) Dry Direct-Seeded Rice (D-DSR)

D-DSR is a method where dry seeds are directly sown into the main field without pre-germination. It is commonly practiced in rainfed uplands, medium lowlands, lowlands, and deepwater areas during the wet season. Weed infestation is a major challenge in D-DSR but can be effectively managed with post-emergent herbicides. This technique offers notable advantages, including up to 30% water savings compared to transplanted rice and an 18-20% reduction in methane (CH_4) emissions. Additionally, D-DSR decreases labor dependency, enhances seedling establishment, and reduces the likelihood of lodging.

b) Wet Direct-Seeded Rice (Wet-DSR)

Wet-DSR is an effective solution when the monsoon arrives late, delaying sowing. By utilizing irrigation and sprouted seeds, farmers can establish their crops on time while using less water than conventional transplanting. When properly managed, Wet-DSR can yield results comparable to transplanted rice. Furthermore, it improves water productivity by 0.3 to 0.4 kg of rice per cubic meter of water consumed.

Precision Land Levelling

Laser land levelling is a key technology that improves water management, weed control, and overall crop performance, making it essential for the success of DSR. Uneven fields disrupt drill operations, affecting seed placement, germination, and crop establishment. This leads to inefficient nutrient-water dynamics, increased weed competition, higher energy consumption, and greater production costs. Poor land levelling can also cause a 10-25% loss of irrigation water, reducing yields and increasing irrigation expenses (Kahlown et al., 2007; Jat et al., 2006).

Traditional levelling with plankers often results in uneven slopes (1º to 3º), which hinders DSR establishment. Precision land levelling, especially with laser technology, enhances crop growth in non-puddled soil, improving no-till surface seeding and permanent bed planting. It also ensures better drainage, supporting seed emergence after rainfall.

Seed Drill for Direct Seeding

Various seed drills are used for direct seeding, including conventional seed-cum-fertilizer drills, zero-till drills, inverted T-Tyne zero-till drills, and drills with vertical or inclined plate metering mechanisms. Among these, machines with an inclined plate metering mechanism are the most suitable for dry direct-seeded rice (DSR) as they ensure uniform row and seed spacing while reducing seed breakage. For dry DSR, seeds should be sown at a depth of 2–3 cm, while in pre-sowing irrigation conditions, a depth of 3–5 cm is ideal. The recommended row spacing is 20 cm.

Suitable Soil Type

Heavy-textured soils are best for DSR as they have fewer iron (Fe) and zinc (Zn) deficiencies than sandy soils, which struggle with low water retention. Soil type significantly affects sowing methods and pre-emergence herbicide effectiveness.

In medium-textured soils, sowing should be done in dry conditions followed by immediate irrigation, with pre-emergence herbicides applied within three days. In heavy-textured soils, where moisture may not develop quickly, sowing in moist conditions and applying herbicides immediately improves efficacy.

Sowing Time

Optimal sowing time is crucial for maximizing water productivity in DSR. Early, vigorous growth before monsoon rains prevents seedling mortality and ensures timely rice harvesting for rice planting. However, early sowing in May may increase water demand and hinder seedling establishment due to high temperatures and low moisture.

The ideal sowing window is 10–15 days before the monsoon, allowing better machinery movement and reducing risks of seed rotting or submergence. Delayed sowing leads to poor emergence, fewer panicles, and lower yields. When monsoon rains are late, Wet-DSR, using irrigation and sprouted seeds, ensures timely planting with lower water consumption than traditional transplanting.

Sowing Depth

Seeding depth is critical in DSR, influenced by the mesocotyl length of rice varieties. Semi-dwarf varieties have shorter mesocotyls than tall varieties, making proper sowing depth vital for germination and growth. Planting too deep or too shallow can hinder germination—deep planting weakens coleoptiles, while shallow planting can cause rapid drying of the soil surface, affecting emergence. For uniform crop establishment, rice should be sown no deeper than 2.5 cm, as deeper planting can lead to poor emergence and inconsistent crop growth.

Seed Rate and Treatment

Using a high seed rate in rice cultivation can lead to nitrogen deficiency, more ineffective tillers, increased vulnerability to pests, and a higher risk of lodging, all of which can reduce grain yield. For optimal crop establishment and yield, a seed rate of 20-25 kg per hectare is recommended for medium-fine-grain rice, with 20 cm row spacing and 5 cm within rows. Reducing the seed rate in DSR makes it more cost-effective, especially when using hybrid rice seeds.

To prevent seed and soil-borne diseases such as bacterial leaf blight, sheath blight, and brown leaf spot, it is advisable to treat rice seeds with fungicides like Streptocycline (1 g) and Bavistin (10 g) per 10 kg of seeds.

However, achieving lower seed rates requires a seed drill with a metering device for precise placement.

Irrigation Management

In heavy-textured soils, DSR is typically established with pre-sowing irrigation. After crop emergence, one or two irrigations are needed before the monsoon begins, and no further irrigation is required once the rains start, unless a dry spell occurs. The first irrigation can be delayed by 7-15 days, with subsequent irrigations spaced 5-10 days apart. During critical growth stages, such as seedling emergence, tillering, panicle initiation, and blooming, water stress should be avoided.

Nutrient Management

Nutrient requirements should be based on soil analysis. If no analysis is done, then the blanket recommendation is recommended.

Blanket fertilizer application

120-150 kg N /ha
60 kg P2O5/ha
40 kg K2O/ha
25 kg ZnSO4/ha

In light-textured soils, one-quarter of the nitrogen and the full amount of phosphorus and potassium should be applied at planting, with the remaining nitrogen applied in two splits during maximum tillering and panicle initiation. Iron deficiency, especially in light-textured sandy loams, can cause iron chlorosis in leaves and the application of iron sulphate ($FeSO_4$) can remedy this.

Weed Management

Effective weed control is crucial in DSR, as weeds can severely impact grain yield, especially in the wet season. Unlike puddled transplanted rice, where standing water prevents weed emergence, DSR fields allow weeds to germinate and compete for nutrients, water, and sunlight, causing significant yield losses. Cultural practices such as stale seedbed technique, surface mulch, and incorporating cover crops like *Sesbania rostrata, Phaseolus radiatus*, and *Vigna unguiculata*, along with brown manuring, can help manage weeds. Pre-emergence herbicide Pendimethalin (0.75 kg/ha) followed by post-emergence Bispyribac (0.025 kg/ha) 15–25 days after sowing you can control grasses, broad-leaf weeds, and sedges.

a) Manual Weeding

Many farmers rely on manual labor for weed control, but timely removal is crucial to minimize crop competition. However, labor availability often determines weeding schedules, which may not align with the optimal weed control period. Additionally, mechanical weeders can damage young rice plants and struggle to differentiate between grassy weeds and rice. Hand weeding is also significantly more expensive—at least five times the cost of herbicide application in wet-seeded rice. In dry DSR, manual weeding should be limited to controlling weeds that escape pre- or post-emergence herbicide treatments.

b) Mechanical Weeding

Mechanical weeding aids in nutrient recycling and soil aeration, promoting root and microbial activity. While rotary weeders effectively control inter-row weeds, they struggle with intra-row weeds. Tools like rotating hoes improve tillering by enhancing soil porosity. Farm mechanization has introduced efficient weeding implements such as the finger weeder, wheel finger weeder, Cono weeder and Blade & Rake weeder, developed by ICAR-NRRI, Cuttack.

The Conoweeder reduces labor requirements and increases grain yield by 10% in the wet season and 3% in the dry season compared to conventional methods.

c) Chemical Weed Control

Cultural and mechanical weed control methods are labor-intensive and often ineffective against regrowing weeds. Due to the similarity between rice and grassy weeds, herbicides are a practical alternative but should complement, not replace, other control measures. Herbicide application should be timed for maximum effectiveness based on weed presence, soil type, and environmental factors.

Research at ICAR-NRRI, Cuttack, found the highest weed control efficiency (95.2%) with bensulfuron methyl @ 60 g/ha at 20 DAS.

Advantages of Direct-Seeded Rice (DSR)

Direct-seeded rice (DSR) offers multiple benefits over traditional puddled transplanting. It enables faster and more efficient sowing, ensuring timely crop establishment. The crop matures 7–10 days earlier (115–120 days), allowing for the timely planting of the next crop. DSR improves water management and enhances the crop's ability to withstand water stress. It also reduces cultivation time, energy consumption, and overall costs. Unlike transplanted rice, DSR eliminates transplanting shock, promoting healthier plant growth. The method is particularly profitable under assured irrigation conditions as it improves soil physical properties and reduces methane emissions—dry direct seeding (DDS) emits less methane than wet direct seeding (WDS) and transplanted rice (PTR). Additionally, DSR lowers production costs, ultimately increasing farmers' income.

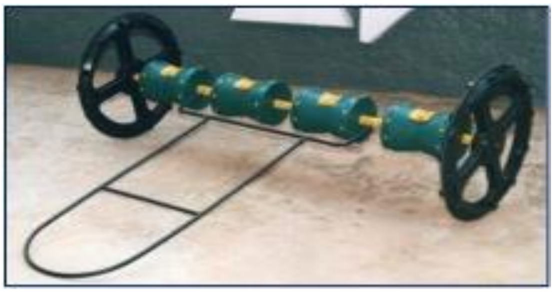
Challenges of Direct-Seeded Rice (DSR)

Despite its advantages, DSR faces certain challenges, primarily in weed management. The method is highly susceptible to weed infestation, particularly from hard-to-control species. Effective management requires adopting crop rotation strategies and herbicide resistance techniques. Unlike transplanted rice, where standing water suppresses weeds, DSR allows weeds to emerge in multiple flushes, competing for nutrients, moisture, and sunlight. Consequently, herbicide application becomes essential, requiring proper farmer training to ensure safe and effective use. Without adequate weed control, DSR can lead to significant yield losses, making informed management practices crucial for its success.

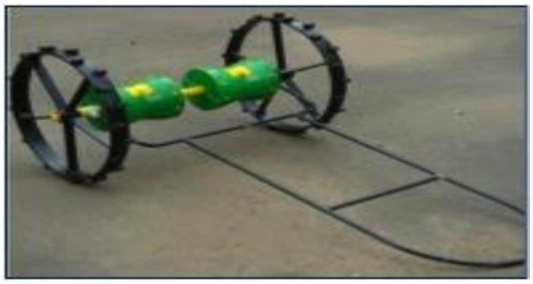
The success of direct-seeded rice (DSR) depends on precise land leveling, high-quality seed drills with advanced metering systems, and skilled tractor and pesticide operators. Adjusting seeding depth according to soil type and moisture levels is crucial for optimal crop establishment. Developing rice varieties specifically suited for dry seeding can further enhance productivity. Effective weed management requires the strategic use of pre- and post-emergence herbicides, selected based on the predominant weed species. Unlike transplanted rice, DSR avoids transplanting shock and matures more quickly, making it easier to integrate into diverse cropping systems. Additionally, it has the potential to contribute to groundwater recharge. Water savings in DSR are influenced by soil type, management practices, and environmental factors, making it essential to optimize water use without inducing water stress that could impact yields.

Direct Seeded Rice

Wetland Laser Leveller



Improved Direct Paddy Seeder – 8 row



Improved Direct Paddy Seeder – 4 row

Seed cum Fertiliser Drill for Paddy

Conoweeder

Two Row Finger Type Paddy Rotary Weeder

Multi Row Paddy Weeder

2.2 Alternate Wetting and Drying (AWD) in Rice Cultivation

Alternate Wetting and Drying (AWD) is a water management practice developed for irrigated lowland rice systems. It is considered a climate-smart and resource-efficient approach that addresses the dual challenges of water scarcity and sustainable intensification of agriculture.

Concept and Principles

Traditionally, lowland rice is grown under continuous standing water, with fields kept flooded throughout most of the growing season. While this practice helps suppress weeds and supports anaerobic microbial activity beneficial to rice, it is also highly water-intensive and contributes significantly to methane emissions. AWD offers a controlled irrigation alternative, where the rice field is not continuously flooded. Instead, irrigation is applied intermittently, allowing the soil to dry to a certain extent between irrigation events.

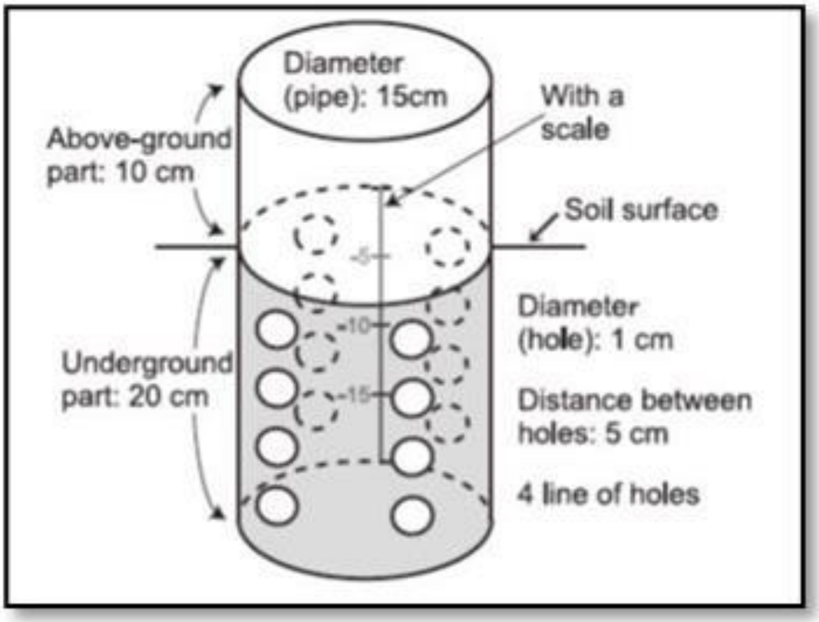


Figure 2.The field water tube

A simple and widely recommended method of implementing AWD involves using a perforated field water tube (usually 30 cm long and 7–10 cm in diameter), inserted vertically into the soil. This tube helps monitor the depth of the water table. Irrigation is applied when the water level inside the tube falls to 15 cm below the soil surface, and the field is re-flooded to a shallow depth (5–7 cm). This cycle is repeated throughout the vegetative and reproductive stages but may be modified during the flowering stage, where continuous flooding is often recommended to avoid yield penalties.

Figure 3. Fixing Field water tube

Benefits of AWD

a. Water Savings

AWD can reduce irrigation water use by 15–30%, depending on factors like soil texture, field topography, and climate. This is particularly beneficial in regions facing water scarcity or where irrigation water is costly or limited.

- IRRI-ICAR Collaborative Studies: In trials conducted across Tamil Nadu under the IRRI-ICAR STRASA and CURE programs, AWD resulted in water savings of 25–30% compared to continuous flooding, with no significant yield loss (IRRI, 2012).
- TNAU Findings: A study by Tamil Nadu Agricultural University (TNAU) in Coimbatore observed that AWD reduced irrigation water use by 29% while maintaining comparable yields to conventional practices.
- In Villupuram and Thanjavur districts, AWD recorded irrigation water productivity increases of up to 60%, particularly when combined with short-duration rice varieties.

b. Reduction in Greenhouse Gas Emissions

Continuous flooding promotes anaerobic decomposition in soils, leading to the release of methane (CH_4)—a potent greenhouse gas. AWD introduces aerobic periods during the drying phases, which disrupt methane production. Studies have shown that AWD can reduce methane emissions by up to 50%, contributing to climate change mitigation.

- A study in Tamil Nadu reported a 48% reduction in methane (CH_4) emissions under AWD compared to continuous flooding. While nitrous oxide (N_2O) emissions slightly increased, the net global warming potential (GWP) was still significantly lower.
- At Annamalai University, research trials showed that AWD significantly curtailed CH_4 emissions while improving nitrogen use efficiency by 12%.

c. Maintained or Improved Yields

When practiced properly, AWD does not reduce rice yields and may even improve them due to enhanced root aeration, stronger tillering, and improved nutrient uptake, particularly nitrogen. The intermittent drying stimulates deeper root systems, making rice plants more resilient to stress.

- A field study at Aduthurai (TNAU Research Station) showed that AWD maintained grain yield (5.6 t/ha) on par with continuous flooding, while increasing tiller number and panicle length due to improved root zone aeration.
- Farmers in Cauvery Delta regions practicing AWD reported yield stability across multiple seasons, especially when AWD was introduced after active tillering.

d. Improved Fertilizer Use Efficiency

Drying periods improve soil aeration and reduce denitrification losses, which are common under continuously flooded conditions. As a result, the efficiency of nitrogen fertilizers is enhanced, leading to higher nutrient uptake and potentially lower input costs.

- It was found that AWD reduced total nitrogen losses by 24–37% compared to continuous flooding. A study in the Philippines by IRRI showed that nitrogen uptake by rice plants increased by 10–15% under AWD compared to continuous flooding, due to better root development and aerobic mineralization.
- In Tamil Nadu, trials at TNAU reported that nitrogen recovery efficiency was improved by 18–20% under AWD. It was showen that combining AWD with ammonium sulfate and vermicompost reduced CH_4 emissions and improved nitrogen efficiency compared to urea under continuous flooding.
- AWD enables split or site-specific nitrogen applications—aligned with critical growth stages—which lowers fertilizer application rates without sacrificing yield. In India, it's demonstrated that using leaf color charts (LCCs) alongside AWD reduced nitrogen use by 20–30%, saving fertilizer costs and maintaining yields.

e. Weed and Pest Management

Although continuous flooding helps suppress weeds, AWD, when combined with integrated weed management, can still maintain effective weed control. Moreover, AWD may reduce the prevalence of certain pests and diseases that thrive under constant waterlogged conditions.

Challenges and Limitations

Despite its benefits, the adoption of AWD is influenced by several practical and socio-economic factors:

- **Need for Proper Monitoring**: Accurate timing of irrigation is critical. Over-drying can lead to plant stress, particularly during flowering, affecting yield. This requires farmers to regularly monitor water levels, which can be labor-intensive without proper tools or training.
- **Infrastructure and Water Control**: AWD is most suitable for areas with controlled irrigation systems. In regions with communal or irregular water supply, applying AWD may be challenging.
- **Farmer Awareness and Training**: Successful implementation requires capacity building, farmer demonstrations, and support from extension services. In many areas, farmers may still believe that more water always means better yield, which needs to be addressed through education.
- **Methane-Nitrous Oxide Trade-off**: Although AWD reduces methane, the aerobic soil conditions may increase nitrous oxide (N_2O) emissions, especially if nitrogen fertilizers are not managed properly. However, total global warming potential still favors AWD if best practices are followed.

Best Practices for AWD

- Begin AWD one week after transplanting or when seedlings are well established.
- Maintain a shallow flood layer (1–5 cm) for the first two weeks after transplanting to ensure proper establishment.
- Use field water tubes to guide irrigation decisions.
- Avoid letting the field crack or become overly dry, especially during panicle initiation and flowering.
- Combine AWD with other sustainable practices like site-specific nutrient management (SSNM), integrated pest management (IPM), and laser land leveling.

Alternate Wetting and Drying (AWD) represents a transformative and climate-resilient approach for sustainable rice cultivation. By breaking away from the convention of continuous flooding, AWD enables significant savings in irrigation water, reduces methane emissions, and enhances nitrogen use efficiency—all while maintaining or even improving rice yields under proper management. This makes AWD a triple-win solution that addresses the key challenges of water scarcity, climate change mitigation, and food security. As pressures on freshwater resources continue to escalate—driven by population growth, urbanization, and climate variability—there is an urgent need for irrigation strategies that are both efficient and adaptable. AWD emerges as a particularly effective intervention in water-stressed regions of Asia and Africa, where rice is both a staple crop and a major consumer of agricultural water.

However, the widespread success of AWD hinges on several enabling factors. Localized adaptation is crucial, as the effectiveness of AWD depends on specific agro-ecological conditions, such as soil type, climate, and water availability. Farmer awareness and capacity building are equally important, requiring extension services to provide training, monitoring tools (such as field water tubes), and technical support. Moreover, the integration of AWD into national water and climate policies can accelerate its adoption by providing incentives, infrastructure, and institutional backing. In conclusion, AWD is not merely a water-saving technique—it is a forward-looking strategy that aligns with the goals of climate-smart agriculture, resource efficiency, and sustainable intensification. With the right support systems in place, AWD can play a pivotal role in shaping the future of rice farming in a warming, water-constrained world.

2.3 STCR Based Soil Management

Soil Analysis

Soil analysis is the process of testing soil samples to determine their physical, chemical, and biological properties. It provides crucial information about soil fertility, nutrient availability, pH, organic matter content, texture, structure, and the presence of contaminants.

Soil analysis is a key tool for precision agriculture, ensuring efficient resource use and improving farm profitability.

Need for Soil Analysis

1. **Nutrient Management:** Determines the levels of essential nutrients (N, P, K, etc.) and helps in recommending appropriate fertilizers.
2. **Soil Fertility Assessment:** Helps in understanding the soil's capacity to support crop growth and yield potential.
3. **Soil Health Monitoring:** Assesses organic matter, microbial activity, and physical properties to maintain long-term soil productivity.
4. **pH and Salinity Management:** Helps in determining the soil pH, electrical conductivity (EC), and lime or gypsum requirements.
5. **Crop Suitability:** Identifies soil characteristics to recommend suitable crops for specific soil conditions.
6. **Environmental Protection:** Prevents overuse of fertilizers and minimizes soil and water pollution.
7. **Sustainable Agriculture:** Promotes judicious use of inputs, improves soil conservation, and enhances long-term productivity.

Major Nutrients

1. Nitrogen (N)

- **Role in Plants:**
  - Essential for vegetative growth, as it is a major component of amino acids, proteins, enzymes, and chlorophyll.
  - Promotes lush green foliage and enhances photosynthesis.
  - Involved in cell division and plant metabolism.
- **Deficiency Symptoms:**
  - Yellowing (chlorosis) of older leaves.

- Stunted growth and poor yield.
- **Excess Effects:**
  - Leads to excessive vegetative growth at the expense of flowering and fruiting.
  - Increases susceptibility to diseases and lodging.

2. Phosphorus (P)

- **Role in Plants:**
  - Vital for root development, flowering, seed formation, and energy transfer (ATP).
  - Improves early growth and enhances stress tolerance.
  - Promotes cell division and development.
- **Deficiency Symptoms:**
  - Dark green or purplish discoloration of leaves.
  - Poor root growth and delayed maturity.
- **Excess Effects:**
  - Can lead to micronutrient deficiencies (e.g., zinc and iron).
  - Reduces nitrogen uptake efficiency.

3. Potassium (K)

- **Role in Plants:**
  - Regulates water balance and improves drought resistance.
  - Enhances disease resistance and improves fruit quality.
  - Activates enzymes and helps in sugar and starch formation.
- **Deficiency Symptoms:**
  - Leaf margin scorching or browning (tip burn).
  - Weak stems, lodging, and reduced stress tolerance.
- **Excess Effects:**
  - Can interfere with magnesium and calcium uptake.
  - May lead to imbalance in nutrient uptake.

Category of N, P, K in Soil

Nutrient	Low (Deficient)	Medium	High (Sufficient/Excess)
Nitrogen (N)	<280 kg/ha	280–560 kg/ha	>560 kg/ha
Phosphorus (P)	<10 kg/ha (Olsen P)	10–25 kg/ha	>25 kg/ha
Potassium (K)	<120 kg/ha	120–280 kg/ha	>280 kg/ha

Note: The values vary based on soil type, agro-climatic conditions, and soil testing methods (Olsen's P, Bray's P, Morgan's P for phosphorus; ammonium acetate extractable K for potassium).

Soil Test Crop Response (STCR) Approach

The Soil Test Crop Response (STCR) approach is a scientific method used to recommend fertilizers based on soil test values, crop response, and targeted yield. It helps in optimizing nutrient application to achieve maximum yield with efficient fertilizer use.

Principle of STCR

The STCR approach is based on the Law of Optimum, which states that crops should receive nutrients in balanced proportions as per their actual requirements, avoiding excess or deficiency. It considers:

1. **Soil fertility status** (based on soil test results).
2. **Crop nutrient requirements** (how much N, P, K is needed for a specific yield target).
3. **Nutrient use efficiency** (how effectively a crop absorbs and utilizes applied nutrients).

Components of STCR Approach

1. **Soil Test Data:** Soil samples are analyzed for available N, P, and K.
2. **Crop Response Data:** Field trials determine how different crops respond to nutrient applications.
3. **Fertilizer Adjustment Equations:** Mathematical equations predict fertilizer requirements based on soil nutrient levels and targeted yields.

Advantages of STCR Approach

- **Precision Fertilization:** Avoids overuse or underuse of fertilizers.
- **Yield Targeting:** Helps farmers set realistic yield goals based on soil fertility.
- **Sustainability:** Reduces environmental pollution by minimizing excess fertilizer application.
- **Economical:** Optimizes fertilizer use, reducing input costs.

Each crop has specific STCR equations developed through research.

Calculation of the quantity of fertilisers to be applied under IPNS

Substitute the yield target in q ha^{-1} and the soil test value of the individual nutrients.

FN = 4.39 T - 0.52 SN - 0.80 ON;
FN = (4.39 x 70) – (0.52 x 240) – (0.80 x 66)
FN = 307.3 - 124.8 - 52.8 =130 kg ha^{-1}.

Similarly, substitute the corresponding values for SP and OP; SK and OK and arrive the doses of fertiliser P_2O_5 and K_2O to be applied. In this example, the fertiliser N, P_2O_5 and K_2O to be applied are 130, 74 and 21 kg ha^{-1}, respectively.

Example Calculation

Blanket recommendation for rice (HYV)

Nutrients	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)
Short duration varieties (dry season)			
a) Cauvery delta & Coimbatore tract	150	50	50
b) For other tracts	120	40	40
Medium and long duration varieties (wet season)	150	50	50
Hybrid rice	175	60	60
Low N responsive cultivars (like Improved White Ponni)	75	50	50

Importance of the STCR Approach

1. **Precision Nutrient Management**
   - STCR provides site-specific fertilizer recommendations, ensuring that crops receive the right amount of nutrients based on soil fertility.
2. **Yield Targeting**
   - Unlike blanket recommendations, STCR helps farmers set realistic yield targets and apply fertilizers accordingly to achieve the desired production.
3. **Efficient Fertilizer Use**
   - Ensures judicious use of fertilizers, reducing wastage and improving nutrient use efficiency (NUE).
4. **Cost-Effective**
   - Helps farmers reduce input costs by preventing excessive fertilizer application while maintaining high yields.

5. **Sustainable Agriculture**
    - Prevents soil degradation by maintaining soil fertility through balanced nutrient management.
6. **Minimizes Environmental Pollution**
    - Reduces nutrient leaching, runoff, and emissions (e.g., nitrate pollution in groundwater and greenhouse gas emissions from excessive nitrogen use).
7. **Enhances Soil Health**
    - Promotes balanced fertilization, preventing nutrient depletion and deficiencies in the long term.
8. **Supports Climate-Resilient Farming**
    - Optimized nutrient management enhances crop resilience to drought, salinity, and other stresses.

Advantages of the STCR Approach over traditional approach

Aspect	STCR Approach	Traditional Blanket Recommendation
Precision	High (based on soil test values)	Low (fixed doses for all regions)
Yield-based Fertilization	Yes (customized for different yield targets)	No (same dose for all yield levels)
Nutrient Efficiency	High (minimizes losses)	Low (over- or under-application possible)
Cost-Effectiveness	Saves input costs	May lead to unnecessary expenses
Sustainability	Maintains soil health	Can cause nutrient imbalances
Environmental Impact	Low (reduces pollution)	High (risk of leaching and runoff)

2.3.1 Integrated Nutrient Management in Rice for Enhancing Yield and Reducing Methane Emissions

In response, Integrated Nutrient Management (INM) has emerged as a sustainable approach that optimizes nutrient use efficiency, enhances crop yield, and mitigates environmental impacts, including methane emissions from rice fields.

Concept of Integrated Nutrient Management (INM)

INM involves the balanced and efficient use of chemical fertilizers, organic amendments, and biofertilizers to sustain soil fertility and improve crop productivity. The approach integrates:

- Chemical Fertilizers (e.g., Nitrogen, Phosphorus, and Potassium - NPK)
- Organic Manures (e.g., Farmyard manure, green manure, compost)
- Biofertilizers (e.g., Azolla, Mycorrhiza)
- Site-Specific Nutrient Management (SSNM) strategies

Importance of INM in Rice Cultivation

1. Enhancing Yield

- INM ensures sustained nutrient availability throughout the rice growth cycle, leading to higher grain yield and better quality.
- Balanced fertilization prevents nutrient depletion and enhances photosynthetic efficiency.
- Improves root development and nutrient uptake, promoting stronger plants and better resistance to diseases.

2.Reducing Methane Emissions

- **Incorporation of organic matter** in an aerobic condition enhances microbial activity, reducing methane production.
- **Intermittent irrigation (Alternate Wetting and Drying - AWD)** limits anaerobic conditions in the soil, thereby reducing CH_4 emissions by up to 48%.
- **Azolla** fixes atmospheric nitrogen and improves soil aeration, thus minimizing methane emissions.

Key Components of INM in Rice for Yield and Methane Reduction

1. Use of Organic Amendments

- **Farmyard Manure (FYM):** Improves soil fertility, water retention, and microbial diversity.
- **Green Manuring (Sesbania, Dhaincha, Azolla):** Enhances soil organic carbon while reducing reliance on chemical fertilizers.
- **Crop Residue Management:** Incorporation of crop residues reduces CH_4 emissions by controlling anaerobic decomposition.

2. Optimized Fertilizer Application

- Split application of nitrogen fertilizers reduces nitrogen losses and boosts nutrient availability.
- Use of slow-release nitrogen fertilizers (e.g., neem-coated urea) minimizes methane emissions compared to conventional urea.

- Balanced NPK application enhances soil fertility and prevents excessive organic decomposition that leads to methane emissions.

3.Water Management Strategies

- Alternate Wetting and Drying (AWD) reduces methane emissions by disrupting anaerobic conditions in the soil.
- System of Rice Intensification (SRI) optimizes plant spacing, enhances aeration, and reduces water stagnation, mitigating methane release.

4. Biofertilizer Application

- Azolla-Anabaena symbiosis enhances nitrogen fixation, reducing chemical nitrogen application.
- Mycorrhiza promote root growth, increasing phosphorus uptake and reducing nutrient losses.

Challenges in Implementing INM in Rice Cultivation

- Lack of awareness and training among farmers regarding INM practices.
- High labor costs associated with the application of organic amendments.
- Limited access to biofertilizers and organic inputs in some regions.
- Need for policy support to promote INM adoption through subsidies and incentives.

Integrated Nutrient Management (INM) is a sustainable approach for increasing rice yield while significantly reducing methane emissions. By combining organic, inorganic, and biofertilizer sources, INM enhances soil fertility, promotes efficient nutrient uptake, and mitigates greenhouse gas emissions. Implementing water-saving irrigation methods like AWD further strengthens the climate resilience of rice production. Future agricultural policies should focus on promoting INM adoption to achieve food security while addressing environmental concerns associated with rice cultivation.

Case Studies and Research Findings

- *Studies indicate that AWD combined with organic manure application reduces methane emissions by 30-50% while maintaining yield levels.*
- *Use of Azolla in rice paddies results in a 20% reduction in CH_4 emissions without compromising productivity.*
- *Integrated nutrient application (FYM + chemical fertilizers + biofertilizers) enhances rice yield by 15-25% compared to conventional fertilization alone.*

2.4 Methyobacterium mediated Methane Mitigation in Rice

Over the past decade, global methane emissions have risen at a rate faster than at any time in the last 30 years. While methane has both human and natural sources, recent increases are attributed to activity in three anthropogenic sectors, namely fossil fuels, waste and agriculture. Readily achievable methane mitigation can deliver nearly 0.3°C of avoided warming over the next two decades while simultaneously reducing ground-level ozone concentrations. Fast and ambitious methane mitigation is one of the best strategies needed today to deliver immediate and long-lasting multiple benefits for climate, agriculture, human and ecosystem health. In addition to the benefits quantified here, methane reduction measures also contribute to multiple Sustainable Development Goals (SDGs), including climate action (SDG13), zero hunger (SDG2), good health and wellbeing (SDG3).

Methane, a dangerous short-lived climate in pollutant (SLCP), is responsible for 40% of global warming and contributes to the increase of tropospheric ozone pollution, which causes over a million premature deaths every year, according to the World Health Organization. In rice production, methane is produced by the anaerobic decay of organic material which occurs in continuously flooded rice paddies. Additionally, the fertilization used in paddy rice production requires nitrous oxide, another source of SLCP pollution. Biological methane oxidation is known to occur aerobically in the presence of oxygen in both terrestrial and aquatic habitats, and anaerobically in sediments and anoxic salt water.

Effective water management practices, like mid-season drainage, intermittent irrigation, system of rice intensification, alternate wetting and drying, direct dry seeding and aerobic rice cultivation, have the possible potential to mitigate methane emissions for irrigated rice cultivation. Although these water management strategies show reduced methane emissions, consumption of more water for initial field setup and surface mode flood irrigation during an entire rice-growing cycle reduces the water productivity of the rice crop. By 2025, Asia's 130 million ha of irrigated rice area may experience physical and economic water scarcity. In addition, India would need to produce up to 156 million tonnes of rice by 2030 to feed its 1,523 million population. As we move into the future, rice grain production must increase to feed an increasing population, while at the same time, methane emissions from irrigated rice agriculture need to be reduced to help stabilize the global climate. Thus, the relationship between rice grain yield and the emission of methane from irrigated rice fields emerges as a major scientific and policy issue. So, it is necessary to develop alternative strategies to mitigate methane emissions as well as to improve the rice yield with limited water.

Developing and deploying new technologies can be expensive, and financial support is often needed, particularly in developing countries. We have developed a *Methylotrophs* biofertilizer that improves carbon sequestration and reduces methanes emissions as well as sustains crop growth and yield. Methylotrophs, including methanotrophs, have the ability to oxidize methane into carbon dioxide and water through natural metabolic processes. This conversion effectively reduces the impact of methane on global warming. Utilizing methylotrophs for methane oxidation complements other greenhouse gas mitigation strategies such as carbon capture and storage (CCS) and sustainable agriculture practices. Methylotrophs use natural biological processes to oxidize methane, making them an eco-friendly option for methane reduction compared to chemical or physical methods. Methylotrophs are commercially exploited for moisture stress mitigation and growth promotion in agriculture

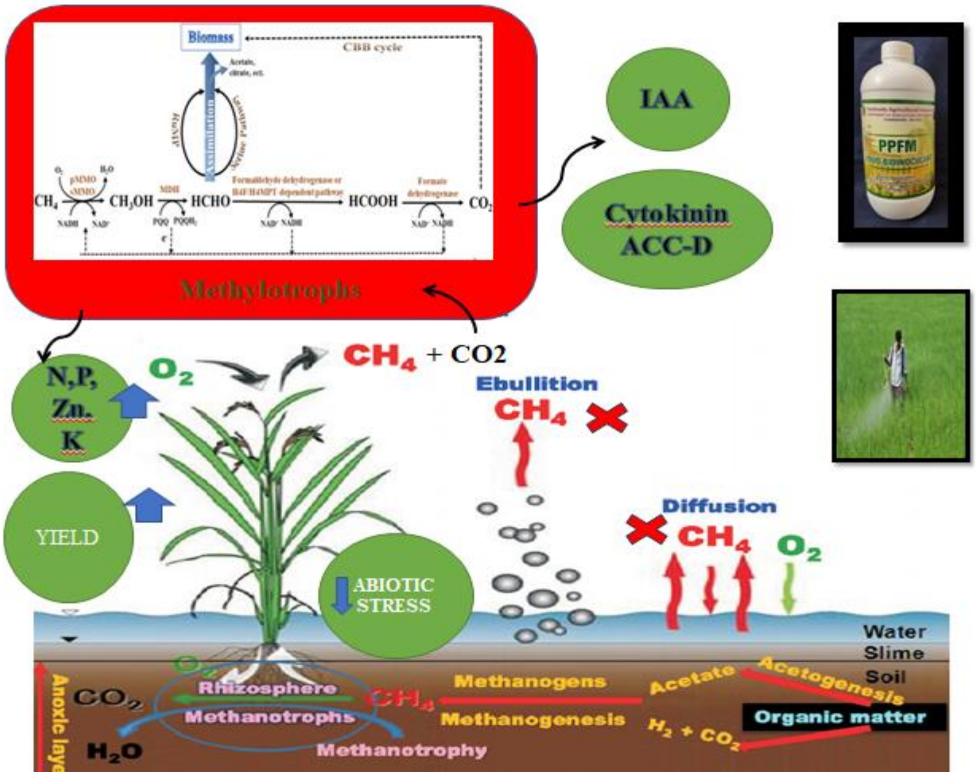


Figure 4. Schematic representation of Methane and CO_2 utilizing Methylotrophs biofertilizer

Methane gas and Methylotrophs

The difference between CH_4 production and emission probably reflects CH_4 oxidation in the oxic zones around the rice roots and at the soil surface, since they contain increased numbers of methane oxidizing bacteria (MOB, methanotrophic bacteria). The enhanced methane oxidation in these areas by MOB decreases the overall methane emission in rice fields. MOBs are characterized by the capability to use CH_4 as a sole carbon and energy source. The initial oxidation of methane to methanol is catalyzed by the enzyme methane monooxygenase (MMO) classified as soluble (sMMO) and particulate methane monooxygenase (pMMO).

Methylobacterium, "pink pigmented facultative methylotrophic bacteria" (PPFMs), are ubiquitous in nature, aerobic, members of the gram-negative class Alphaproteobacteria. Although they can grow on a wide range of multi-carbon substrates, they are known to utilize single carbon compounds such as formate, formaldehyde or methanol, and methylamine. Several Methylobacterial species are plant growth promoting bacteria (PGP) through the production of ACC (1-aminocyclopropane 1-carboxylate) deaminase, indole acetic acid, cytokinin, organic acids to release insoluble phosphate and potash minerals, siderophore produciton, nitrogen fixation and pathogen antagonism. Some novel species of *Methylobacterium* can survive using CH_4 as the sole source of carbon and energy source. Considering the abundance and PGP effects of Methylobacterial strains, studying their methane utilization adds value to their application as methane oxidizing PGP for sustainable agricultural purposes.

Metabolism of methane gas by Methylotrophs

Methylotrophs aerobically utilize C_1 compounds by oxidizing them to yield formaldehyde, which in turn can either be used for energy or assimilated into biomass. Methane is first oxidized to methanol by the enzyme methane monooxygenase. The methanol is then oxidized to formaldehyde by methanol dehydrogenase, and the electrons from this oxidation are donated to an electron transport chain for ATP synthesis. The oxidation of methane to methanol is consistent with the fact that thegrowth yield of methanotrophs is the same whether methane or methanol is used as substrate. Formaldehyde can be assimilated into cell material by the activity of either of two pathways, one involving the formation of the amino acid serine (serine pathway in Type II organisms) and the others proceeding through the synthesis of sugars such as fructose 6-phosphate and ribulose 5-phosphate (RuMP pathway in type I organisms). This initiative represents a big step forward in tackling methane emissions in the crucial rice sector.

Methylobacterium spp. has the ability to convert methane into methanol through a monooxygenase enzyme complex. Two different methane-monooxygenase (MMO) enzymes catalyse methane oxidation to methanol, followed by two to four PQQ-linked MDH that contribute to methanol oxidation. *M. extrorquens* contains the *mmoX* gene encoding the soluble methane monooxygenase enzyme. In case of methanol dehydrogenase enzyme, methanol can be converted into formaldehyde by calcium dependent methanol dehydrogenase enzyme or to formate by lanthanide dependent alcohol oxidase system. The formaldehyde derived from methanol or methane oxidation is assimilated through theserine and ethyl malonyl CoA pathway with formaldehyde as intermediary compound. During this process, for every molecule of formaldehyde uptake, one CO_2 molecule is utilized by phosphoenol pyruvate which is catalyzed by the PEP carboxylase enzyme.

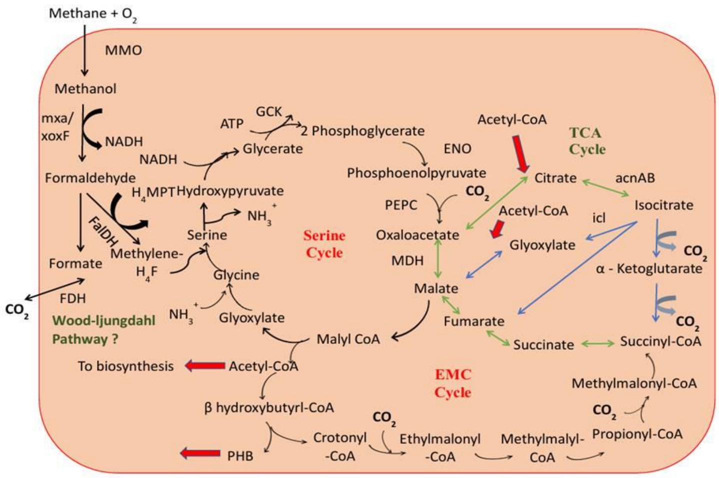


Figure 5. Metabolism of methane gas by Methylotrophs

Methylotrophs – How it Works

This novel approach seeks significant reductions in greenhouse gas emissions from rice cultivation - the second largest source of methane generated by agriculture globally - while making production more efficient and resilient to a changing climate. Scientific studies have shown that standing water in rice field causes the formation of methane that eventually is released into the atmosphere, where it is far more efficient at trapping radiation than equivalent amounts of carbon dioxide. We have identified that Methylotrophs offer a climate smart technology with the potential to contribute significantly to the reduction of greenhouse gases through the oxidation of methane and also increase the yield and induce stress tolerance in plants through cytokinin synthesis and ACC deaminase production when used as biofertilizer. The Application of Methylotrophs can be integrated with the currently existing or developing technology for methane mitigation.

Introducing *Methylobacterium* into rice, either through foliar application, soil inoculation or through seed treatments can outcompete or inhibit methanogenic microbes by consuming available substrates. *Methylobacterium* utilizes carbon compounds such as methanol and other methylated substances, reducing their availability for methanogens. By reducing the availability of carbon sources that methanogens use to produce methane, *Methylobacterium* indirectly lowers methane production.

This leads to a shift in microbial community dynamics and can lead to a decrease in methanogen populations and a reduction in methane production. In addition, *Methylobacterium* can improve soil health by producing growth-promoting substances or enhancing nutrient availability.

Healthier soil and better plant growth can contribute to more efficient nutrient use and potentially reduce methane emissions by promoting conditions less favorable to methanogens.

S. No.	Features of Methylotrophs in methane mitigation		Impact
1	Short-Term change		
i	Reduced Methane Emissions	:	Achieves a measurable reduction in methane emissions from rice ecosystem under wetland condition. Decreased methane emissions from rice fields due to reduced methanogen activity.
ii	Improved Soil Conditions	:	Potential improvements in soil health and nutrient availability
2	Long-Term change		
i	Sustainable Rice Farming	:	Lower methane emissions contribute to better climate outcomes and more sustainable rice production practices
ii	Increased Adoption	:	This method could be adopted more widely, leading to significant reductions in methane emissions from rice cultivation globally
3	Economic and Environmental Impact Assessment		
i	Economic Savings	:	Using Methylotrophs with methane utilization potential and simultaneous growth promotion is the most economic and sustainable way to reduce methane emissions.
ii	Environmental Benefits	:	Reduces greenhouse gas impacts, improves air quality, and contributes to climate change mitigation goals.
4	Public Health Improvement.		
i	Health Impact Studies	:	Reduces methane-related health risks by reducing methane emission
5	Policy and Regulation Development		
i	Best Practices	:	Soil Application and Foliar spray of Methylotrophs can be recommended in the crop cultivation practices.
ii	Regulatory Recommendations	:	Data supporting policy recommendations or changes in regulations to enhance methane mitigation efforts at local, national, or international levels
6	Educational and Outreach Contributions		
i	Awareness and Training	:	Development of educational resources and training programs based on research findings to promote better practices in methane management
7	Challenges and Considerations		
i	Effectiveness	:	The success of *Methylobacterium* in reducing methane might vary based on environmental conditions, rice varieties, and other factors.

2.5 Weather-based Climate Resilient Techniques for Rice Cultivation

Weather-based operations play a crucial role in rice cultivation, as the crop is highly sensitive to climatic conditions. Factors such as temperature, rainfall, humidity, and sunlight directly influence its growth and yield. To optimize production and minimize losses, farmers must adapt their planting schedules, irrigation practices, and pest management strategies.

Weather based Decision-making regarding method of cultivation

Seasonal forecasts aid decision-making in rice cultivation by predicting rainfall patterns, temperature trends, and water availability. Transplanted rice is suitable for normal or above-normal monsoon, ensuring sufficient water for puddling. Direct-seeded rice is ideal for delayed or deficient monsoons, reducing water dependence. Forecast-based planning helps optimize yield, resource use, and climate resilience.

Weather-based Land preparation

- Farmers can utilize rainfall for land preparation in rice cultivation.
- When rainfall of 10 cm is expected before land preparation, farmers can take advantage of natural moisture to prepare the main field efficiently. Ensure bunds and drainage channels are well-maintained to regulate water levels.
- A minimum of 50-75 mm of rainfall is needed to sufficiently wet the soil for primary tillage. For effective puddling (wet ploughing), about 100-150 mm of accumulated rainfall is ideal.

Choosing varieties based on seasonal forecast

- Based on IMD’s and TNAU's seasonal forecast farmers can choose flood-resistant, drought-tolerant, or high-yielding rice varieties recommended by TNAU.
- The success of monsoon-based agriculture depends on seasonal climate conditions. Real-time weather information helps farmers provide informed crop management decisions, reducing risks from extreme weather.
- TAWN collects 10 key weather parameters hourly from AWS and hosts them online, supporting medium-range forecasts. Agricultural officers use this data for block-level agro advisories. This first-of-its-kind dense weather network aids in monitoring global warming and climate change impacts on Tamil Nadu is agriculture.

Delayed and early onset of monsoon

- During a delayed monsoon farmers can choose short-duration, drought-tolerant varieties, and direct-seeded rice to reduce water dependency and ensure timely maturity. Supplemental irrigation may be required during critical growth phases. In delayed monsoons, choose short-duration varieties (125-135 days).

  In contrast, an early onset of the monsoon allows for the use of medium to long-duration high-yielding varieties and transplanted rice to maximize yield potential.

I. Short duration varieties: IR-64, CO-47, ADT-36, ADT-37, ADT-43, ADT-45, ADT-47, ADT-48, ASD-16, ASD-17, ASD-20, and MDU-5
II. Medium duration varieties: IR 20, IR 36, CO 43, CO 46, ADT 38, ADT 39, ADT 46, Bhavani, MDU 3, MDU 4, TRY 1, ASD 19, TPS 2, TPS 3 and White ponni
III. Long-duration varieties: Ponmani (CR 1009), BPT 5204, and ADT 44
IV. Hybrids: CORH 1, CORH 2, CORH 3, ADTRH 1

Above-normal rainfall in flood-prone areas

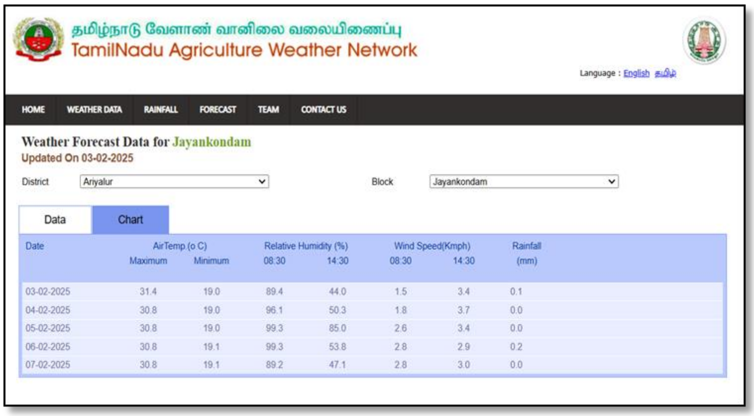
- To mitigate potential losses, farmers are advised to cultivate flood-resistant rice varieties such as CR1009 Sub 1(IET 22187). Some of the traditional varieties like Kuzhi Vedichan, Pichavari, and Vai Kunda are also suggested.
- For effective management, farmers should reinforce field bunds to prevent soil erosion and excessive water stagnation.

Normal rainfall

The recommended high-yielding varieties from TNAU include CO 51, a short-duration variety with high yield potential; ADT 45, known for its high yield and pest resistance; CO 50, a medium-duration variety well-suited for Tamil Nadu conditions; and ADT 39 and ADT 46, which are popular choices for normal rainfall areas.

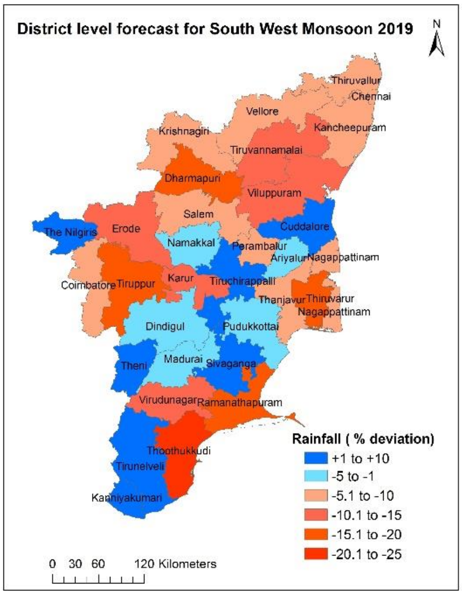
Below normal

For below-normal rainfall in drought-prone areas, recommended drought-tolerant varieties for direct-seeded conditions. Management practices such as using direct-seeded rice (DSR) instead of transplanting to conserve water and applying mulching and alternate wetting and drying (AWD) techniques to reduce water loss can help mitigate the effects of drought. Eg: MDU 5, RMD(R) 1, PMK(R) 4 or Anna(R) 4.



Date	AirTemp (o C) Maximum	AirTemp (o C) Minimum	Relative Humidity (%) 08:30	Relative Humidity (%) 14:30	Wind Speed(Kmph) 08:30	Wind Speed(Kmph) 14:30	Rainfall (mm)
03-02-2025	31.4	19.0	89.4	44.0	1.5	3.4	0.1
04-02-2025	30.8	19.0	96.1	50.3	1.8	3.7	0.0
05-02-2025	30.8	19.0	99.3	85.0	2.6	3.4	0.0
06-02-2025	30.8	19.1	99.3	53.8	2.8	2.9	0.2
07-02-2025	30.8	19.1	89.2	47.1	2.8	3.0	0.0

Figure 6. Medium Range Weather Forecast



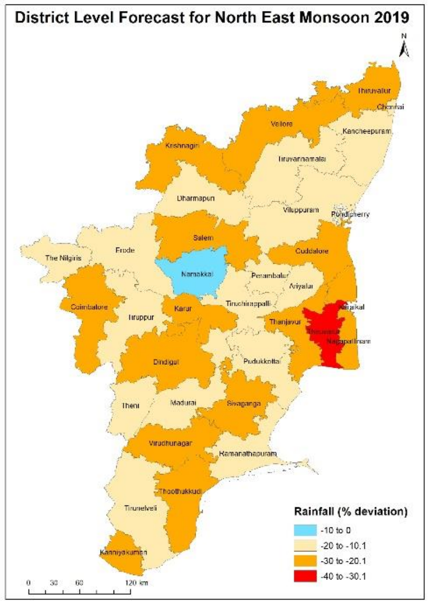


Figure 7. Seasonal forecast

Nursery bed preparation

- Prepare a seedbed 2.5 m wide with channels 30cm wide all around the seedbeds.
- Avoid sowing during heavy rainfall forecasts (above 50 mm in a day) to prevent seed washout.
- Raised Bed Planting can improve drainage and prevent complete submergence. Ensure proper field drainage to avoid prolonged water stagnation. Beds offer advantages such as mechanical weed control and improved fertilizer placement.
- Drain the water 18 to 24 hrs after sowing. Care must be taken to avoid stagnation of water on the seedbed.

Transplanting

- Transplanting can be done after a rainfall event, and it can be avoided during high evaporation conditions (>35°C). If heavy rain is expected, provide drainage to the recently planted rice field. If not planted, postpone the planting

Stress mitigation

Drought

- Foliar application of 400 mg L^{-1} silica improved plant growth during seedling stage
- Ideal concentrations of KCl, thiourea, Gibberellic acid (GA3), and Salicylic acid (SA) are able to alleviate drought stress in rice. Apply potassium and silicon fertilizers to strengthen plants against drought.

Heat stress

- Foliar spray of potassium nitrate (KNO_3) at 1% to reduce spikelet sterility. If temperatures exceed 35°C, apply extra irrigation.
- Applying mist in rice fields during heat waves can lower canopy temperatures and increase humidity, thereby reducing heat stress on the plants.
- Incorporating biochar into the soil enhances the rice plant's resilience to heat stress.

Weather forecast-based operations

Nutrient management

Rainfall

- When moderate to heavy rainfall (>50 mm) is expected, avoid fertilizer application to prevent leaching and apply only after rainfall subsides. During moderate rainfall (10–50 mm) forecast, use split doses of nitrogen (N) and slow-release fertilizers. When light rainfall (<10 mm) is forecasted, top-dressing is advised.
- Under dry conditions (no rain for 5–7 days), irrigate before applying fertilizers to improve absorption.
- As a best practice, apply urea before light rainfall (5–10 mm) and use phosphorus (P) and potassium (K) as a basal dose before planting.

Windspeed

- During strong winds (>20 km/h), avoid top-dressing fertilizers like urea to prevent drift. Under moderate winds (10–20 km/h), apply fertilizers close to the ground to minimize loss. In calm conditions (<10 km/h), it is ideal for foliar spraying and top dressing.

Water management

Rainfall

- During moderate to heavy rainfall (>50 mm in 24 hours), improve drainage to prevent waterlogging, maintaining bunds (15–20 cm) to prevent erosion, and avoid additional irrigation. For moderate rainfall (10–50 mm), delay irrigation until excess water recedes.
- Under light rainfall (<10 mm), continue the normal irrigation schedule. In dry periods (5–7 days without rain), use the AWD method and maintain 5 cm of standing water during critical stages like panicle initiation and flowering.
- After heavy rainfall, drain excess water within 24 hours to prevent root suffocation. If rainfall is irregular, stores water using on-farm reservoirs or rainwater harvesting for supplementary irrigation.

Temperature

- At optimal temperatures (20–30°C), maintain 2–5 cm of standing water to support plant growth. When the temperature exceeds (>30°C), evaporation increases, leading to drought stress; therefore, increase irrigation frequency and use mulching to retain moisture.

- During high temperatures, irrigate early morning or late evening to minimize evaporation losses. Maintain standing water during reproductive stages (panicle initiation to flowering) to prevent yield loss.

Wind speed

- In strong winds (>20 km/h), evaporation increases, requiring more frequent irrigation and field bunds to reduce exposure.
- Under moderate winds (10–20 km/h), apply irrigation during low-wind periods like morning or evening to minimize water loss. In calm conditions (<10 km/h), follow the normal irrigation schedule as evaporation is minimal.

Weed and Pest Management

The rain may trigger weed growth; therefore, timely control using mechanical or chemical methods are necessary.

Rainfall

- Rainfall-Based Pest and Disease Management helps to address pest and disease risks. During moderate to heavy rainfall (>50 mm), fungal diseases and pests like leaf rollers increase; ensure drainage, apply fungicides, and treat pests with insecticides.
- Moderate rainfall (10–50 mm) favors diseases like rice blast, so apply fungicides and systemic insecticides. With light rainfall (<10 mm), monitor for pests like plant hoppers and whiteflies and use insecticides as needed.
- In dry periods (5–7 days), control thrips with insecticides or biological methods and ensure proper irrigation to prevent stress.

Temperature

- When temperature drops (<20°C), pest activity is slow, and disease development is reduced.
- Optimal conditions (20–30°C) promote pest and disease growth, especially fungal diseases like rice blast; apply fungicides and systemic insecticides.
- In high heat (>30°C), the risk of heat stress and pest migration increases, leading to thrips, leafhoppers, and plant hoppers; use insecticides for pest control and apply stress management treatments.

Wind speed

- In strong winds (>20 km/h), pests can be blown to new areas, increasing infestations. To manage this, insecticides should be applied during calm periods (<10 km/h), pests may concentrate in certain areas
- In moderate winds (10–20 km/h), wind can spread fungal spores, so fungicides should be applied to prevent disease spread, and pest outbreaks should be monitored.

Important Diseases in Rice and Their Weather-Based Management

1. **Blast *(Pyricularia oryzae)***
   - **Favorable Weather:** High humidity (>90%), rainfall 30-50 mm/week, Wind speed <5 km per hour, and temperatures between 20–30°C.
   - **Management:**
     - Avoid excessive nitrogen application. Ensure proper drainage and avoid water stagnation.
     - Apply Tricyclazole (75 WP, 0.6 g/L) or Azoxystrobin (0.5 ml/L) during high-risk periods.

2. **Sheath rot *(Rhizoctonia solani)***
   - **Favorable Weather:** High humidity (>90%), rainfall 30-50 mm/week, Wind speed <5 km per hour, and temperatures between 20–30°C.
   - **Management:**
     - Maintain proper plant spacing and, avoiding excessive nitrogen.
     - Spray Hexaconazole (2 ml/L) or Validamycin (2.5 ml/L) when initial symptoms appear.

3. **Bacterial Leaf Blight *(Xanthomonas oryzae pv. oryzae)***
   - **Favorable Weather:** High humidity (>70%), rainfall >50 mm/week, Wind speed <5 km per hour, and temperatures between 20–30°C.
   - **Management:**
     - Avoid field operations when plants are wet to prevent spread.
     - Spray Copper oxychloride (3 g/L) + Streptocycline (0.1 g/L) at disease onset.

Important Pest in Rice and Their Weather-Based Management

1. **Brown Planthopper (BPH)** ***(Nilaparvata lugens)***
   - **Favorable Weather:** High humidity (>70%), rainfall 0-30 mm/week, Wind speed <5 km per hour, and temperatures between >30°C.
   - **Management:** Avoid excessive nitrogen use, promote natural predators (spiders, mirid bugs), and drain fields periodically to disrupt BPH habitat.

2. **Rice Yellow Stem Borer** ***(Scirpophaga incertulas)***
   - **Favorable Weather:** High humidity (>70%), rainfall 0-30 mm/week, Wind speed <5 km per hour, and temperatures between 0-30°C.
   - **Management:** Use pheromone traps, apply Trichogramma egg parasitoids, and maintain proper plant spacing to reduce humidity.

3. **Leaf Folder** ***(Cnaphalocrocis medinalis)***
   - **Favorable Weather:** High humidity (>70%), rainfall 0mm/week, Wind speed <5 km per hour, and temperatures between 20-30°C.
   - **Management:** Encourage natural enemies, apply need-based insecticides, and avoid over-irrigation to reduce excessive leaf growth


Brown Plant Hopper


Yellow Stem borer


Leaf folder

Experimental Protocol for Methane Gas Sampling and Analysis

3

Gas Sample Collection

The sampling of methane gas was performed using the closed chamber technique (Minamikawa et al., 2015). The chamber is illustrated in Figure 8.

Chambers with rectangular cross sections are usually made of acrylic plates as shown in the images is used for collecting the methane gases. Inside the chamber, an electric fan should be installed to circulate the air. Samples are collected between10:00 AM to 12:00 noon at critical stage of crop growth (10days after transplanting, active tillering stage, panicle initiation, flowering stage and grain maturity stage) or depends on the objective of the study. The gas samples are withdrawn from the top of the chamber using 20-ml gas-tight syringes at 0, 30 and 60 min after placing the chamber in the field or based on the experimental objective. Air inside the chamber should be thoroughly mixed by flushing the syringe five times before collecting the gas sample. The sample gases are transferred to 20 ml vacum glass vials with a rubber stopper and stored in cool and dark place until analysis. The temporal increment of methane concentration inside the chamber is measured in terms of methane flux (Hutchinson & Mosier, 1981).

Figure 8. Methane gas collecting chamber

Chamber design

Shape and size

The chamber cross-sectional shape often depends on the materials that are available. However, the interior volume of the chamber must be known. Chambers with rectangular cross sections are usually made of acrylic plates (optionally with a stainless steel frame for reinforcement and bonding). An appropriate thickness for acrylic or PVC plates is usually 3–5 mm. The larger the area that is covered by the chamber, the more reliable the gas flux data will be. The maximum chamber size is constrained, however, by the need for portability, and its minimum size is constrained by the need to obtain representative measurements and by rice plant height

In general, the method used to sow the rice plants in the field determines the recommended chamber shape. A chamber with a rectangular footprint should be used in transplanted rice fields, and the area it covers should be a multiple of the area occupied by one rice plant (hill). For example, a chamber with a 40 cm × 40 cm footprint is required to cover four hills, each occupying an area of 20 cm × 20 cm. Otherwise, the area-scaled gas flux will be over- or underestimated, unless a post hoc correction is applied. If the chamber footprint size is fixed, the planting density should be adjusted as necessary to achieve the recommended relationship.

With regard to chamber portability, a 60 cm × 60 cm chamber, regardless of its height, is the maximum size that can be carried, even by two people. At least two rice hills should be covered by a rectangular chamber, because the compensatory effect can be expected on rice growth, reducing the spatial variability in the gas flux. Measurement at one point (one chamber) in each replicated plot allows statistical comparison of the plots, but at least three points in a plot are recommended for chambers of the usual size.

For fields seeded by direct broadcasts, chambers with either a round or a rectangular footprint can be used. However, the actual seed or plant density inside the covered area must be recorded because this information is useful for interpreting spatial variations in the gas fluxes. The top of chamber should always be higher than the rice plant height so that rice growth will not be suppressed. However, the lower the height of the chamber, the more reliable the gas measurement will be. Because a chamber deployed in a paddy is usually equipped with an inside fan, rice height should probably be the primary criterion used to determine chamber height.

The chamber base provides a gas-tight means of chamber closure and prevents soil disturbance during chamber deployment. The base should be equipped with a water seal to ensure gas-tight closure. The base usually remains installed throughout the rice growing period. The installation of the chamber base inevitably disturbs the environmental conditions around the rice plants to some degree. The aboveground height of the base should be minimal (usually less than 5 cm) so that the base does not interfere with solar radiation. The belowground depth (usually 5–10 cm) depends on the soil hardness and structure, and artificial CH_4 ebullition must be avoided during chamber deployment.

During chamber deployment, the internal environment of the chamber should be maintained under conditions as close as possible to ambient conditions. To achieve this, the inside of the chamber should be equipped with (1) a small fan, (2) a thermometer and (3) a vent hole.

The small battery-driven fan is used to thoroughly mix the gases in the chamber, so that the target gas concentrations will be uniform (IGAC, 1994). In upland fields, headspace mixing may cause gas flow through the soil, but in rice field, a fan should be used because (1) mixing the inside air scarcely affects the air–water–soil gas concentration gradient, (2) rice plants often obstruct air circulation, and (3) little natural mixing occurs in tall chambers. A vent hole with a rubber stopper is used to prevent drastic changes in inside air pressure during chamber deployment. Chambers used for upland fields occasionally are equipped with thin vent tubes, but their use is still being debated. A vent tube prevents a pressure gradient between the interior and exterior of the chamber from influencing gas exchange. The gas sampling port should be separate from the chamber body to prevent the chamber from possibly being shaken during the sampling. We recommend attaching a flexible tube (20–30 cm long) fitted with a valve to the chamber body.

Category	Minimum requirements and recommendations
Material	Use lightweight material that is break resistant and inert to CH_4 and N_2O (e.g., acrylic and PVC)
Shape and size	1. Use a rectangular chamber for transplanted rice fields. 2. The area covered by the chamber (i.e., its footprint) should be a multiple of the area occupied by a single rice hill. 3. At least two transplanted rice hills should be covered by each chamber. 4. Either a cylindrical (e.g., made from a trash container) or rectangular chamber can be used in fields seeded by direct broadcasting. 5. Record the seed/plant density inside the chamber. 6. Make sure that the chamber height will always be higher than the rice plant. 7. Measure at least three points in each plot. 8. Adjust the planting density to one suitable for the chamber size, if the chamber size is already fixed.
Base	1. Use a water seal between the base and the chamber to ensure gas-tight closure. 2. Minimize the aboveground height of the base. 3. Determine a belowground depth of the base suitable for the soil hardness (e.g., 5-10 cm).
Chamber area and number of chambers within a plot	1. The area covered by each chamber (i.e., its footprint) and the number of chambers that should be deployed within a plot depend on the required measurement accuracy. 2. The larger the chamber area and the greater the number of chambers deployed, the more reliable the gas flux data will be. 3. However, practically, the chamber area and the number of chambers may be limited by the number of people available to carry out the measurements. 4. There is no consensus as to what percentage of the plot area should be covered to obtain a representative gas flux value.

Other components	1. Install a small fan 2. Install a thermometer inside the chamber 3. Drill a vent hole and install a vent stopper 4. Equip the chamber with a gas sampling port (e.g., a flexible tube connected to a valve) that is separate from the chamber body.

Time of day for gas sampling

CH_4 fluxes vary considerably diurnally — they tend to be high in the daytime and low at night. In particular, in temperate parts of Asia, measurement at approximately 10:00 (09:00–11:00) local mean time is recommended. Although twice-per-day measurement can improve trueness, measurements in the early morning (when the plants may be wet) and at night (when it is dark) in a rice paddy are not recommended. For various reasons, it may not always be possible to collect gas samples at a fixed time of day. However, because the actual diurnal pattern on the measurement day cannot be known, we recommend conducting measurements at a fixed time of day if at all possible. The measurement time or times and any correction applied should be reported along with the data. From a practical standpoint, it is often the case that not all the chambers can be deployed simultaneously at multiple sampling points, base of lack of personnel or because the number of available chambers may be insufficient. In such cases, it is necessary to determine a suitable chamber measurement sequence within an appropriate time window. We recommend measuring the CH_4 flux at least once a week during the flooded growing period.

Schedule for methane gas collection and estimation

Experimental details	0 – 30 days	31 – 60 days	61 – 90 days	91 – 120 days	121 - 150 days
Nursery	Initial CH_4 estimation (0 day)				
Nursery	CH_4 estimation 15th and 30th DAS				
Main field (Short duration variety)		Initial CH_4 estimation 31st, 41st ,51st & 60th day	CH_4 estimation 70th , 90th DAT	100 DAT & After harvest	
Main field (Long duration variety)		Initial CH_4 estimation 31st, 41st ,51st & 60th day	CH_4 estimation 70th , 90th DAT	91 DAT, 101 DAT, 110 DAT,120 DAT	130 DAT, 140 DAT and After harvest

Example of an appropriate time schedule for one person performing three measurements during a 30-min closure at three positions with three chambers

Chamber	Placement	1st sampling	2nd sampling	3rd sampling
1	10:00	10:01	10:16	10:31
2	10:04	10:05	10:20	10:35
3	10:08	10:09	10:24	10:39

Gas sampling

Category	Minimum requirements and recommendations
Period	1. Determine the measuring period according to the research objectives. 2. The measurement period should encompass the entire rice growing period for the estimation of seasonal emissions of CH_4 and N_2O.
Time of day	Mid-morning during flooded rice-growing periods (measure once daily to obtain the daily mean CH_4 flux). Measure all treatments at the same timing. Daytime during temporary drainage events during the rice growing period. Late morning during dry fallow periods. Measure the N_2O flux concurrently with the CH_4 flux
Frequency	1. At least weekly during flooded rice-growing periods. 2. More frequently during agricultural management events (e.g., irrigation, drainage, and N fertilization) and some natural events (e.g., heavy rainfall). 3. Weekly or biweekly during dry fallow periods.
Chamber deployment time and number of gas samples	1. Deploy chamber for 20–30 min during rice-growing periods. Obtain at least three gas samples per deployment depending on sampling and analytical performance. 2. Use a longer deployment time (up to 60 min) during fallow periods.
Instruments	1. Use a syringe or a pump for gas sampling, depending on the required sample volume. 2. Use plastic or glass containers for the gas samples, taking into account the allowable storage period. 3. Use an evacuated glass vial equipped with a butyl rubber stopper for gas storage. 4. Use a vacuuming machine to prepare evacuated glass vials, instead of

	manually evacuating the vials. 5. Use a gas replacement method if the use of evacuated glass vials is impractical.
Notes for manual operation	1. Check the water volume for water seal in the chamber base. 2. Fill soil cracks up with kneaded soil collected from outside the plot. 3. Prevent water from overflowing the base when the field is drained 4. Be gentle when placing the chamber on and removing it from the base. 5. Avoid placing items on top of the chamber and avoid directly touching the chamber body. 6. Avoid dead volume in the gas sampler. 7. Store each gas sample in an evacuated vial under pressurized conditions. 8. Replace the inside air of the chamber after each measurement by tipping it sideways for a few minutes. 9. Use an elastic cord to gently bind the rice plants inside the chamber together and then remove the cord before the chamber is closed. 10. Check the degree of inflation of the air buffer bag (if one is used).

Chamber deployment duration and number of gas samples

The duration of chamber deployment and the number of gas samples collected during each deployment affect the accuracy of the calculated gas fluxes. A shorter deployment time is preferred for healthy rice growth, because the air temperature becomes elevated within the closed chamber and the CO_2 concentration decreases. On the other hand, a longer deployment time and a greater number of gas samplings improve the accuracy of the flux calculation. Most researchers deploy the chamber for 30 mins and collect gas samples 3 or 4 times per deployment. On the basis of empirical knowledge, we recommend deploying each chamber for 20–30 min during the rice growing period so as to not interfere with rice growth. On the other hand, a longer time (< 60 min.) is acceptable during fallow periods to improve the accuracy of the gas analysis.

Gas collection

Generally, gas samples can be collected from a chamber with a syringe or with a pump. The instrument chosen depends partly on the storage container used. A plastic syringe (e.g., 25-50 ml) should be used if the samples are to be stored in (evacuated) glass vials (e.g., 10-30 ml).

Gas replacement method

One problem with preparing evacuated vials yourself oneself is that additional equipment is required to create the vacuum. If the necessary equipment is not available, a gas replacement method can be used instead of evacuated vials. In brief, a double-needle technique is used to replace the air in a non-evacuated vial with a sufficient volume of sampled gas. A theoreticaly gas replacement of more than 4.5 times the volume of the container leaves less than 1% of the original air remaining. However, the actual accuracy will vary depending on the skill level of the operator, so the results should be verified by GC before the actual experiment is carried out.

A gas replacement procedure with a 10-mL vial used for gas storage

Step	Detail
1	Plug a 10-ml non-evacuated vial with a butyl rubber stopper.
2	First, insert a needle (for degassing) into the vial through the stopper
3	Second, insert the needle of a 50-ml syringe containing 50 ml of gas sample.
4	Inject 45 ml of the gas sample into the vial, replacing the original air.
5	Quickly remove the first needle.
6	Inject the remaining 5 ml of gas sample to establish a pressurized condition

Notes on manual chamber operation

The chamber should be placed gently on the base to prevent increasing the initial CH_4 concentration by ebullition from the soil. If failed, we recommend removing the chamber and placing it again. In addition, permanent placement throughout the rice growing season should be avoided not to adversely affect rice growth.

To prevent CH_4 ebullition during sampling, avoid placing measurement components on top of the chamber. For the same reason, avoid directly touching the chamber body. Note that gas sampling at constant intervals is not necessary for the calculation of the gas flux. Therefore, if the regular sampling time is missed, gas can be collected at a different time (which must be recorded). Avoid dead volume in the gas sampler (i.e., syringe or pump) so that the gas concentration in the sampler will be in equilibrium with that in the chamber.

The collected gas should be stored in an evacuated vial under a pressurized condition. For example, if a 20-mL vial is being used, manually inject ~30 mL of gas while minimizing leakage or contamination; this also allows the gas concentration to be analyzed several times. If a pump is used, the first several seconds of collected gas should be discharged, before the storage container is filled.

Chamber removal: First, the vent plug should be removed and then the chamber should be gently lifted off the base. If failed when the field is drained, water in the base may overflow and moisten the soil. After the chamber is removed from the base, we recommend tipping it sideways for a few minutes to replace the air inside with ambient air, to prevent an initial high CH_4 concentration during the next deployment of the chamber.

GC requirements for CH_4

A flame ionization detector (FID), which uses a hydrogen flame to detect ionized hydrocarbons (HCs), is the most suitable for the detection of CH_4. A FID uses H_2 and air (O_2) as a supplemental fuel and a carrier gas. Atmospheric air contains not only CH_4 but also other HCs, so the FID signal obtained from air is a mixture of signals from CH_4 and other HCs. Therefore, CH_4 and other

HCs should be separated from each other so that the target CH_4 concentration can be analyzed precisely. Packed separation columns are commonly used to separate CH_4 from other components of the gas sample. Generally, the retention times of CH_4 and other HCs can be shortened by increasing the column temperature. However, higher temperatures (>150°C) risk an increase in signal noise due to the discharge of particulate matter. Therefore, we recommend using a column temperature between 50 and 130°C for CH_4 separation. The random signal noise level should be reduced to achieve a signal-to-noise (S/N) ratio of more than 10. We recommend the following to reduce the noise level.

1. Use He or N_2 (99.999% purity) as the carrier gas.
2. Use a charcoal filter to maintain the high purity of the carrier gas.
3. Sufficiently dehumidify the air from the compressor used for supplemental combustion in the FID by using a membrane filter and a silica-gel moisture trap.
4. Use a catalytic combustor to eliminate HCs contained in this dehumidified air.
5. Allow an idling time of at least 30 min after ignition of the FID.
6. Even when the FID is not being used, we recommend maintaining a continuous flow of the carrier gas at a low rate (upto 10 ml min^{-1}).

Gas analysis

Category	Minimum requirements and recommendations
GC requirements	1. Use a commercially made GC instrument equipped with a flame ionization detector (FID) and an electron capture detector (ECD) for analysis of CH_4 and N_2O, respectively. 2. Use packed separation columns to separate the target gas from other gases. 3. Use pre-cut filters to remove expected contaminants. 4. Regularly maintain the GC system (e.g., column conditioning).

Quantification of Gases

Collected gas samples were analyzed using gas chromatography with flame ionization detector (FID). 1 ml of collected gas sample is injected into the GC port with specific oven temperature for methane. The methane present in the sample is detected using an FID detector. The result is expressed in peak areas.

The following formula is used to the calculate methane gas emitted and the concentration of gas denoted as mg m^{-2} hr^{-1}:

Total methane emissions (mg m^{-2} hr^{-1}) = [(Ps × Cs / Pstd) × Vv / Va] × Vh x A × H.

Where Ps = peak area for sample in gas chromatography; Cs = standard methane gas concentration (mg L-1); Vv = vial volume (ml); Vh = headspace volume of the chamber, i.e., [Chamber length*breadth*height] (ml); Va = air volume sampled (ml); A = chamber area covered (m^2); H : enclosure period (hr); Pstd : standard peak area in gas chromatograph.

Calculation of hourly gas fluxes and cumulative emissions

Hourly gas flux

Linear regression is the recommended method for calculating the hourly CH_4 flux from a rice field. This method is based on the principle that the concentration gradient of CH_4 between flooded soil and the atmosphere is quite large, so that CH_4 can be considered to be emitted at a constant rate. The hourly fluxes of CH_4 (mg CH_4 m^{-2} h^{-1}) and N_2O (μg N m^{-2} h^{-1}) are calculated as follows:

$$\text{Flux}_{CH4} = \frac{\Delta C}{\Delta t} \times \frac{V}{A} \times \rho \times \frac{273}{273+T}$$

$$\text{Flux}_{N2O} = \frac{\Delta C}{\Delta t} \times \frac{V}{A} \times \rho \times \frac{273}{273+T} \times \frac{28}{44}$$

where $\Delta C/\Delta t$ is the concentration change over time (ppm-CH_4 or ppb-N_2O h^{-1}); V is chamber volume (m^3) ; A is chamber area (footprint; m^2); ρ is gas density (0.717 kg m^{-3} for CH_4 and 1.977 kg m^{-3} for N_2O at 0°C); and T is the mean air temperature inside the chamber (°C).

Experimental results of *Methylobacterium* in methane mitigation

Preliminary experimental results of a field trial conducted at the Agricultural Research Station, Thanjavur, with graded level of fertilizers and *Methylobacterium* foliar spray at critical stage of

crop growth revealed the complete stoppage of methane and Co_2 gas escape from the soil or plant was not observed.

PPFM →

Field Trial

Overall Layout

100% RDF – Control

100% RDF – PPFM Foliar spray (1%)

Empowering Rural Women in Climate Change

4

All work is half done when women are not involved

Climate Change is the long term changes in temperature, precipitation and wind pattern. This may be due to natural factors and human activities. Since the 20th century, human activities have became the prime driver. Burning of fossil fuels increases the level of green house gases in the atmosphere. Deforestation results in an increase of CO2. Rice farming and livestock farming releases methane.

It is important to understand climate change since the increase in temperature leads to the melting of ice zone resulting in an increase in sea level. This will affect the lives of villagers living adjoining sea shore. Increased heat wave leads to spread of diseases among mankind and plants. Increased drought affects agricultural production. There will be habitat loss and threatening of species. What is needed is to reduce greenhouse gas emissions, transition to renewable energy sources and implementation of sustainable energy practices.

Emission of green house gas can be reduced only by a small change in our day - to - day activity. It is not going to cost anything. Let me take your house as an example and discuss. Getting up in the morning to have coffee you sent your son to get milk. He takes the two wheeler go to the milk depot, which is 500 meters away & get the milk. This he can do by walk & save petrol & save carbon emission. Walking is also good for health.

For breakfast everyone in the house needs dishes that are hot. So mother has to prepare dishes for everyone using the gas store every time. Instead she can prepare dishes one time & put them in a hot box for use. By this, gas is saved and carbon emission is reduced. While preparing lunch normally, the gas stove is lit and rice, veg, etc, cut into & start cooking. Instead, if you keep rice, veg etc., ready & put on the gas there is saving in gas and reduction in carbon emission. Family members sit and have their lunch. After lunch, there is wastage of food on each plate. This is thrown as land fill. This will lead to the emission of methane. As per data, everyone is found to waste 125 grams of food every day. So get what you want and eat what you have got.

In the evening we put on the lights and fans and sit & watch T.V. If someone calls we go out & talk with them come, by this time the lights & fans are on. So when you go out of the rooms, switch off the lights & fans. This will reduce electricity consumption and reduce carbon emission.

There will a saving in electricity bill. While watching the T.V we switch off the remote when not needed. But the electricity is on. So please put off the plug to save electricity.

So far we have discussed in our daily life what changes can be made which will help in the reduction of carbon emission and cost savings. Now let us discuss what are the other changes that can lead to reduction of green house gas emission? In villages, cooking is done using mud chulah and firewood. There is emission of smoke which affects the health of women and emission of carbon. Instead, if we use double walled smokeless chulah, it reduces carbon emission by 200 grams per day per household. Due to an increase in heating efficiency the firewood use reduced to from 8kg per day to 5kg. There is a saving. The cooking time is reduced 30 minutes per day. The lady can use this time for other work. By using smokeless chulah, the concentration of carbon inside and outside the house gets reduced by 65% and 60% respectively. This will promote the health of the people. If a pressure cooker is used for cooking instead of cooking pot and lid, the annual carbon emission reduction is 125kg.

Instead of Kerosene lamp for better light, use a 6 Watt solar lantern. Use of solar lanterns 12 hours a day reduces 6 units of electricity per month. Using solar lantern for 3 hours a day instead of Kerosene lamp saves Rs. 200/- on Kerosene per month. This gives better light, reduction in carbon emission and cost savings.

Normally in the house, we use round bulbs or tube lights for lighting. This consumes more electricity. Instead, if you use CFL bulbs, carbon emission is reduced by 83 kg per year.

Paper is used by all for many purposes. The raw material for paper making is wood pulp. So making paper needs to cut trees. Take students using paper for their rough work. When you use paper, please see that both sides are used. 100 students doing rough work on one side used paper instead of fresh paper reduces carbon emission by 870kg per year.

The tree is a friend of mankind. We take oxygen and release carbon- di- oxide. But tree sequeses carbon-di-oxide and emit oxygen. One tree can sequese about 10kg of carbon every year. For a man to get the oxygen needed for life he needs 18 trees. By coming out and playing for a couple of hours instead of sitting computer or TV, Carbon emission can be reduced by 62 to 53 Kg per year per person. It is also on a good for your health.

Women who work in farms are employed in cultural operations like transplanting, weeding and harvesting in rice cultivation. The normal practice done under puddled conditions results in the release of methane. A small change in the practice will result in less emission of methane. The special operation of puddling in paddy cultivation provides water logging, creating anaerobic condition favoring methenobacterium cultures which produce methane gas in the rice eco-system. The alternate strategies for the reduction of methane are:

- Sowing of seeds by women either by broadcasting or using seed drill
- Weeding by women using a rotary weeder or cono-weeder helps in turning of soil for exchange of air limit bacterial activity and reduce methane emission.
- Women labourers help in preparing mat or tray nursery which reduces nursery area from 20 cents to 2.5 cents instead of traditional puddled nursery.

Let me close my talk by saying that every one of us releases 2.00 tons of carbon every year. So it is our responsibility to reduce green house gas emission. Let us make a small change in our day - to - day activity as discussed above & achieve this goal and give our next generation a green environment.

References

1. Agricultural Statistics at a Glance 2023.
2. Season and Crop Report of Tamil Nadu
3. Suresh Kumar, D. (2019). Rice Production in India: Analysis of Trend, Constraints and Technologies. In: Climate Change and Future Rice Production in India. India Studies in Business and Economics. Springer, Singapore. https://doi.org/10.1007/978-981-13-8363-2_2
4. https://agritech.tnau.ac.in/agriculture/agriengg_farm_rich_mech_index.html
5. https://agritech.tnau.ac.in/agriculture/agri_weedmgt_rice.html
6. http://www.agritech.tnau.ac.in/agriculture/agri_min_fldcrops_cereals_rice.html
7. https://agritech.tnau.ac.in/crop_protection/crop_prot_crop_insectpest%20_cereals_paddymain.html
8. http://www.agritech.tnau.ac.in/crop_protection/crop_prot_crop%20diseases_cereals_rice_main.html
9. https://agritech.tnau.ac.in/agriculture/agri_cropproduction_cereals%20index%20new_rice.html

Annexure

1. Package of Production for Rice

Transplanted Rice

Seed rate/ac

- 12 kg for long duration
- 16 kg for medium duration
- 24 kg for short duration varieties and
- 8 kg for hybrids

***Nursery Area* : 8 cents /ac**

Seed treatment

Treat the seeds in Carbendazim or Pyroquilon or Tricyclozole solution at 2 g/l of water for 1 kg of seeds. Soak the seeds in water for 10 hrs and drain excess water

Seed treatment with biofertilizers: Two packets (400g /ac) each of Azospirillum and Phosphobacteria or Two packets (400g /ac) of Azophos bioinoculants are mixed with sufficient water wherein the seeds are soaked overnight before sowing in the nursery bed.

Forming Seedbeds

Prepare a seed bed size of 2.5m breadth with channels 30cm wide all around the seedbeds.

Land preparation

- Plough the land during summer to economize the water requirement for initial preparation of land.
- Flood the field 1 or 2 days before ploughing and allow water to soak in.
- Keep the surface of the field covered with water.
- Keep water to a depth of 2.5cm at the time of puddling

Optimum age of seedlings for quick establishment

- Optimum age of the seedlings is 18-22 days for short, 25-30 days for medium and 35-40 days for long duration varieties.
- For medium and low fertile soils, spacing of 15cm x10 cm for short, 20 cm x 10 cm for medium and 20 x 15 for long duration varieties should be followed.

- Transplant 2-3 seedlings/hill for short duration and 2 seedlings/hill for medium and long duration varieties . Shallow planting (3 cm) ensures quick establishment and more tillers.
- Fill the gaps if any within 7 - 10 days after planting.

Nutrient management

- Apply 5tonnes of compost per ac
- If green manure is raised @ 20 kg seeds/ac in situ, incorporate it to a depth of 15 cm using a green manure trampler or tractor

Stubble incorporation

Apply 4 kg N/ac (8.8 kg urea) at the time of first puddling while incorporating the stubbles of previous crop to compensate immobilization of N by the stubbles.

Application of Inorganic Fertilizers (Per acre)

	Basal	Active Tillering	Panicle Initiation	Heading
Fertilizer Dose	15Kg N (32.55 Kg Urea) 5 Kg K (8.35 Kg MOP) 20 Kg P (125 Kg SSP)	15Kg N (32.55 Kg Urea) 5 Kg K (8.35 Kg MOP)	15Kg N (32.55 Kg Urea) 5 Kg K (8.35 Kg MOP)	15Kg N (32.55 Kg Urea) 5 Kg K (8.35 Kg MOP)
Short Duration		35 - 40 DAT	45-50 DAT	70-75 DAT
Medium Duration		50-55 DAT	70-75DAT	100-105DAT
Long Duration		55-60 DAT	85-90 DAT	115-120 DAT

Apply 10 Kg $ZnSO_4$ per ac as basal – soil application.

Foliar Application

- Foliar spray of 1% urea + 2% MAP + 1% KCl at Panicle Initiation (PI) and 10 days after first spray to improve grain filling rate and yield in all varieties.
- 1 % of PPFM spray (3 litre /acre) can be given after 10 days of transplanting, Active Tillering Stage and Panicle Initiation stage.

Weed management

- Use of rotary weeder from 15 DAT at 10 days interval. It saves labour for weeding, aerates the soil and root zone, prolongs the root activity, and improves the grain filling though efficient translocation and ultimately the grain yield.

- Use Butachlor 0.5kg/ac as pre-emergence application followed by one hand weeding on 30 - 35 DAT will have a broad spectrum of weed control.
- PE Pyrazosulfuron ethyl @ 8 g ac^{-1} on 3 DAT + hand weeding (HW) on 45 DAT.
- PE butachlor 0.3 kg ac^{-1} + bensulfuron methyl 20 g ac^{-1} on 3 DAT + HW on 45 DAT
- PE Oxadiazon 35 g ac^{-1} followed by Post emergence (POE) 2,4-D 0.4 kg $^{ac-1}$ along with hand weeding on 35 DAT.
- PE butachlor 0.3 kg per ac + bensulfuron methyl 20 g ac^{-1} on 3 DAT followed by mechanical weeding on 45 DAT is effective for broad spectrum weed control.

Water management

Maintain 2 cm of water up to seven days of transplanting.

Alternate Wetting and Drying Irrigation (AWDI)

- AWDI is done on the field using 'Field Water Tube' (FWT) which is made of 40 cm long plastic pipe with a diameter of 15 cm so that water table is easily visible.
- Tube is perforated with 0.5 cm diameter holes in the bottom and the top 15 cm portion is non-perforated.
- Above the perforated portion, markings are made for 5 cm so that irrigation at 5 cm depth could be done.
- One Field Water Tube is required for adopting the AWDI in an area of 1 acre.
- The FWT is installed in the field using mallet and it is inserted upto the perforated portion buried inside the soil.
- The soil inside the tube is to be removed.
- FWT to be installed near the field levies so that the water level inside the FWT could be monitored easily.
- Safe AWDI of 10 cm depletion in light soils and 15 cm depletion in heavy soils was found to improve the water use efficiency in rice.

Harvesting

Taking the average duration of the crop as an indication, drain the water from the field 7 to 10 days before the expected harvest date as draining hastens maturity and improves harvesting conditions

Direct Sown Rice (Wet seeded Puddled)

Follow a seed rate of 24 kg / ac

Sow the seeds by drum seeder or broadcast uniformly with thin film of water.

Thinning and gap filling should be done 14 - 21 days after sowing, taking advantage of the immediate rain.

Application of Inorganic Fertilizers

	Basal	Active Tillering	Panicle Initiation	Heading
	15Kg N (32.55 Kg Urea)	45 - 50 DAS	55-60 DAS	80-85 DAS
Short Duration	15Kg N (32.55 Kg Urea) 5 Kg K (8.35 Kg MOP) 20 Kg P (125 Kg SSP)	15Kg N (32.55 Kg Urea) 5 Kg K (8.35 Kg MOP)	15Kg N (32.55 Kg Urea) 5 Kg K (8.35 Kg MOP)	15Kg N (32.55 Kg Urea) 5 Kg K (8.35 Kg MOP)
Medium Duration		60-65 DAS	80-85DAS	110-115DAS
Long Duration		65-70 DAS	95-100 DAS	125-130 DAT

Foliar application

1 % of PPFM spray (3 litre /acre) can be given on 30 DAS, Active Tillering Stage and Panicle Initiation stage.

Weed management

Pre emergence application of pyrazosulfuron ethyl at 8 g a.i /ac on 3 DAS followed by cono weeding on 25 DAS had higher weed control efficiency in drum seeded rice.

Water management

- During first one week irrigate the soil with thin film of water.
- Depth of irrigation may be increased to 2.5 cm progressively as per the crop age

Other practices as like transplanted rice

Economic thresholds for Important Pest

Pest	ETL
Stem Borer	2 egg masses / m2 or 10% dead heart or 2% white ear
Leaf folder	10% leaf damage at vegetative phase and 5% flag leaf damage at flowering
Gall Midge	10% silver shoots

Whorl Maggot	25% damaged leaves
Thrips	60 numbers in 12 passes or rolling of the first and second leaves in 10% of seedlings
Brown Plant Hopper	1 hopper / tiller in the absence of predatory spider and 2 hoppers / tiller when spider is present at 1/hill
Green leafhopper	60/25 net sweeps or 5/hill at vegetative stage or 10/hill at flowering or 2/hill in tungro endemic area
Earhead bug	5 bugs/100 earheads at flowering and 16 bugs/100 ear heads from milky stage to grain maturity

Pest	Management strategies
Stem Borer	Release of the egg parasitoid, Trichogramma japonicum thrice (at weekly interval from 37 DAT) @ 4000/ac each release (when moth activity is noticed) Bacillus thuringiensis var. kurstaki @ 0.6 kg/ac Spray Carbofuran 3% CG 10 kg/ac or Carbosulfan 6% G 6.68 kg/ha
Leaf folder	Release Trichogramma chilonis thrice (at weekly interval from 30 DAT) @ 4000/ac each (when moth activity is noticed) Spray Bacillus thuringiensis var. kurstaki 0.6 kg/ac Apply Beauveria bassiana 1.15 WP 1 kg/ac Spray Carbosulfan 6% G 6.68 kg/ha
Gall Midge	Spray Quinalphos 5% G 2 kg/ac Thiamethoxam 25% WG 40 g/ac
Whorl Maggot	Spray Cartap hydrochloride 4% G 7.5 – 10 kg/ac
Thrips	Spray Azadirachtin 0.15% W/W 0.6 – 1.0 kg/ac or Thiamethoxam 25% WG 40 g/ac
Brown Plant Hopper	Avoid excessive use of nitrogen Control irrigation by intermittent draining Set up light traps during night or yellow pan traps during day time Drain water before use of insecticides Direct spray towards the base of the plants. Spray Neem oil 3% 6 lit/ac or Pymetrozine 50% WG 120g/ac
Green leafhopper	Spray Carbofuran 3% CG 10 kg/ac
Earhead bug	Dust/ spray any one of the following, the first during flowering and second a week later Quinalphos 1.5% D 10 kg or Neem seed kernel extract 5% (10 kg kernel/ha)

Plant Diseases

Blast	Spray carbendazim 50WP @ 200 g/ac or tricyclozole 75 WP @ 200 g/ac
Brown spot	Spray metominostrobin @ 200 ml/ha after observing initial infection of the disease
Sheath rot	Spray neem oil 3% or Ipomoea leaf powder extract @ 10 kg/ac or Prosopis leaf powder extract @ 10 kg/ac. First spray at boot leaf stage and second at 15 days later Spray carbendazim @ 200 g/ac or metominostrobin @ 200 ml/ac
Sheath blight	Foliar spray with neem oil 3% @ 6 l/ac starting from disease Appearance Spray carbendazim 50 WP @ 200 g/ac or azoxystrobin @ 200 ml/ac
Bacterial leaf blight	Spray twice copper hydroxide 77 WP @0.5 kg/ac at 30 and 45 days after planting or spray streptomycin sulphate + tetracycline combination @ 300 g + copper oxychloride @ 1.25 kg/ha. If necessary repeat 15 days later.

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TNAU

Tamil Nadu Agricultural University (TNAU), a century old premier institute providing higher education in Agriculture. TNAU had its genesis from establishment of an Agricultural School at Saidapet, Chennai, Tamil Nadu, India as early as 1868 which was later relocated at Coimbatore during 1906. Tamil Nadu Agricultural University (TNAU) was established during 1971 and now celebrating Golden Jubilee Year (1971-2021). TNAU is leading agro-technology provider of India and has diverse sphere such as Research, Education regular and distance mode, Extension, Agri-business development, Market intelligence, Weather forecasting and Community Radio.

CARDS

Cards at TNAU is involved in conducting policy-oriented research on different issues. It has been collaborating with various national and international level organizations in different domains of research. Our alumni are occupying coveted positions in different organizations across the Globe. The Centre has mandatory functions of education, research, outreach and policy interfacing through the Departments of Agricultural Economics, Agricultural Extension and Rural Sociology and Agricultural Rural Management.

IFPRI

The International Food Policy Research Institute (IFPRI), established in 1975, provides research-based policy solutions to sustainably reduce poverty and end hunger and malnutrition. IFPRI provides cutting edge research and policy options on food and nutrition security to support these goals. IFPRI is working through five major impact areas, to advance our joint mission of transforming food systems for a sustainable, climate –resilient world free from hunger and malnutrition. For more than 40 years, IFPRI has collaborated with stakeholders and partners to contribute needed evidence for country- and region led policies that help ensure that all people have access to safe, sufficient, nutritious and sustainably grown food. IFPRI maintains a strong regional and country presence to respond to demand for food policy research and deliver holistic support for country-led development.

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