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Evaluation of rice cultivation systems for greenhouse gases emission and productivity

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Abstract
A field experiment was conducted at Tamil Nadu Rice Research Institute, Aduthurai during two consecutive *Kharif* season to evaluate the different rice cultivation systems for greenhouse gases (CH4, CO_2 and N_2O gas flux) and grain productivity. Rice cultivation systems viz., transplanted rice (TR), wet seeded rice (WSR), system of rice intensification (SRI), drip irrigated rice and aerobic rice (dry seeded rice) were tested. Gas sample was collected at critical stages of rice by static chambers installed in the field. Gas Chromatography (GC) Varian 450 was used for analysis of gas. The results revealed that CO_2 emission was less during tillering stage and reached maximum during flowering stage and thereafter declined under transplanted, wet seeded rice and SRI cultivation. Whereas, drip irrigated and aerobic rice emitted higher CO_2 during tillering stage and thereafter it started to decline. Transplanted rice emitted higher methane at all the stages of observation whereas aerobic rice and drip irrigated rice emitted lesser methane as compared other methods of rice cultivation. During flowering stage, transplanted rice emitted higher CH_4 (8.20 mg/m^2/day), followed by wet seeded rice (7.70 mg/m^2/day), SRI (6.05 mg/m^2/day). Aerobic rice (2.13 mg/m^2/day) and drip irrigated rice (1.82 mg/m^2/day) emitted lesser CH_4 over other methods of rice cultivation. SRI paddy emitted an average of 26.8% lesser CH_4 and 3.8% higher N_2O over conventional flooded paddy. Wet seeded rice showed 16.6 and 18.1% lesser CH_4 and N_2O emission than transplanted rice. In case of drip irrigated rice, an average of 68.6 and 34.4% lesser CH_4 and N_2O emission was noticed over conventional flooded paddy. Changing rice cultivation from conventional flooded rice to aerobic rice emitted an average of 79.8% lesser CH_4. But, it was emitted 14.4% more N_2O over transplanted paddy.
Wet seeded rice produced significantly more number of productive tillers (392 m^{-2}) over transplanted, aerobic and drip irrigated paddy. However, it was on par with SRI. Significantly more number of filled grains (157.5 m^{-2}) was recorded under SRI over other methods of rice cultivation. The highest mean grain yield of 5855 kg/ha was recorded under SRI over other methods of cultivation which was 10.5% higher over transplanted rice. Drip irrigated rice and aerobic rice registered 17.9 and 29.5 per cent lesser grain yield respectively. Even though, these new systems of rice cultivation (drip irrigated and aerobic rice) had better advantages in reducing greenhouse gases emission, the crop establishment was under aerobic condition did not favour enhanced growth and yield over SRI and wet seeded rice. Thus, SRI method of rice cultivation is considered as best method to reduce CH_4 emission (26.8%) with increased grain productivity (10.5%) over transplanted rice in the present context of climate change.

Keywords: transplanted rice, SRI, wet seeded rice, drip irrigated rice, aerobic rice, methane, nitrous oxide, productivity

Introduction
Rice (*Oryza sativa* L.) is a major staple food crop for half of the world's population. In India, rice cultivation occupies the largest area of 43.8 million hectares with production of 115.6 million tonnes during 2018-19 (Sangeeta Soi, 2019) [12] and ranks number one crop among the crops grown in the country. In Tamil Nadu, rice is being cultivated in an area of 2.0 million hectares, production of 6.59 million tonnes. Global warming is an important issue that threatens human life on the earth. A major attributor of global warming is increases in greenhouse gases in the atmosphere. Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are considered as major greenhouse gases. The global warming potential of CH_4 and N_2O are 21 and 296 times more than CO_2 respectively, so that CH_4 and N_2O are important gases. Rice fields are a major source of agricultural methane (CH_4) emissions contributing 20–40 Tg CH_4 year^{-1} with a global emission of 52% (Sun *et al*., 2016) [16]. Rice cultivation is also a significant source of greenhouse gas emissions, primarily methane (CH_4) and nitrous oxide (N_2O). Methane emission from paddy field makes up 29% of the total of CH_4. Also N_2O emission from agricultural land makes up 52% of the total of anthropogenic N_2O. So, greenhouse gas emissions from rice paddy fields are considered as one of the most important emission sources. Methane emission from paddy fields is high in a flooded field, but decreases in a drained field. Nitrous oxide emission from paddy fields is little in flooded, but increases sharply in drained fields. It is reported that the factors affecting CH_4 and N_2O emissions are soil temperature, soil redox potential, net irradiance and organic matter (Hou *et al.* 2000) [4]. Field studies have shown that alternative management practices such as changes in water, fertilizer, and crop residue management can have a significant influence on GHG emissions from rice (Wassmann *et al*., 2000) [21].
Reducing greenhouse gas emissions from paddy fields is very important to stabilize atmospheric concentration of the greenhouse gas, which can contribute significantly to mitigate global warming. Because of the possibility of controlling the emissions by agronomic practices, paddy field management must be one of the most likely means of mitigating CH_4 emissions.

Effective water management practices, like midseason 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 emission for irrigated rice cultivation (Trost *et al*., 2013) [17]. Few reports indicated that intermittent irrigation of System of Rice Intensification (SRI) has a potential to overcome this problem. Similarly, aerobic paddy also reduces the methane emission, but it may favours the NO_2 emission. Methane emissions can be reduced by an average of 36.5% with a single drainage and by 43% with multiple aerations (Sander *et al*., 2015) [11]. In this context, it is highly essential to evaluate the different rice cultivation systems for greenhouse gas emission and select suitable method rice cultivation which emits lesser greenhouse gases without affecting yield. The objective of this study is to quantify the greenhouse gas emissions from paddy fields under different rice cultivation systems so that the low greenhouse gas emitting system could be recommended to mitigate the climate change impact on rice production.

Materials and Methods

A field experiment was conducted at Tamil Nadu Rice Research Institute, Aduthurai during two consecutive *Kharif* season to evaluate the rice cultivation systems for their greenhouse gases (CH4, CO_2 and N_2O gas flux) emission. Tamil Nadu Rice Research Institute (TRRI) is present in the middle of the Cauvery Delta Zone, Tamil Nadu, India, geographically located at 11º N latitude 79.3º E longitude with an altitude of 19.4 m above MSL. The soil of the experimental field was alluvial clay with pH of 7.6 and EC of 0.3 dS/m and low, high and medium in available nitrogen, phosphorus and potassium contents respectively. Rice cultivation methods viz., transplanted rice (TR), wet seeded rice (WSR), system of rice intensification (SRI), drip irrigated rice and aerobic rice (dry seeded rice) were tested. Rice variety ADT 45 was used for this study. Recommended dose of fertilizer at150: 50:50 kg NPK/ha was applied in all the methods. Transplanted rice was established by planting of 22 days old seedlings at 20 x 10 cm in puddle and leveled field**.** Irrigation was given at 5 cm depth of water after disappearance of ponded water. In SRI, 14 days old seedlings were transplanted at 22.5 x 22.5 cm under puddled and leveled field. Irrigation was given at 2.5 cm depth of water after formation of hairline cracks (alternate wetting and drying method). The N as urea and K as Muriate of Potash were applied in 4 equal splits from basal, active tillering, panicle initiation and heading stages in both transplanted and SRI method. In wet seeded rice, direct seeding was done using drum seeder at 20 x 8-10 cm. During establishment, irrigation was done similar to nursery and later irrigation at 5 cm depth of water after disappearance of ponded water. Whereas, manual sowing at 20 x 10 cm was followed in aerobic and drip irrigated rice. Top dressing of N and K was given in 4 splits from 14DAS, active tillering, panicle initiation and heading stages in both wet seeded rice and aerobic rice. Surface irrigation was given at 4-5 days interval depends on the weather condition in aerobic rice. Drip irrigation was laid out at 80 cm lateral spacing, dripper spacing of 30 cm with discharge rate of 1.0 litre per hour. Irrigation was given at 150% PE throughout the cropping period in every alternate day. Drip fertigation of N as urea and K as Muriate of Potash were given in 13 splits starting from 14 DAS to heading stage at 5 days interval along with irrigation water. Recommended phosphorus was applied as basal in all the methods.

Gas sampling and analysis

Greenhouse gas was quantified during critical stages of rice viz., tillering, panicle initiation, flowering and maturity. Gas flux was collected by static chambers installed in the field as method suggested by Mosier (1989) [8]. There were two parts in static chamber (anchor or base and chamber). Anchor was made up of thin-walled stainless steel to minimize physical disturbance upon insertion. Round chambers diameter and height was 47 cm and 24 cm respectively. Chambers were fabricated with non-reactive materials and were painted with white paint. It had two ports for air thermometer and gas sampling. Area occupied by round chamber for measuring plant-mediated emissions was 1562 cm^2. Anchors were installed at 10 cm into the ground at least 24 hours prior to first flux measurement and were packed well around the sides. Chamber was kept upside down upon the base at time of gas sampling. Plants were included inside the chambers during gas sampling (Smart and Bloom, 2001) [14].

Before sampling, the base position and presence of water in the rim of base were noticed. Flood water level both inside and outside the base were noted, soil temperature were recorded and chamber temperature was recorded immediately after sampling. Sampling was performed by inserting a polypropylene syringe into the chamber septa and slowly removing a gas sample. Sampling was done in four times at ten minutes interval *viz*., 0, 10, 20 and 30 minutes after deployment of chamber. Typically, 50 ml sample were removed and transferred to a previously evacuated 30 ml glass vial sealed with a grey butyl rubber septum. Excess gas was injected into the evacuated vial to produce an overpressure. This overpressure facilitates the subsequent removal of a gas sample for analysis.

Gas chromatography (GC) Varian 450 equipped with three different detectors was used for analysis of gas. Thermal Conductivity Detector for CO_2, Electron Capture Detector for N_2O and Flame Ionization Detector for CH_4 analysis were used. To run GC, 5 gases were used namely Helium, Hydrogen, Nitrogen, Mixed air (argon + methane) and Zero air. Several different standard concentrations were fed to run, as detector response was nonlinear. The range of standards was 0.5 and 1 ppm for N_2O, 2 and 10 ppm for CH_4 and 1000 ppm for CO_2 were used. Standard curves used to convert the GC output of the samples into units of ppm. GHG emission was calculated based on area of static chamber and expressed as mg/m^2/day.

Observations on rice growth, yield parameters and grain yield were recorded at the time of harvest. All the recorded data were analyzed statistically as per the method suggested by Gomez and Gomez (1984) [3] to find out the treatment differences. The critical differences were calculated at five per cent probability level to know the treatment differences and writing interpretations.

Results and Discussion

Greenhouse gases emission

Carbon di-oxide (CO_2) emission

Emission of CO_2 was less during tillering stage and reached maximum during flowering stage and thereafter declined under puddled fields in transplanted, wet seeded rice and SRI cultivation. Whereas, under aerobic field condition in drip irrigated and aerobic rice methods emitted higher CO_2 during tillering stage and thereafter it started to decline. During tillering stage, maximum CO_2 emission was noticed under drip irrigated rice (4005 mg/m^2/day), followed by aerobic rice (1787 mg/m^2/day). Frequent wetting with aeration under drip irrigated paddy might have favoured faster decomposition and release of more amount of CO_2 during early stage. Under puddled condition, presence of standing water would have reduced the aerobic decomposition of organic residues resulted in lesser CO_2 emission under SRI (2394 mg/m^2/day), wet seeded and transplanted rice as compared to drip and aerobic rice. During flowering and maturity stages, significantly higher CO_2 emission was recorded under SRI over other methods of rice cultivation. This was followed by transplanted and wet seeded rice (Fig 1).

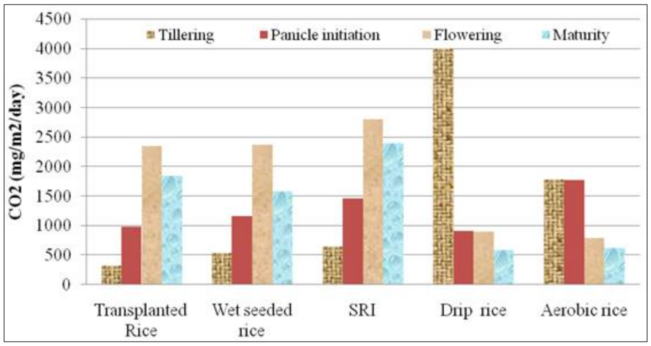

Fig 1: Carbon dioxide emission during critical stages of rice under various rice cultivation systems (mean of two years)

Alternate wetting and drying method of irrigation under SRI caused aerobic decomposition and emitted more CO_2 as compared to transplanted and wet seeded rice. Reductions in the irrigation water volume to the rice led to a lower surface standing water depth and even no standing water above the surface in AWD irrigation. This increased the oxygen penetration into the soil and led to soil organic C being oxidized to CO_2 instead of CH_4 (Sun *et al*., 2016) [16]. Drip irrigated and aerobic rice recorded lesser CO_2 emission during flowering and maturity stages.

Methane emission

Methane emission under different rice cultivation methods revealed that transplanted rice emitted higher methane at all the stages of observation whereas aerobic rice emitted lesser methane as compared other methods of rice cultivation (Table 1). During tillering stage, transplanted rice emitted higher methane (5.23 mg/m^2/day), followed by SRI (4.08 mg/m^2/day) and the lowest emission was occurred under aerobic rice (0.88 mg/m^2/day) followed by drip irrigated rice (2.19 mg/m^2/day). During flowering stage, transplanted rice emitted higher CH_4 (8.20 mg/m^2/day), followed by wet seeded rice (7.70 mg/m^2/day) and SRI (6.05 mg/m^2/day). Puddled condition and standing water under transplanted rice increased the anaerobic decomposition of organic residues resulted in higher methane emission over aerobic condition.

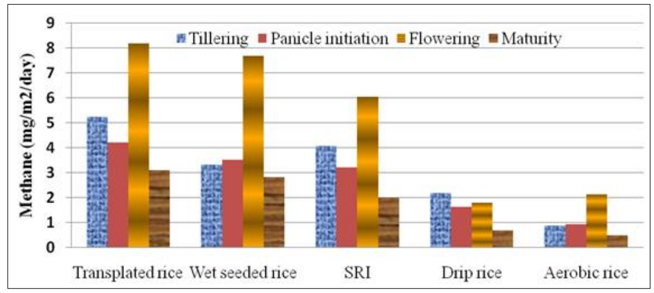

Fig 2: Methane emission during critical stages of rice under various cultivation systems (mean of two years)

Compared to conventional transplanted rice, SRI method reduced by an average of 26.8% lesser CH_4 emission. Under SRI, alternate wetting and drying method of irrigation and formation of hairline cracks before irrigation might have supplied more oxygen to the rhizosphere which favoured aerobic decomposition of organic waste thus resulted in lesser methane emission than transplanted rice. Alternate wetting and drying method of irrigation followed in SRI considerably reduced methane emission as compared continuous flooding (Setyanto, 2004) [13]. Methane emission in SRI decreased by 61.1% compared to transplanted rice (Jain *et al*., 2013) [5]. Tyagi *et al*. (2010) reported that midseason drainage and drainage of paddy fields twice suppressed CH_4 emission by 37 and 41 %, respectively.

Wet seeded rice registered 6.1% lesser methane than transplanted paddy during flowering stage (Fig 2). Similar trend was noticed during maturity stage also. Aerobic rice (2.13 mg/m^2/day) and drip irrigated rice (1.82 mg/m^2/day) emitted lesser CH_4 over other methods of rice cultivation. Drip irrigated rice registered 68.6% lesser CH_4 by an average of four stages of observation than transplanted rice. Drip irrigation might have increased more oxygen to the root zone that inhibits the activity of methanogenic bacteria by methane oxidation. However, the dissolved oxygen content declined significantly in drip practice over the conventional methods; Soil methanotrophic bacteria oxidizing methane gas using molecular oxygen in drained paddy soil (Jiao *et al*., 2006) [6] was the reason for the above reduction in methane flux rate, cumulative methane flux under drip irrigated rice (Parthasarathi *et al*., 2019) [9].

Nitrous oxide emission

Variation in water and nutrient management practices under different rice cultivation systems considerably altered the N_2O emission in all the critical stages of observation (Fig 3). Significantly higher nitrous oxide emission was recorded under aerobic rice cultivation (2.55, 1.89 and 1.77mg/m^2/day during tillering, PI and flowering stages respectively), followed by SRI (2.42, 1.71 and 1.69 mg/m^2/day during tillering, PI and flowering stages respectively). Average of four observations on N_2O emission found that aerobic rice and SRI emitted 14.7 and 3.8% higher N_2O respectively than transplanted rice (Table 1).

Alternate wetting and drying method of irrigation and artificial aeration through cono weeding in SRI and unpuddled field preparation and non-flooded condition under aerobic rice cultivation increased the availability of oxygen, thus favoured more nitrous oxide emission. Similarly, an average of 22.5 % increase in N_2O emission under SRI over transplanted rice was reported by Jain *et al*. (2013) [5]. Switching from anaerobic to aerobic rice production system can create conditions that increase nitrous oxide emissions (Maris *et al*., 2016) [7] However, the degree to which nitrous oxide emissions increase ranges substantially and is influenced by soil characteristics and the history of soil and water management in a given location (Wang *et al*., 2012) [20].

Drip irrigated rice emitted lesser N_2O as compared to other methods of rice cultivation. The average reduction in nitrous oxide emission was to the tune of 34.4% under drip irrigated rice over transplanted rice. Frequent irrigation and more numbers of split applications of nitrogen fertilizer (Irrigation at alternate days and fertigation of urea at five days interval) in drip irrigated rice might have facilitated better crop uptake and lesser loss of nitrogen as nitrous oxide. Variation in water and nutrient availability under drip and flooded transplanted paddy would have been the reason for creating such difference in N_2O emission (Ramesh *et al*., 2019) [2]. In conventional system of transplanting, maintaining 5 cm depth of water reduced the oxygen supply in the rhizosphere resulted in lesser emission of nitrous oxide.

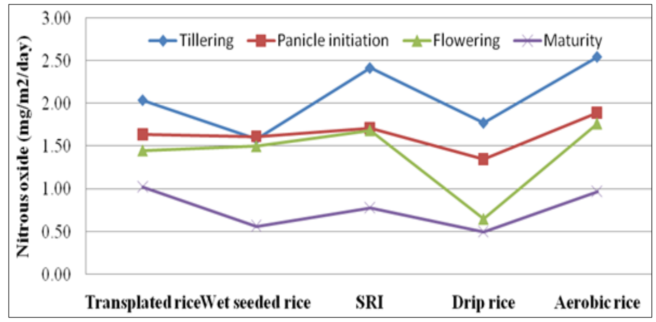

Fig 3: Nitrous oxide emission during critical stages of rice under various rice cultivation systems (mean of two years)

Table 1: Methane and N_2O emission (mg/m²/day) and percentage variation over transplanted rice under rice cultivation systems (mean of two years)

Rice cultivation methods	Methane emission (mg/m²/day) during critical stages of rice								mean % variation over TR (mean of four stages)
	Tillering	% variation over TR	Panicle Initiation	% variation over TR	Flowering	% variation over TR	Maturity	% variation over TR	
Transplanted rice (TR)	5.23	-	4.21	-	8.20	-	3.10	-	-
Wet seeded rice	3.34	-36.1	3.54	-15.9	7.70	-6.1	2.84	-8.4	-16.6
System of rice intensification (SRI)	4.08	-22.0	3.22	-23.5	6.05	-26.2	2.00	-35.5	-26.8
Drip irrigated rice	2.19	-58.1	1.65	-60.8	1.82	-78.0	0.70	-77.4	-68.6
Aerobic rice	0.88	-83.2	0.95	-77.6	2.13	-74.0	0.49	-84.2	-79.8
C.D. (P=0.05)	0.47	-	0.41	-	0.78	-	0.27	-	-
	N_2O emission (mg/m²/day) during critical stages of rice								
Transplanted rice	2.04	-	1.64	-	1.45	-	1.03	-	-
Wet seeded rice	1.59	-22.3	1.62	-1.5	1.40	-3.44	0.57	-45.1	-18.1
System of rice intensification (SRI)	2.42	+18.6	1.71	+4.3	1.69	+16.6	0.78	-24.3	+3.8
Drip irrigated rice	1.78	-13.0	1.35	-17.7	0.65	-55.2	0.50	-51.5	-34.4
Aerobic rice	2.55	+25.0	1.89	+15.2	1.77	+22.1	0.97	-5.8	+14.1
C.D. (P=0.05)	0.28	-	0.22		0.17		0.11	-	-

Growth parameters

Growth parameters like plant height and total tillers were significantly influenced by various rice cultivation methods (Table 2). System of rice intensification produced significantly taller plants (89.4 cm) than aerobic and drip irrigated paddy. However, it was on par with transplanted and wet seeded rice. Availability of standing water and puddled condition under SRI, transplanted and wet seeded rice favoured better crop growth and increased plant height over unpuddled condition of aerobic and drip irrigated paddy. Significantly more number of tillers (578 m^{-2}) was recorded under wet seeded rice over other methods of rice cultivation. Sowing using drum seeder caused more number of plants per unit area over other methods was the reason for more number of tillers. SRI and transplanted rice recorded 514 and 476 tillers per m^2 respectively. Shorter plants and lesser tillers were noticed under drip irrigated and aerobic rice. Availability of lesser soil moisture under aerobic rice and rows away from the lateral in drip irrigation might be the reason for reduced plant growth.

Table 2: Growth, yield parameters and grain yield of rice as influenced by rice cultivation methods (mean of two years)

Rice cultivation methods	Plant height (cm)	Total tillers (Nos./m²)	Productive tillers (Nos./m²)	Filled grains / Panicle (Nos.)	Grain yield (kg/ha)	% variation in grain yield over TR
Transplanted Rice (TR)	86.5	476	348	134.5	5300	-
Wet seeded rice	88.1	578	392	141.6	5548	+4.7
SRI	89.4	514	372	157.5	5855	+10.5
Drip irrigated rice	81.1	385	334	119.8	4350	-17.9

Aerobic rice	77.0	368	275	111.7	3735	-29.5
C.D (P=0.05)	4.9	40.4	26	16.5	349	-

Yield attributes

Yield parameters like productive tillers and filled grains per panicle were significantly influenced by various rice cultivation methods (Table 2). Wet seeded rice produced significantly more number of productive tillers (392 m^{-2}) over transplanted, aerobic and drip irrigated paddy. However, it was on par with system of rice intensification. Lesser number of productive tillers was noticed under aerobic and drip irrigated paddy. Significantly more number of filled grains (157.5 m^{-2}) was recorded under SRI over other methods of rice cultivation. Practicing of SRI components viz., young seedlings, single seedling, cono weeding and alternate wetting and drying favoured better eco-physiology of individual plants resulted in more number of filled grains per panicle (Geethalakshmi *et al*., 2011) [2]. However, this was comparable with wet seeded rice. Minimum number of filled grains was recorded under aerobic rice mainly due scarcity of soil moisture in the root zone under aerobic condition.

Grain yield

Grain yield of rice varied significantly under various rice cultivation methods (Table 2). Significantly higher mean grain yield of 5855 kg/ha was recorded under system of rice intensification over other methods of cultivation. The increment in grain yield under SRI over transplanted rice was to the tune of 10.5%. Similarly, rice cultivation by SRI increased the grain yield by 5–7% besides savings of water by 12–15% over the conventional method of rice cultivation under a wetland ecosystem (Geethalakshmi *et al*., 2011) [2]. Increased grain yield under SRI was mainly due to the synergistic effects of modification in the cultivation practices such as use of young and single seedlings per hill, limited irrigation, and frequent loosening of the top soil to stimulate aerobic soil conditions (Stoop *et al*. 2002) [15]. Transplanting of very young seedlings, usually 8–12 days old, preserves its potential for tillering and rooting, which was reduced if transplanted after the occurrence of fourth phyllochron. Further, the combination of plant, soil, water and nutrient management practices followed in SRI increased the root growth, along with an increase in productive tillers, grain filling and higher grain weight that ultimately resulted in the maximum grain yield (Uphoff 2001) [15]. Wet seeded rice recorded mean grain yield of 5548 kg/ha which was 4.7% higher over transplanted rice. Drip irrigated rice and aerobic rice registered grain yield of 4350 and 3735kg/ha respectively. The percentage reduction in grain yield under drip irrigated rice and aerobic rice was 17.9 and 29.5 as compared to transplanted rice. Even though, these new systems of rice cultivation had better advantages in reducing greenhouse gases emission and water saving, the crop establishment under aerobic condition did not favour enhanced growth and yield over SRI, wet seeded and transplanted paddy.

From the field experiments, it could be concluded that new systems of rice cultivation (drip irrigated and aerobic rice) had better advantages in reducing greenhouse gases emission and considered as mitigation options for climate change. Drip irrigated rice emitted lesser N_2O (34.4%) as compared to other methods of rice cultivation needs further attention. However, the crop establishment under aerobic condition did not favour enhanced growth and yield over SRI and wet seeded rice. Thus, SRI method of rice cultivation is considered as best method to reduce CH_4 emission (26.8%) with increased grain productivity (10.5%) over transplanted rice in the present context of climate change.

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