GRAIN YIELD AND ENVIRONMENTAL IMPACTS OF ALTERNATIVE RICE (*ORYZA SATIVA* L.) ESTABLISHMENT METHODS IN MYANMAR

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Abstract. Field experiments were conducted in the summer rice growing season of 2019 in Myanmar, to examine the grain yield and environmental impacts of rice under two alternative crop establishment methods: system of rice intensification (SRI) and modified SRI (MSRI), and two conventional methods: farmers' practices (FP) and direct seeded rice (DSR). A randomized complete block design with five replications was used. In the present study, the leaf area index (LAI) with all tested methods was not significantly different at flowering and harvesting stages. Grain yield and the soil and plant analysis development (SPAD) reading at flowering stage did not significantly differ among the three transplanted methods. However, DSR showed significantly lower yield than FP and MSRI. This reduction might be due to shorter panicle length and fewer spikelets per panicle in DSR. The global warming potentials were 4066.94, 4067.08, 4475.75 and 4136.74 kg CO_2 eq ha^{-1} for SRI, MSRI, FP and DSR, respectively. MSRI emitted less greenhouse gas (GHG) than FP with statistically similar grain yield, indicating that it could be a better alternative to other methods. In addition, somewhat closer spacing with two seedlings per hill (MSRI) can further enhance rice yield with higher resource use efficiency in Myanmar or similar agroclimatic regions.
Keywords: *MSRI, GHGs emission, sustainable, LAI, plant spacing*

Introduction

To feed the growing population, germplasm development and crop production management are important in improving resource use efficiency (Guo et al., 2017; Roberts et al., 2018). Rice cultivation consumes more water than other crops. Water resources are becoming scare as a result of climate change, with a short rainy period and urban consumption patterns. Today's intensive agriculture relies heavily on chemical fertilizers and affects the environment adversely (Iqbal et al., 2019). Combination of organic and inorganic fertilizers can increase grain yield (Hasanuzzaman et al., 2010) and support sustainable crop productivity (Myint et al., 2011). Along with this, farmers need to modify their management practices to adapt to current and further changing demands (GRiSP, 2013).

Different rice cultivation methods have been adopted depending on the available resources and geographic conditions. Transplanting rice is the predominant practice in Myanmar, as this provides a chance to suppress weed growth before transplanting rice seedlings and favours easy management. However, some farmers in Myanmar are interested in direct seeding of rice, since the labour for transplanting and seedbed preparation can be saved. Weed infestation, however, is a common problem in directly seeded rice (DSR), as rice and weeds germinate at the same time, and land levelling is necessary for effective weed control. The yield of direct seeded rice was lower than that of transplanted rice in Dera Ismail Khan, Pakistan (Javaid et al., 2012). Similarly, early transplanted rice had higher grain yield than directly seeded rice (Kumhar et al., 2016). However, grain yields of direct seeded and transplanted method were not significantly different (Rana et al., 2014). The SRI method resulted higher leaf area index (LAI), grain yield and harvest index (HI) in comparison with a non-SRI method or direct seeded rice in India (Tomar et al., 2018). In Bangladesh, the grain yield under SRI and the recommended transplanting method were statistically similar (Nahar et al., 2018). Different rice varieties respond differently to the SRI method (Kesh et al., 2017). Thus, Stoop et al. (2002) encouraged testing the SRI method for specific environments and considering some changes, for example, in spacing or age of seedling to be transplanted, for successful application.

Harvest index of rice varies by genotype, season, location, nutrient condition and plant density (Amanullah and Inamullah, 2016; Bozorgi et al., 2011; Mohamad, 1994). Leaf area index (LAI) is a well-known growth indicator influenced by variety, plant density, soil nutrient status, CO_2, temperature, crop establishment method and season (Fagade and De Datta, 1971; Geethalakshmi et al., 2017). Hirooka et al. (2017) stated that LAI at the heading stage of rice in farmers' filed in Loa PDR, correlated with the grain yield. The soil and plant analysis development (SPAD) chlorophyll meter is widely used nowadays to estimate nitrogen (N) status in leaves. Light intensity in low N conditions affects the reading, and different points of rice leaves give different measured values (Yuan et al., 2016).

Three main gases: methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O) are responsible for increasing global warming potential in agriculture. Rice fields are considered the major source of methane emission which can lead to global warming potential (Arunrat et al., 2016). However, rice is a staple food crop for most people in Southeast Asian countries. Therefore, increasing rice production to accommodate the growing population is crucial while it need to perform better management of rice cultivation method to mitigate greenhouse gas emission (Islam et al., 2018a; Wang et al., 2016). It is demonstrated that decomposition of organic matter in flood rice field is ideal for methanogenesis. Nitrogen fertilizer application method, rate, time and fertilizer type, and water status of field have a significant effect on nitrous oxide emission (Islam et al., 2018b; Millar et al., 2014). Methane production in rice field is affected by number of factors. Application of sulphate containing fertilizer, gypsum, and intermittent irrigation could reduce its emission (Aulakh et al., 2001; Oo et al., 2016). Yi-hu et al. (2014) investigated the effect of different kinds of organic fertilizer on GHGs emission. The results revealed that all organic fertilizer emitted more than non-fertilized treatment. In addition, green manure had greater effect on CH_4 emission than animal and biogas residues (Traore et al., 2017).

Myanmar is an agricultural country where agriculture contributes 20% of the GDP. The actual total sown area of paddy rice was about 7.21 million hectares in 2015-2016,

comprising monsoon and summer paddy (MOALI, 2016). System of rice intensification method (SRI) was introduced in northern Myanmar and spread to other parts of Myanmar. This is a strategy contributing to climate resilient cultural practices in Myanmar and it is aiming for higher productivity and profitability by using effective natural resources management practices (Hom et al., 2015; MRDS, 2015). The number of seedlings per hill affected the number of panicles per hill and final grain yield (Promsomboon et al., 2019). Therefore, the number of effective tillers for a unit area is one of the most important yield components for increasing the grain yield. One issue with the SRI method is the cost and drudgery for refilling places of the dead seedlings during the recovery period. Based on above mentioned, we modified the SRI method here to have two seedlings per hill, instead of one seedling per hill, to reduce those costs and increase the number of the effective tillers per unit area. This study was conducted to investigate how the alternative crop establishment methods: SRI, MSRI perform and contribute to grain yield, and global warming potential in comparison with FP and DSR.

Materials and methods

Experimental procedure

Field experiments were conducted in the summer rice growing season in 2019, at Pwint Phyu Seed Farm (20°21'41.3"N, 94°40'24.3"E), in central Myanmar (*Fig. 1*). A randomized complete block design with five replications was used. The treatments were system of rice intensification (SRI), modified SRI (MSRI), farmer's usual transplanting method (FP) and directly seeded rice (DSR). The SRI and MSRI were considered as alternative rice cultivation methods for the protection and conservation of the limited resources without compromising grain yield. Yadanartoe rice variety was planted in this study since most of the farmers in that region use this variety. The minimum and maximum temperature and rainfall during the experiment were recorded in the experimental farm, and given in *Table 1*. The rainy weather was observed only in the later growth stage of rice. The soil is silty clay loam with a pH of 6.59, total N of 0.27%, available phosphorus (P) of 0.02 ppm, exchangeable potassium (K) of 0.468 $cmol_c$ kg^{-1}, and cation exchange capacity (CEC) of 18.03 $cmol_c$ kg^{-1}. The seeds were soaked for 24 h and incubated for another 24 h before seeding. Then, the germinated seeds were sown on well prepared raised beds and seedlings were transplanted to the main field as per treatments (SRI, MSRI, FP). For DSR, the sprouted seeds were planted manually to the line with the seed rate of 80 kg per acre to compensate the damage from rodents, poor seedlings establishment in low lying spot area, and suppress the growth of weed. Simplifications of some differences among the treatments are shown in *Table 2*.

Table 1. Weather condition during the experiment

Months	Rainfall (mm)	Minimum temperature (°C)	Maximum temperature (°C)
01 March − 31 March	-	18	41
01 April − 30 April	-	20	43
01 May − 31 May	8.13	26	43
01 June − 30 June	72.13	21	43
01 July − 05 July	5.08	25	36

Table 2. *Simplification of some components in different rice cultivation methods*

Components	System of rice intensification (SRI)	Modified system of rice intensifcation (MSRI)	Farmers' practices (FP)	Direct seeded rice (DSR)
Farmyard manure at final land preparation (t ha^{-1})	15	15	-	-
Chemical fertilizer (N-P$_2$O$_5$-K$_2$O kg ha^{-1})	5-5-5	5-5-5	53-29-37	53-29-37
Application time				
- At final land preparation	-	-	Full dose of P$_2$O$_5$, 1/3 dosage of nitrogenous fertilizer and half dose of K$_2$O	Full dose of P$_2$O$_5$, 1/3 dosage of nitrogenous fertilizer and half dose of K$_2$O
- 2 weeks after transplanting	Half dose of N, P$_2$O$_5$, K$_2$O	Half dose of N, P$_2$O$_5$, K$_2$O	1/3 dosage of nitrogenous fertilizer	
- 4 weeks after seeding				1/3 dose of nitrogenous fertilizer
- Panicle initiation (PI)	Half dose of N, P$_2$O$_5$, K$_2$O	Half dose of N, P$_2$O$_5$, K$_2$O	1/3 dose of nitrogenous fertilizer and half dose of K$_2$O	1/3 dose of nitrogenous fertilizer and half dose of K$_2$O
Transplanting (seedling(s)/hill)	1	2	3 to 4	Directly seeded
Seedling age (days)	15	15	30	-
Spacing (cm^2)	25×25	25×25	20×20	25 cm between row
Water level	Moist condition at vegetative growth stage and 2-5 cm from PI to 2 weeks before harvest was maintained	Moist condition at vegetative growth stage and 2-5 cm from PI to 2 weeks before harvest was maintained	2-8 cm of water level was kept throughout growing season up to 2 weeks before harvest	2-8 cm of water level was kept throughout growing season up to 2 weeks before harvest

Figure 1. *Overview of the experiment*

A multipseQ device (PhotosynQ, United States) was used for photosynthetic efficiency measurement (maximum and effective quantum yield, and chlorophyll (SPAD) reading) (Kuhlgert et al., 2016; Ndikuryayo et al., 2020). The fully developed uppermost leaf was measured at the 1/3 from the leaf tip position for four random hills per plot, and the averages were used to get the mean value by treatment. Measurements were taken from 10:00 to 11:00. The maximum quantum yield was measured at predawn (Shanker et al., 2019).

Each plot occupied 7.5 m × 21 m and the plots were surrounded by bunds (0.3 m height × 0.3 m width), and the bunds were separated by 1 m wide alleys (Pimratch et al., 2015). At the harvesting time, 5 m× 5 m at the center of the plot was harvested for grain yield determination, which was converted to kg ha^{-1}. The moisture content of rice was 14% (dry weight basis). Straw was over dried at 70 °C until constant weight and the dry weight of straw was recorded. Twelve randomly hills from each plot were selected, and the average value per plot was used for the yield components and plant height data (Chen et al., 2019). The plant height was measured from the base of the plant to the longest leaf tip at early tillering stage, panicle initiation (PI; BBCH 34) and flowering stages (BBCH 61) while it was measured from the base of the plants to the tip of panicle at harvesting stage (BBCH 89; Lancashire et al., 1991). ImageJ software was applied for the leaf area measurement (Savvides and Fotopoulos, 2018). The leaf area index and harvest index were calculated with *Equations 1* and *2* (Yoshida, 1981).

$$Leaf\ area\ index\ (LAI) = \frac{Total\ leaves\ area\ (cm^2)}{Ground\ area\ where\ the\ leaves\ have\ been\ taken\ (cm^2)} \quad \text{(Eq.1)}$$

$$Harvest\ index\ (HI)\% = \frac{Dry\ weight\ of\ grain\ yield\ (kg\ ha^{-1})}{Dry\ weight\ of\ the\ total\ aboveground\ biomass\ (kg\ ha^{-1})} \quad \text{(Eq.2)}$$

Greenhouse gas emissions

The greenhouse gas emission was calculated with the following formulas (Arunrat and Pumijumnong, 2017; IPCC, 2006; Tubiello et al., 2015; Yodkhum et al., 2018) and calculation was considered within the farm gate. The global warming potential (GWP) conversion parameters of CO_2, CH_4 and N_2O (over 100 years) were 1, 25 and 298 kg ha^{-1} CO_2 equivalent (IPCC, 2007). Imidacloprid (70% WP) insecticide was used in this experiment and emission factors were presented in *Table 3*. Annual methane emission for 1 ha was estimated by the multiplication of adjusted daily emissions factor (EF_i) with the duration of rice (days) (*Eqs. 3* and *4*). The fields under FP and DSR were continuously flooded, and weeding was done by manually.

$$EF_i = EF_c \times SF_w \times SF_p \times SF_0 \quad \text{(Eq.3)}$$

where: EF_c = baseline emissions factor for continuously flooded field without organic amendments, SF_w = a scaling factor for varying water status in rice cultivation, SF_p = a scaling factor for water status of field before cultivation, SF_0 = a scaling factor for farmyard manure (FYM) application.

$$SF_0 = (1 + \sum_i ROA_i \times CFOA_i)^{0.59} \quad \text{(Eq.4)}$$

where: ROA_i = amount of farmyard manure applied (t ha^{-1}), $CFOA_i$ = conversion factor for farmyard manure i.

Direct and indirect emissions by synthetic fertilizer were calculated by *Equations 5* and *6* (IPCC, 2006).

$$\text{Direct N}_2\text{O emissions (kg N}_2\text{O yr}^{-1}) = (F_{SN} \times 0.01 \times 44/28) \quad \text{(Eq.5)}$$

$$\text{Indirect N}_2\text{O emissions (kg N}_2\text{O yr}^{-1}) = [(F_{SN} \times \text{Frac}_{GASF} \times 0.01) + (F_{SN} \times \text{Frac}_{leach} \times 0.0075)] \times 44/28 \quad \text{(Eq.6)}$$

where: Frac_{GASF} = fraction of synthetic fertilizer that volatilizes as NH_3 and NO_x, Frac_{Leach} = fraction of synthetic fertilizer that leaches as NH_3 and NO_x.

Table 3. *Emission factors for the calculation of greenhouse gas*

Activity	Emission factor	Unit	References
Diesel	2.76	$kgCO_2$ eq L^{-1}	Ilahi et al., 2019
Insecticide	5.1	$kgCO_2$ eq kg^{-1}	Arunrat and Pumijumnong, 2017; Lal et al., 2004
EF_c	1.3	$kgCH_4$ ha^{-1}day^{-1}	IPCC, 2006
SF_w	0.52 = SRI and MSRI, 1 = FP and DSR		IPCC, 2006
SF_p	1 in all methods		IPCC, 2006
CFOAi	0.14		IPCC, 2006
Frac_{Leach}	0.3	Kg.N kg^{-1} N applied	Tubiello et al., 2015
Frac_{GASF}	0.1	Kg.NH_3-N. + NO_x-N.kg^{-1} N applied	Tubiello et al., 2015

Statistical analysis

One-way ANOVA was performed to test the differences among the treatments means. Comparison of means were made by Tukey's test at 5% level of confidence. Before conducting ANOVA, a homogeneity test (Levene's test) and a normality test (Kolmogorov-Smirnov) were carried out.

Results

Plant height (cm)

The plant height of rice under the different rice cultivation methods at tillering, PI, flowering and harvesting stages is shown in *Figure 2*. At the tillering stage, the heights with SRI, MSRI and DSR did not significantly differ. The FP method showed the shortest plant height among the treatments (P < 0.001). At PI stage, there was no significantly different (P > 0.05). As for flowering stage, the tallest plants were observed with the SRI method, which was on par with the MSRI. The shortest plant height occurred under FP, without significantly difference from DSR (P < 0.001). The plants grown under SRI and MSRI were significantly higher than those under FP and DSR at harvesting stage (P < 0.001).

Leaf area index (LAI)

Rice cultivation methods affected LAI at different growth stages (*Fig. 3*). The highest LAI with MSRI and DSR methods achieved at PI stage, while the FP method

showed the highest LAI at flowering stage. At PI stage, LAI of MSRI and DSR was significantly higher than those of the other three methods (P < 0.001). Regarding LAI at flowering stage, the higher LAI values were observed under MSRI, FP and DSR although there were no significantly different among the treatments (P > 0.05). All methods showed statistically similar LAI at harvesting stage (P > 0.05).
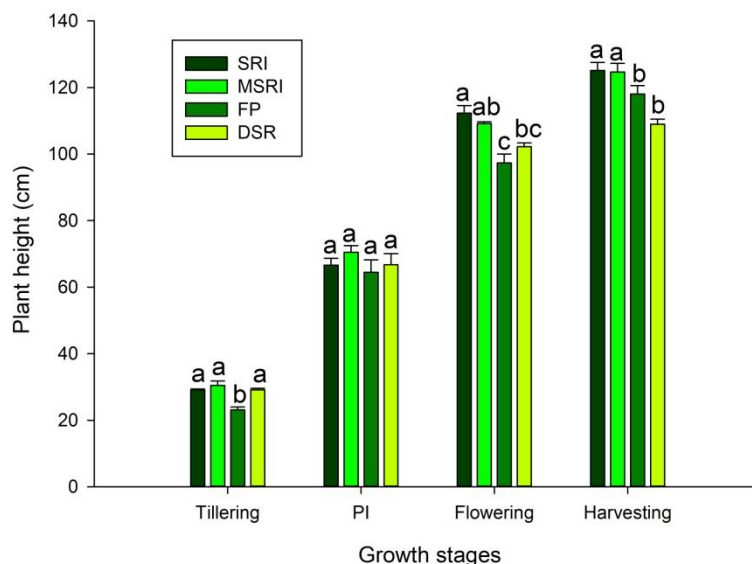

Figure 2. *Plant heights by four rice cultivation methods at different growth stages.*
SRI = System of Rice Intensification, MSRI = Modified System of Rice Intensification,
FP = Farmer's practices, DSR = Direct Seeded Rice, PI = Panicle initiation. Bars indicate
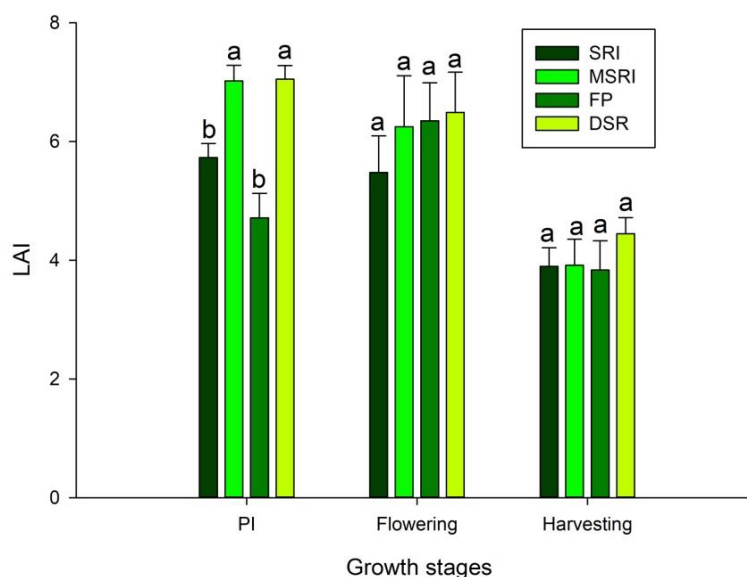*mean ± SE (n = 5). Significant differences are shown by different lowercase letters (P < 0.05)*

Figure 3. *Leaf area index (LAI) by rice cultivation method at different growth stages.*
SRI = System of rice intensification, MSRI = Modified system of rice intensification,
FP = Farmers' practices, DSR = Direct seeded rice, PI = Panicle initiation. Bars indicate
mean ± SE (n = 5). Significant differences are shown by different lowercase letters (P < 0.05)

Number of tillers m^{-2}

Number of tillers m^{-2} was significantly affected by planting method. At tillering stage, the most number of tillers m^{-2} was observed with DSR, followed by MSRI, FP and SRI ($P < 0.001$). At PI stage, similar trend was observed, in that, the SRI method had significantly lower number of tillers than the other methods ($P < 0.001$). At flowering stage, the number of tillers with three transplanted methods were not significantly different while DSR produced the most number of tillers m^{-2} among the treatments (*Fig. 4*; $P < 0.001$).
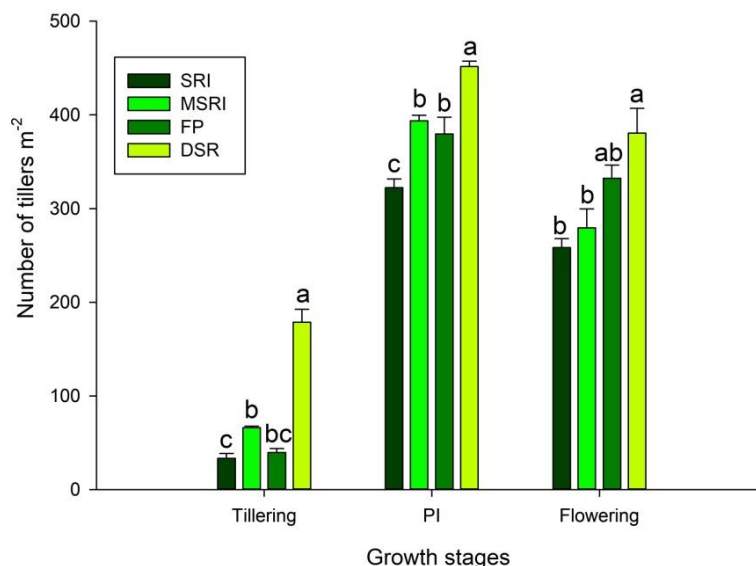

Figure 4. *Number of tillers by rice cultivation method at different growth stages. SRI = System of rice intensification, MSRI = Modified system of rice intensification, FP = Farmers' Practices, DSR = Direct seeded rice, PI = Panicle initiation. Bars indicate mean ± SE (n = 5). Significant differences are shown by different lowercase letters (P < 0.05)*

Chlorophyll SPAD value and Phi2 in light and in the dark conditions

Chlorophyll content (SPAD) is an indirect indicator of nitrogen status of the leaf. The chlorophyll content, in this study, was measured with the multispeQ device. SPAD values of all the treatments were statistically similar at PI stage ($P > 0.05$). SRI and MSRI methods showed significantly higher chlorophyll content than DSR ($P = 0.012$) at flowering stage, while there were no significantly different among three transplanted treatments. Chlorophyll contents under DSR and FP were not statistically different (*Fig. 5*). Phi2 (fraction of light utilized for photochemistry) in daytime and in the dark condition was not affected by the planting method (*Fig. 6*; $P > 0.05$).

Grain yield and its attributes

Effects of rice cultivation methods on yield components are shown in *Table 4*. Among the yield components, there were no significantly differences in 1000-grain weight, number of panicles m^{-2} and filled grain percentages. The SRI and MSRI methods showed significantly longer panicles than FP and DSR ($P < 0.001$). Panicle lengths of SRI and MSRI were statistically similar. Furthermore, the SRI and MSRI

produced more spikelets per panicle than FP and DSR ($P < 0.001$). The least number of spikelets per panicle was observed with DSR.
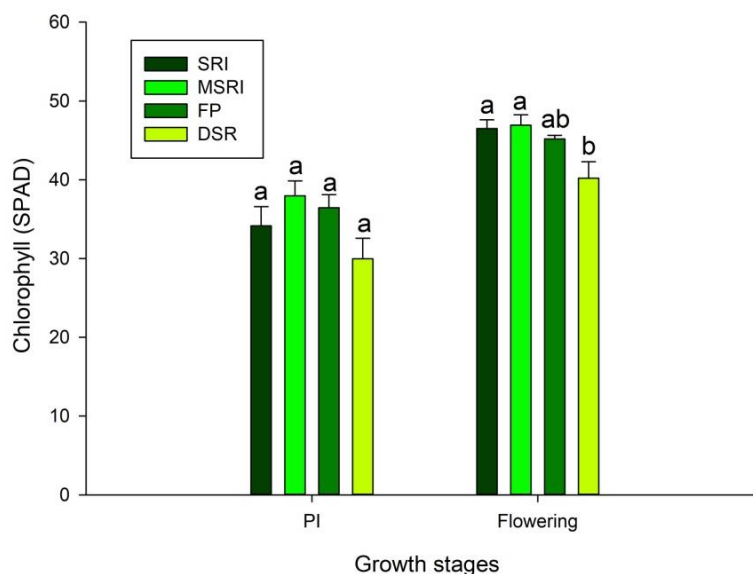

Figure 5. Chlorophyll content (SPAD) by rice cultivation method at PI and flowering stages. SRI = System of rice intensification, MSRI = Modified system of rice intensification, FP = Farmers' Practices, DSR = Direct seeded rice, PI = Panicle initiation. Bars indicate mean ± SE (n = 5). Significant differences are shown by different lowercase letters (P < 0.05)
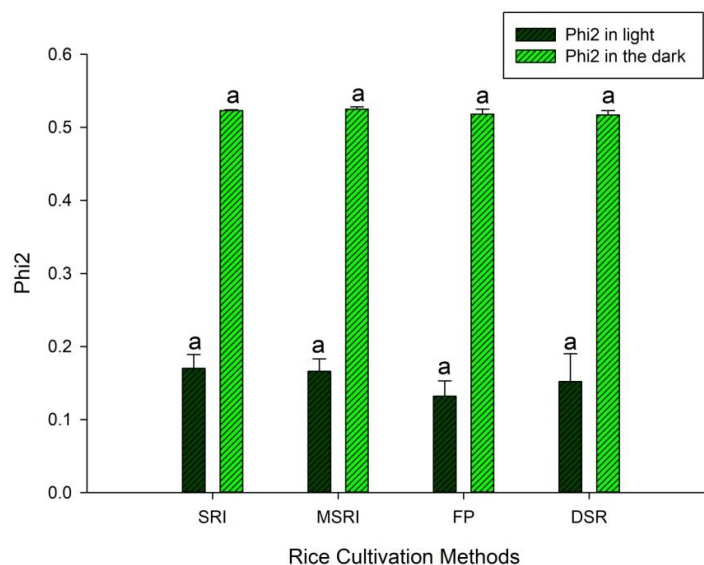

Figure 6. Phi2 by rice cultivation method in light and in the dark conditions at flowering stage. SRI = System of rice intensification, MSRI = Modified system of rice intensification, FP = Farmers' practices, DSR = Direct seeded rice. Bars indicate mean ± SE (n = 5)

Grain yield of SRI, MSRI and FP methods were not significantly different, while DSR produced a significantly lower grain yield than other tested methods (*Table 5*;

P = 0.013). The yield of SRI and DSR were statistically similar. Harvest index of rice was not affected by cultivation methods in this study (P > 0.05).

Table 4. *Yield components and panicle lengths of different rice cultivation methods (mean ± SE)*

Treatment	1000-grain weight (g)	Spikelets panicle $^{-1}$	Number of panicles m^{-2}	Filled grain (%)	Panicle length (cm)
SRI	25.38 ± 0.23	135.48 ± 8.05 a	254.82 ± 16.96	91.20 ± 0.76	28.17 ± 0.23 a
MSRI	25.00 ± 0.13	131.18 ± 4.13 a	268.99 ± 27.44	89.50 ± 0.64	26.78 ± 0.46 a
FP	25.50 ± 0.80	94.23 ± 7.47 b	283.11 ± 20.35	86.94 ± 1.78	23.96 ± 0.52 b
DSR	25.46 ± 0.55	61.98 ± 2.74 c	328.66 ± 23.25	89.40 ± 1.43	23.78 ± 1.01 b
Significance	ns	***	ns	ns	***

SRI = System of rice intensification, MSRI = Modified system of rice intensification, FP = Farmers' practices, DSR = Direct seeded rice. Significant differences are shown by different lowercase letters (P < 0.05). *** = significantly different at P < 0.001, ns = non-significant

Table 5. *Grain yield and harvest index by rice cultivation method (mean ± SE)*

Treatment	Grain Yield (kg ha^{-1})	Harvest Index (%)
SRI	6587.79 ± 267.98 ab	52.78 ± 1.14
MSRI	6662.95 ± 182.63 a	52.59 ± 2.67
FP	6819.65 ± 178.37 a	56.33 ± 1.72
DSR	5816.29 ± 158.01 b	49.37 ± 1.70
Significance	*	ns

SRI = System of rice intensification, MSRI = Modified system of rice intensification, FP = Farmers' practices, DSR = Direct seeded rice. Significant differences are shown by different lowercase letters (P < 0.05). * = significantly different at P < 0.05, ns = non-significant

Greenhouse gas emissions

The calculated greenhouse gas emission of different rice cultivation methods is depicted in *Figure 7*. The global warming potentials were 4066.94, 4067.08, 4475.75 and 4136.74 kg CO_2 eq ha^{-1} for SRI, MSRI, FP and DSR, respectively. Higher N_2O emission was occurred under FP and DSR, which was contributed from higher amount of chemical fertilizer application than those under SRI and MSRI (alternative methods). In the case of methane emission, the application of FYM (15 t ha^{-1}) accounted for increasing emission of CH_4 under SRI and MSRI methods.

Discussion

Potentially facing water scarcity, climate change and soil degradation, agricultural practices that will sustain productivity for future generations are crucial. Performances of different rice establishment methods were evaluated experimentally in this study. The plant heights of SRI and MSRI were generally taller than those of FP and DSR, indicating better crop growth of the former. However, number of tillers m^{-2} was affected by cultivation method at all growth stages, with the lowest value generally provided by the SRI method. This in turn was mainly affected by the number of hill m^{-2}. At harvesting stage, the FP method produced 10 and 5% more effective tillers m^{-2} than SRI and MSRI, respectively, in the present study (*Table 4*). In a previous study, grain yield

reduction due to lower plant density could not be offset by increased application of N fertilizer (Huang et al., 2013). Therefore, optimum plant population per unit area is important for increasing grain yield.
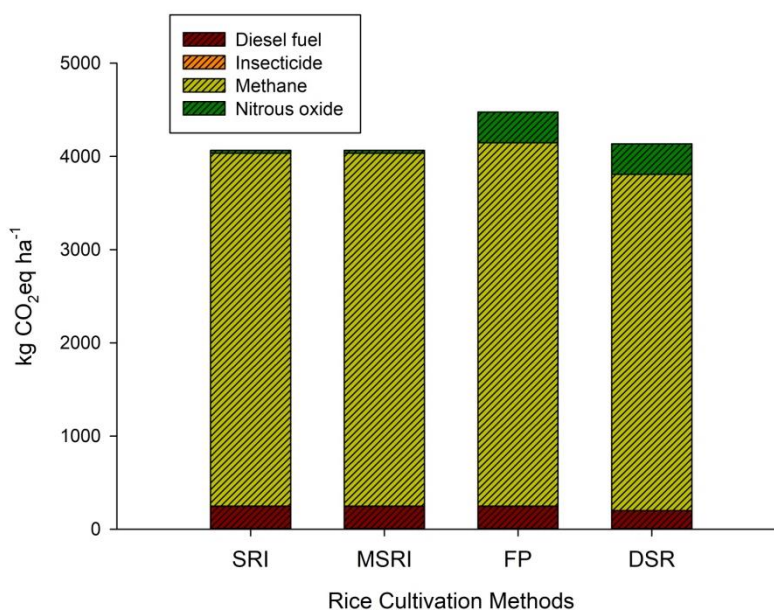

Figure 7. Greenhouse gas emission from different rice cultivation methods. SRI = System of rice intensification, MSRI = Modified system of rice intensification, FP = Farmers' practices, DSR = Direct seeded rice

Leaf area index is an important parameter affecting grain yield of rice. Leaf area index of rice is influenced by leaf size and number of leaves per unit area (Tanaka and Kawano, 1965). In the present study, rice cultivation methods affected leaf area index significantly at PI stage. The MSRI and DSR attained the higher LAI than the others, which was mainly attributed by number of leaves per field area. Our results are in line with the report of Gautam et al. (2019), which revealed SRI with some modification gave higher LAI than conventional transplanted rice at PI stage in India. In addition, dry direct seeded rice achieved higher LAI than traditional transplanted rice (Ishfaq et al., 2020). The earlier studies of Sen et al. (2014) and Singh et al. (2014) reported that a wider spacing gave greater LAI value for transplanted rice than a closer one. At flowering and harvesting stages, all rice establishment methods had statistically similar LAI. The MSRI method gave the highest LAI at PI stage, which then decreased gradually towards the harvesting stage. This might be due to the drying of some tillers in the later growth stages.

Chlorophyll content (SPAD) is an indirect indicator of nitrogen status of the leaf. Chlorophyll content at PI stage was influent on grain yield of rice (Ramesh et al., 2002; Gholizadeh et al., 2017). In addition, leaf N content at flowering stage is also important for grain filling and it was positively and significantly correlated with grain yield (Ghosh et al., 2020). In the present study, SPAD value under DSR was low although there was not significantly different from others at PI stage. The SPAD values of SRI, MSRI and FP were statistically similar at flowering stage. However, SRI and MSRI had more leaf nitrogen than DSR. This might be due to higher plant populations per unit

area in DSR, competing for the resources. Phi2 is the fraction of light that is used for photochemistry (Kramer et al., 2004). Phi2 in both light and dark conditions were not affected by planting method in this study. Similarly, different N levels did not significantly affect Phi2 of rice in a hydroponic experiment (Shrestha, 2012). However, SRI with 20 cm × 20 cm, resulted in higher chlorophyll content, maximum and effective quantum of PSII than the recommended rice transplanted method in India. Effective quantum yield of PSII (Phi2) was affected by crop management practices under unstressed conditions (Thakur et al., 2010a).

There was no significant difference in grain yield among SRI, MSRI and FP. In fact, production with SRI was statistically similar to DSR. In other words, MSRI and FP yielded significantly more than DSR. That higher yield was mainly contributed by a greater number of spikelets per panicle, and longer panicle length of the former. Although, DSR had more panicles per unit area, it could not compensate for a smaller number of spikelets per panicle. Our results are supported by Huang et al. (2011). They reported shorter panicles length and a smaller number of spikelets per panicle was observed under DSR and this was related to the poorer nutritional status with DSR in comparison with transplanted rice. Birhane (2013) reported that panicle length of transplanted rice was significantly longer than that of direct seeded rice. In a previous study, transplanted rice gave higher grain yield than DSR (Dileep et al., 2018; Hossain et al., 2002). However, the productions of direct seeded and transplanted rice were statistically similar in the reports of Liu et al. (2015) and Kar et al. (2018). The effectiveness of weed control in DSR might be one of the reasons for differences in grain yield. Harvest index (HI) is the ratio of paddy rice to total plant biomass, excluding the root. In the present study, HI of rice was affected by cultivation method. Similarly, HI with SRI and recommended management practices (RMP) were statistically similar (Thakur et al., 2010b). However, Chandankute et al. (2015) reported grain and HI under SRI method were higher than that under FP. This might be due to differences in agroclimatic conditions. A 20 cm × 20 cm spacing with 3 seedlings per hill achieved the highest HI in Iran (Bozorgi et al., 2011).

Rice cultivation emits greenhouse gases: carbon dioxide, methane and nitrous oxide which contribute global warming potential (GWP). Methane emission from the rice field is affected by water regime, crop duration and manure application in the present study. Methane emission under DSR was a little bit lower than those under SRI and MSRI methods in this study. However, in a previous report, SRI and wet seeded rice emitted 26.8 and 16.6% lesser CH_4 over transplanted method, respectively (Ramesh and Rathika, 2020). It might be due to differences in fertilizer application. In addition, Fazli and Man (2014) reported that modifications of current rice cultivation method in Malaysia can suppress CH_4 emission. In the present study, the GWP were 4066.94, 4067.08, 4475.75 and 4136.74 kg CO_2 eq ha^{-1} for SRI, MSRI, FP and DSR, respectively. These were within the range of the report by Arunrat and Pumijumnong (2017). FYM was responsible for elevating GHGs emission in alternative rice cultivation methods while nitrogenous fertilizer compounded to anoxia effect for increasing it in FP and DSR. Application of organic manure increased GHGs emission compared with nonfertilized treatment. The effect is more obvious in conventional method than that in SRI (Ly et al., 2013). Some other reports revealed the effect of farmyard manure on GHGs emission although it depends on many factors, for instance, time of FYM application (Linquist et al., 2012; Pokhrel and Soni, 2019; Ren et al., 2017). The lower value of GHGs emission was observed in DSR method than that in FP

in the present study, which could be explained by different in lower fuel consumption for tillage operation and crop duration. However, weed infestation was serious in DSR, hence, the field was continuously flooded. That anoxia condition attributed to comparatively high CH_4 emission under direct seeded rice in the present study.

Conclusions

Farming practices that preserve the natural resources and ensure economic returns are crucial for sustainable agriculture. Effective quantum yield of PSII and maximum quantum yield of PSII were not affected by cultivation method. This study concluded that SPAD value at flowering stage and grain yield of system of rice intensification (SRI), modified system of rice intensification (MSRI) and farmers' practices (FP) were not significantly different. Direct seeded rice (DSR) produced the lowest grain yield among the tested methods. Global warming potentials of SRI and MSRI were approximately 10% lower than that of FP. Of the two superior cultivation methods in term of grain yield, the MSRI method utilized fewer resources (inputs) of chemical fertilizer, seeds and water, in comparison with the FP method. Further adjustment of plant spacing with optimum combination of organic and chemical fertilizers was recommended to make agriculture more productive and sustainable.

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