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Sobering Rice Production from Conventional to Climate Smart

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A B S T R A C T

This study sobers the penchant searches on sustainable rice production systems. Three aspects of different rice cultivation, carbon footprint, water productivity, and Energy efficiency were analysed. GHG emissions from rice cultivation estimated are CH_4, N_2O and CO_2.Three rice cultivation systems SRI (System of Rice Intensification), AWD (Alternate Wetting and Drying) and conventional were selected which differ in agronomic and water management practices. The gas samples were collected using static closed chamber and was analysed using a gas chromatograph equipped with FID. Water irrigated to the field was measured in m^3 using a water meter. The estimates of carbon footprint were prepared using the global warming potential of the above GHGs as suggested by IPCC. The results indicates that SRI method of cultivation recorded less carbon footprint of 0.491 kg CO_2 eq. /kg of dry matter with higher yield 10.82 t and water 1.69 kg/m^3.

Introduction

The global warming phenomenon is closely related to the rise in greenhouse gas (GHGs) emissions such as CO_2, CH_4 and N_2O that contribute to global warming at a share of 60, 20 and 6 percent respectively (IPCC, 1996). The climate will continue to change over the coming decades as more and more heat trapping greenhouse gases emitted by human activities accumulate in the atmosphere. The contribution of agricultural sectors to climate change in India comprises of 28 per cent, of which 23 per cent is by rice cultivation (INCCA, 2010). Rice is the most important food crop of India covering about one-fourth of the total cropped area and providing food to half of the Indian population. Globally rice is estimated to be responsible for 19 per cent of anthropogenic methane emissions, second only to ruminants 23 per cent (Chen and Prinn, 2006). Hence modifying the emissions without affecting the yield is a prime matter of concern. Methane emissions being the major emissions from rice fields are determined by the rates of production, oxidation and transportation of methane, but from the management perspective, two key options can modify the amount of methane emitted. First, organic matter content of the soil and second by managing water applied to the field. Methane emissions can be reduced by changing the water management strategies and understanding the trade-offs between methane and nitrous oxide emissions are important before different methods of rice production are advocated on grounds of climate change mitigation.

The water productivity of rice in India is 0.5-1.1 k gm^{-3} ranging through various systems of cultivation. As water becomes meagre in rice production regions all over the world, producers are cognizant about the importance of increasing water productivity in rice cultivation. The challenge for sustainable rice production is to decrease the amount of water used while maintaining or increasing grain yields to meet the demands of an ever-growing population by improving water productivity (Zhang and Yang, 2010). Techniques like AWD (Alternate Wetting and Drying) and SRI (System of Rice Intensification) have the potential to improve the water productivity in addition of minimizing GHG emission. In the recent years, SRI method of cultivation has received wide attention and it has even become a buzzword for many rice growers due to higher water and grain productivity. The SRI was introduced in irrigated lowland rice in order to reduce the amount of water used for irrigation (Uphoff, 2003), which includes transplanting of young seedlings (8–14 days) singly in square pattern keeping paddy field moist by intermittent drying and wetting. It leads to better plant growth, less use of chemicals and fertilizer, increases productivity of land and economizes use of water, which helps in maintaining the system productivity as well as sustainability.

Amending the current cultivation system might be a way to reduce the methane emission from rice fields. In this regard, SRI has been introduced. Suryavanshi *et al.,* (2013) documented that CH_4 emissions from SRI and conventional practices, the results of which indicated that CH_4 emissions from SRI were reduced by 32–38 per cent compared to conventional system.

Energy consumption being a prime concern in the recent years where the energy resources are being truncated brutally. Hence, production technologies, which decipher the chances of less energy consumption, can endorse the aspects of sustainable production.

Therefore, developing sustainable methods, which focus at climate resilient future by reducing GHGs and energy consumption, not only reduce the driving factors of climate change but also ensure the efficient distribution and utilization of natural resources.

The concept of carbon footprint is a holistic approach for measuring the emission potential of the system. Carbon footprint estimates are always expressed in terms of a mass of 'carbon dioxide equivalents' or kg of CO_2 equivalents per unit of product. Carbon foot printing in rice production systems is an attractive and important issue not only because of the importance of crop but also because of the huge carbon sequestration potential in farmland soils.

On this background, this study was conducted to assess the carbon footprints, water productivity and energy efficiency of different rice cultivation systems, which provides an opportunity to promote climate smart cultivation methodologies. Moreover, production systems with less carbon footprint can be promoted for carbon trading that would provide financial assistance to growers for their eco services. The carbon footprint was found out considering only the direct GHG emissions from rice cultivation systems (kg-CO_2eq./Kg of dry matter).

Materials and Methods

The study was conducted at Coimbatore, Tamil Nadu, India cropped during *Rabi* season. Three systems of rice cultivation, SRI, AWD and conventional were selected which is significantly differ in their agronomic and water management practices. The GHG emission from three different rice cultivation systems were found out separately using fabricated static closed chamber method. The results obtained were analysed for significance using AGRES software.

Cultivation practices

SRI is a system of cultivation where young single seedling with square planting; conoweeder is used in between the hills; and following intermittent wetting and draining water management strategy that keeps the soil wet only, not allowing continuous flood.

All the SRI practices were systematically adopted as per the recommendations described in the technical bulletin on SRI (Thiyagarajan *et al.*, 2009). All the agronomic practices for conventional method were followed as per the standard recommendations in crop Production Guide for Tamil Nadu by TNAU (CPG, 2012). For AWD; all the agronomic practices were followed as per the conventional system of rice cultivation except the water management, which was followed similar to SRI method.

Energy efficiency calculation

Energy consumption was calculated by using TNAU Energy soft where energy was calculated from the details of inputs given for cultivation. Energy productivity and Energy efficiency were calculated based on the grain yield obtained from respective systems of cultivation. The total energy production from the system was calculated based on the values as imparted in TNAU Energy soft as one Kg of grain produced = 14.7 MJ.

$$\text{Energy Efficiency} = \frac{\text{Energy Output}}{\text{Energy Input}}$$

$$\text{Energy Productivity} = \frac{\text{Energy output (MJ)}}{\text{Yield in grams}}$$

Collection of gas samples

The static closed chamber technique was used to collect gas samples from the field (Minami and Yagi, 1988). The gas chambers were casted as per the several studies on trace gas measurements under field conditions (Mosier, 1989; Adhya *et al.*, 1994Denmead, 2008). Collection of air samples for CH_4 and N_2O estimation was done as described by Khosa *et al.*, (2010), each chamber was placed on the soil surface with 4-5 cm inserted into the soil 10 minutes before each sampling for equilibration to bring down the disturbance to the sampling site. Care was taken for minimum disturbance for the plants during the whole measurement process. After covering the plants with the chamber, four air samples were collected in Tedlar bags starting with zero time and afterward sampling at an interval of 15 minutes using syringe and one way gas pump valve as described by Rath *et al.*, (1999) and Jayadeva *et al.*, (2009), the air samples were collected in the morning (09:00-10:00 hours) and in the evening (14:00-15:00 hours) and the average of morning and evening fluxes were used as the mean flux value for the day. At every critical stages of crop growth *viz.*, active tillering, panicle initiation, flowering and maturity stages, gas samples were collected continuously for a week and the average of the seven days were reported as the mean daily methane, nitrous oxide and carbon dioxide emission rate for the respective stages.

GHG estimation

The estimation of CH_4, CO_2 and N_2O was done using a Shimadzu GC-2014 gas chromatograph equipped with FID. The GC was calibrated using 1 ppm, 2.3 ppm and 5 ppm of standards (Chemtron® science laboratories Pvt. Ltd., Mumbai) as primary standard curve linear over the concentration ranges used before and after each set of measurements. The obtained CH_4, CO_2 and N_2O concentrations were determined by peak area and gas flux was calculated using the equation formulated by Rolston (1986)

$$f = (V/A)\ (\Delta C/\ \Delta t)$$

Where f is greenhouse gas emission rate (mg m^{-2} hr^{-1}), V is volume of chamber above soil (m^3), A is cross-section of chamber (m^2), ΔC is concentration difference between zero and t times (mg cm^{-3}), and Δt is the time duration between two sampling periods (hrs.)

Water productivity

The quantum of water used per irrigation was measured using water meter, Itron WEN50 and from the number of irrigations the total quantity of water used was calculated. Water Productivity (WP) was expressed on agronomic yield (kg of dry matter) per unit of water used (m^3 of water) as follows (Grassi, 2009).

$$WP = \frac{Y}{\Sigma\ (I+R)}$$

WP = Water productivity
Y = Yield
I = Irrigation water applied
R = Amount of rainfall

Accounting carbon footprint

In this study, the carbon footprint was estimated using the global warming potential of the GHGs as given in Table 1.The GHG emissions, which were quantified as mg m^{-2} hr^{-1} were converted into seasonal emission and expressed as Kg ha^{-1} $season^{-1}$. Further, the collected GHG data were translated into CO_2 equivalents using global warming potentials of different GHGs as suggested by IPCC (2007). Global warming potentials for 100 years' time horizon (GWP 100) were used to illustrate the results. According to the 4^{th} assessment report of Intergovernmental Panel on Climate Change (IPCC), the cumulated Carbon dioxide Equivalent (CE) emission was worked out using the following formula:

$$CE\ (Kg\ CO_2\ eq.) = CO_2 + 25\ CH_4 + 298\ N_2O$$

Based on the CE value and yield, the carbon footprint (CF) was worked out and expressed as CO_2 equivalents (Kg CO_2 eq. / Kg of dry matter.)

Results and Discussion

Methane emission

Methane emission rate was notably higher in conventional system than AWD and SRI throughout the crop period. The reduced methane flux in SRI and AWD can be ascribed by more aeration resulted because of intermittent irrigation. In conventional system, the rice rhizosphere was subjected to more intense reducing conditions due to water logging that favoured the activities of methanogenic bacteria resulted in higher methane emissions. IPCC (2006) recognizes the effects of aeration on CH_4 emissions with an average of 40 per cent reduction in CH_4 emissions for single aeration events and 48 per cent for multiple aeration events. In this study also aeration due to alternate wetting and drying method of water management reduced methane emission in AWD by 41 per cent and SRI by 44.3 per cent when compared with conventional system. SRI cultivation encompasses components such as square planting, cono weeding, alternate wetting and drying. These components would have favoured better aeration in soil that led to higher dissolved oxygen and lower methane emission and the results are in conformity with earlier reports of Sudhalakshmi (2002).

Nitrous oxide emission

Nitrous oxide (N_2O) emission rate was comparitevely higher in AWD than other cultivation systems. The microbiology of nitrous oxide is more complex than that of methane and is produced by soil bacteria by nitrification and de-nitrification processes. Accordingly both oxidative and reductive processes that happen because of drying and wetting water management practices in rice release nitrous oxide. The total seasonal emission of nitrous oxide was maximum in AWD and minimum in conventional system. The nitrous oxide emission measurements at five critical stages of rice growth revealed that the flux of N_2O was high in all treatments in initial stages, which was preferably due to denitrification of soil NO_3^- -N. As NO_3^- –N in soil decreased due to plant uptake and losses through denitrification and leaching, N_2O flux declined later. Here emissions of N_2O from soil in conventional rice cultivation were lower than SRI and AWD plots, which indicated that intermittent wetting, and drying treatments had more supply of NO_3^- -N through nitrification as compared to saturated soil moisture regime. NO_3^- -N served as a substrate for denitrification by the denitrifiers and resulted in N_2O emission. Previous studies have confirmed our results that soil moisture is the most sensitive factor in regulating N_2O emissions from croplands (Zheng *et al.*, 2000; Yan *et al.*, 2000).

Carbon dioxide emission

The mean carbon dioxide emission was higher for SRI, followed by AWD, conventional systems Carbon dioxide emission is directly influenced by respiration rate and vegetative growth, and CO_2 emission from soil in paddy fields is strictly suppressed during the submerged period, but considerably enhanced by the intermittent drainage. This was evident from our results that SRI and AWD fields have marginally higher flux than conventional system. Moreover, among the treatments SRI had more vegetative growth and more respiration rate, resulting in higher carbon dioxide emission. The variation in flux rate between rice cultivation systems was high for methane and low for nitrous oxide. The average hourly, daily and seasonal methane, Carbon dioxide and Nitrous oxide flux for conventional, AWD and SRI systems are represented from tables 2 to 4.

Yield

The dry matter yield under SRI system (10820 kg) was significantly higher than AWD (8140 kg per ha) and conventional systems (7410 kg per ha). Amodkumar Thakur (2014) reported 49 per cent increased grain yield in SRI compared to conventional. He also reported an increase in grains per panicle, 1000-grain weight and longer panicles in SRI. The grain yield for SRI (4.92 t/ha), AWD (3.6 t/ha) and conventional (3.25 t/ha) systems forms 33.04 per cent, 27.76 per cent and 25.96 per cent respectively of total biomass yield. The increase in yield in SRI can be attributed by the increased LAI and better microbial mineralization and nutrient uptake due to soil aeration.

Energy consumption

Conventional system consumed relatively higher energy to produce one unit of grain. This was due to the higher inputs and lower yields. SRI in contrast consumed very less energy as this system was in requirement of less chemicals and labour. SRI consumed 1.26 MJ to produce one Kg of rice whereas conventional consumed 2.12 MJ. The Energy efficiency of SRI (10.70) was found to be 67 per cent more than that of conventional (6.38).

Table.1 Global warming potential of greenhouse gases (IPCC, 2006)

Greenhouse Gas	Global Warming Potential (GWP) for 100 years' time line
Carbon dioxide	1
Methane	25
Nitrous oxide	298

Table.2 Average methane emission rate of different systems of rice cultivation

	Hourly emission (mg m^{-2} hr^{-1})	Daily emission (Kg ha^{-1} day^{-1})	Seasonal Emission (kg ha^{-1} $season^{-1}$)
SRI	5.73	0.45	34.41
AWD	6.04	0.48	36.27
conventional	10.28	0.82	61.69

Table.3 Average nitrous oxide emission rate of different systems of rice cultivation

	Hourly emission (µg m^{-2} hr^{-1})	Daily emission (kg ha^{-1} d^{-1})	Seasonal emission (kg ha^{-1} $season^{-1}$)
SRI	56.80	0.0045	0.3408
AWD	56.91	0.0046	0.3414
conventional	55.28	0.0044	0.3317

Table.4 Average carbon dioxide emission rate of different systems of rice cultivation

	Hourly emission (mg m^{-2} hr^{-1})	Daily emission (Kg ha^{-1} day^{-1})	Seasonal Emission (kg ha^{-1} $season^{-1}$)
SRI	724.85	57.99	4349.08
AWD	687.70	55.02	4126.18
conventional	680.13	54.41	4080.76

Table.5 Energy consumption in MJ (Million Joules) and energy efficiency

	SRI	**AWD**	**Conventional**
Initial Land preparation	625.45	723.45	723.45
Seeds and sowing	706.50	1020.50	1020.50
Manure and fertilizer	8603.45	8701.45	9319.30
Plant protection & Weed Management	998.00	1742.00	1644.00
Intercultural operations	1707.00	1884.00	1413.00
Irrigation	266.30	266.30	299.59
Harvest and Post-Harvest	706.50	1311.00	1256.00
Total Energy Consumed	**13613.20**	**15648.70**	**15675.84**
Energy from Grain production(Yield X 14.7)	72,324.00	52,920.00	47,775.00
Energy from Straw production(Yield X 12.5)	73750.00	56750.00	52,000.00
Total Energy production from dry matter	146074.00	109670.00	99975.00
Energy Efficiency	10.70	7.01	6.38
Energy Productivity (gm of grain/MJ)	33.68	32.83	32.51

Table.6 Yield from different systems of rice cultivation (t ha^{-1})

	Grain Yield	Straw Yield	Total Dry matter yield	Harvest Index
SRI	4.92	5.90	10.82	0.45
AWD	3.60	4.54	8.14	0.44
conventional	3.25	4.16	7.41	0.43

Table.7 Emission of greenhouse gases (Kg) and energy consumption (MJ), per tonne of rice production in different rice cultivation systems

	Methane Flux	Nitrous oxide Flux	Carbon dioxide Flux	Energy consumption
SRI	3.18	0.032	401.95	1258.15
AWD	4.46	0.042	506.90	1922.44
conventional	8.33	0.045	550.71	2115.50

Table.8 Water usage and water productivity in different rice cultivation systems

	No. of irrigations	Total water used (m^3ha^{-1})	Water Productivity (Kg of dry matter per m^3 of water)
SRI	18	6401.36	1.69
AWD	16	5886.39	0.72
conventional	24	7532.65	1.02

Table.9 Total emission of different greenhouse gases (kg ha^{-1} $season^{-1}$) and their CO_2 Equivalents (kg CO_2 Equivalents) in different rice cultivation systems

	Carbon dioxide (a)	Methane (b)	Nitrous oxide (c)	CO_2 Equivalents of Methane (d) (b) X 25	CO_2 Equivalents of Nitrous oxide (e) (c) X 298	Total CO_2 Equivalents (a + d + e)
SRI	4349.076	34.41	0.3408	860.25	101.56	5310.88
AWD	4126.176	36.27	0.3414	906.75	101.74	5134.66
Conventional	4080.756	61.69	0.3317	1542.25	98.85	5721.85

Table.10 Relationship between carbon footprint, grain yield and energy consumption in different rice cultivation systems

	Carbon Footprint (kg CO_2 eq./kg of dry matter)	Dry matter Yield (tonnes)	Energy Consumption (MJ /kg of dry matter)
SRI	0.491	10.82	1.26
AWD	0.631	8.14	1.92
Conventional	0.772	7.41	2.12

Water productivity

Water productivity of various systems of rice cultivation, number of irrigations, total quantity of water consumed and water productivity is presented in table 8.

The water productivity (kg of dry matter produced per m^3 water: kg m^{-3}) for SRI, AWD and conventional systems were 1.69, 0.72 and 1.02 respectively. The alternate irrigation method irrigation water applied after the formation of hairline cracks showed considerable water savings in addition of providing a better root-growing environment in SRI.

Carbon footprint

The carbon footprints for rice production was calculated by correlating the methane and nitrous oxide emissions with total dry matter yield for different systems of rice cultivation. Carbon dioxide Equivalent (CE) of emissions was worked out from greenhouse gas emission by multiplying with the Global Warming Potential (GWP) of Methane (25) and Nitrous oxide (298). Earlier studies (Xiaoming Xu *et al.,* 2013; Nivetha Jain *et al.,* 2014) have also expressed the carbon footprints for rice production systems in terms of kg CO_2 eq./ kg of product or ton of CO_2 eq./ ton of product. Therefor in this study, the carbon footprint is indicated as kg CO_2 eq./ kg of dry matter. The carbon footprint for conventional system was more (0.772 kg CO_2 eq. /kg of dry matter) than SRI and AWD. In SRI and AWD, the methane emission, which is the prime contributor of carbon footprint, was low compared to conventional method. Despite the fact that emission of nitrous oxide was slightly high in AWD and SRI than conventional, the relative contribution of nitrous oxide to global warming and carbon footprint calculation is low. Here, the relative contribution of methane and nitrous oxide towards carbon footprints were 1.98 per cent in AWD; and 26.95, 16.20 & 1.96 per cent in SRI, 17.65 && 1.73 per cent in conventional system respectively. Between SRI and AWD, there is minimal variation in the emission of methane and nitrous oxide, but owing to the higher grain yield in SRI, the final carbon footprint calculation were in favour of SRI (0.491 kg CO_2 eq./kg of dry matter).

This results has asserted SRI to be more ecologically sustainable rice production system owing to higher water productivity, higher yield, energy efficient and lesser carbon footprint (0.491 kg CO_2 eq./kg of dry matter). In SRI, the improved energy efficiency and water productivity can be achieved with low greenhouse gas fluxes in rice soil ecosystem. Even though SRI has some practical problems for field adoption, this system of rice cultivation needs to be explored more due to low carbon footprints.

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