Methane and Nitrous Oxide Emissions from Lowland Rice as Affected by Farmers' Adopted Fertilizer Applications under Two Crop Establishment Methods in Myanmar

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ABSTRACT

Identifying the optimal rice establishment option combined with specific fertilizer application can lower the global warming potential (GWP) and greenhouse gases intensity (GHGI) of rice production. In this study, methane (CH_4) and nitric oxide (N_2O) emissions and rice yields under different fertilizer application methods and two different planting methods, transplanted rice (TPR) and wet bed direct seeded rice (WDSR), was measured. Field experiments using a split plot design and closed chamber-GC method for gas flux measurements were conducted. CH_4 and N_2O emissions ranged from 1.83-4.68 mg/m^2/h and 0.073-0.135 mg/m^2/h, respectively. Minimum CH_4 and N_2O emissions were observed at 48-69 days after seedling (DAS) (tiller stage), while maximum emissions were generally found at 90 DAS or early primordial initiation (EPI) stage. It was found that TPR produced more CH_4 and N_2O than WDSR across fertilizers methods almost each growth stage throughout the growing period. Regarding GHGs emission factors, CH_4 emissions were negatively correlated with soil pH (-0.35*, N=18). At higher soil pH, lower CH_4 emissions were found in early growth stages. The N_2O emissions did not correlate with soil pH (-0.04 ns, N=18). The highest average CH_4 emission was reached in 90 days after seedling and EPI when the soil temperature was maximal at 34.8°C. The correlation coefficient (r) between CH_4 emission and soil temperature was 0.48*, N=18, indicating a positive correlation.

1. INTRODUCTION

The addition of greenhouse gases (GHGs) to the global atmosphere has been ascending since the very first days of civilization. Among the several GHGs, the two major gases are methane (CH_4) and nitrous oxide (N_2O) which have global warming potentials (GWP) 28 and 265 times higher than carbon dioxide(CO_2) equivalent in a 100 year time horizon, respectively (Pachauri et al., 2014). Methane emissions from anthropogenic activities has been increasing at a rate from 0.5% to 1% per year and reached 16% of the total anthropogenic GHGs emissions in 2010. An additional 6% of the anthropogenic GHGs emission was from N_2O emissions (Pachauri et al., 2014).

The agriculture sector is the one of the main causes of anthropogenic GHGs emissions and accounts for 1.5% of global anthropogenic GHGs emissions (Lam et al., 2017; Mosier et al., 1998; Timilsina et al., 2020; Tubiello et al., 2013). Methane (CH_4) and nitrous oxide (N_2O) are released from agricultural practices and are considered as the major source of greenhouse gases producing 60% of global N_2O emission and 50% of CH_4 emission (Linquist et al., 2012; Shukla et al., 2019). In the case of GHGs emission from the agricultural sector, rice cultivation is one important source of emitting CH_4 (Zhang et al., 2020) and N_2O (Lam et al., 2017; Mosier et al., 1998; Timilsina et al., 2020). Globally, rice is mostly grown and consumed in Asia and it will continue to influence

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the world rice economy as per capita rice consumption of Asia increased from 85 kg per year in the early 1960s to nearly 103 kg in the early 1990s (Chauhan et al., 2017). Moreover, rice production in Asia accounts for 90% of total rice production (Bandumula, 2018).

The major cause of CH_4 emissions from agriculture land is biologically mediated processes of methanogenesis bacteria as a consequence of organic matter decomposition especially in anaerobic soil conditions (Conrad, 2002; Sass et al., 2002) while nitrification and denitrification of soil influence N_2O emissions (Smith, 2010). Therefore, mitigation strategies of CH_4 and N_2O emissions are considered on the management of soil submergence duration or irrigation practices and controlling the carbon inputs, for instance, crop establishment management and fertilizer application (Linquist et al., 2012; Yan et al., 2005). Additionally, The rice cultivation practice including selection of rice cultivar crop variety, fertilizer management and water management are the determinant factors of these emissions (Sun et al., 2013).

Myanmar is traditionally an agricultural country and this sector contributes 20.1% of the national Gross Domestic Profit (GDP) (MoALI, 2019). Among the diverse crops, rice is major crop and yield maximization strategies are given as high priority for domestic consumption and for exports as well. Two popular practices for local farmers are transplanted rice (TPR) and wet bed direct seeded rice (WDSR). Generally, TPR method utilizes intensive inputs and large amounts of water and labor resulting in a high cost of production (Chauhan et al., 2017; MoALI, 2019). Meanwhile, WDSR method seeded directly on non-puddle soil has become very popular since it can solve water shortage and labor scarcity problems. It also has a high cost-benefit ratio (Janz et al., 2016; Pathak et al., 2013). Several studies have indicated that crop establishment using WDSR with appropriate water management will be a potentially better CH_4 mitigation strategy than TPR (Liu et al., 2014). Gupta et al. (2016) also highlighted the average CH_4 emission from TPR practice was more than 80% greater than the WDSR practice in two year experiments. In addition, WDSR with midseason drainage probably reduced the CH_4 emission rate up to 50% (Wassmann et al., 2004). WDSR may be easily accepted by different levels of rice farmers through less requirement of water and lower cost of production. The capacity for adaptation to climate change may also be good using WDSR which is relatively tolerant to drought and water stress (Pathak et al., 2013).

Concerning GHGs emissions from paddy fields in Myanmar, there are no robust research programs that have investigated the GHGs emissions from rice fields under different conditions. Both private and public sector have still overlooked that the agricultural sector can harm the environment. The Ministry of Natural Resources and Environmental Conservation (MONREC) issued the Environmental Conservation Law in 2012. This law has totally ignored GHGs emission from the agriculture sector and only paid attention upon the industrial sector, urbanization, tourism, and mining sectors. Furthermore, the System of Rice Intensification (SRI) policy was issued in 2018 as a national plan by the Ministry of Agriculture, Livestock and Irrigation (MOALI), Department of Planning (DoP) with two main objectives, securing national food security and increasing rice exports through developing agricultural economics, without consideration of environmental problems. As a consequence of current circumstances in Myanmar, it is truly necessary to initiate primary field experiments that underline the GHGs emission from the agricultural sector.

In this regard, the objective of this study was to answer the following question: Among the rice establishment methods and fertilizer applications currently practiced by the farmers in lowland rice system, is there a combination that significantly mitigates CH_4 and N_2O emissions?

If a particular rice establishment option or fertilizer application method can result in less CH_4 or N_2O emissions without reducing rice yield, it would be a valuable practice for cost effective GHGs mitigation strategy in sustainable rice production. Furthermore, the desired mitigation strategy should be compatible with the ongoing processes of farmers and can improve their current system to achieve systemic change for GHGs mitigation.

2. METHODOLOGY

2.1 Study area

The field experiment was carried out at Kyaukse research station in Kyaukse Township, Mandalay region, Myanmar (Figure 1) situated at 21°36′47″N 96°7′49″E and 77 m above average sea level, where many varieties of agricultural practices have been traditionally exercised by the farmers. Soil property of this area is carbonated Alluvial (Gleysol) in FAO/UNESCO system with very fine texture and shallow soil profile. There is good water drainage and high water percolation but low moisture retaining capacity. The soil is suitable for cultivation of field crops with paddy-upland cropping system: green gram, chickpea, and sesame, sunflower as upland crops and rice as lowland crop.

As per lab analysis, soil texture in top soil is clay loam consisting of sand (34.2%), silt (38%), and clay (27.8%) with soil organic matter (2.9%). Soil reaction is moderately alkaline with a pH of (8.1) and electrical conductivity (EC) is 0.12 d/Sm. Low, medium and high rating of available N (59 mg/kg), K (225 mg/kg), and P (30 mg/kg), respectively. Relatively high exchangeable Calcium (12.4 cmole/kg) and exchangeable magnesium (11.9 cmole/kg) are contained in this soil. Calcium extractable SO_4-S was found to be sufficient (11 mg/kg) and DTPA extractable Zn (0.6 mg/kg), and Fe (53 mg/kg) could be rated as marginal and adequate, respectively, but exchangeable Mn (6.8 mg/kg) was rated as adequate in soil.

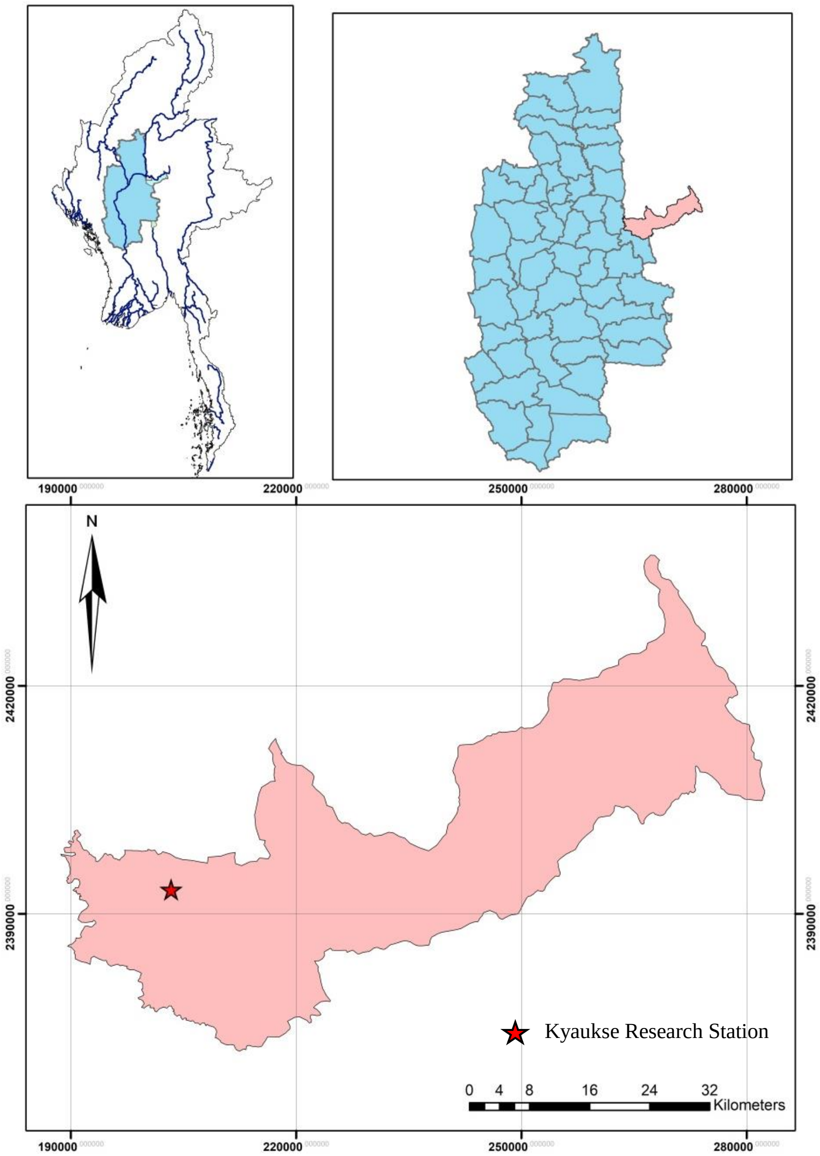

Figure 1. Location map of Kyaukse Township in Mandalay Region

2.2 Field experiment design, treatments, and layout

The two factors based on current local farmers' existing practices were designated as Crop establishment factor (Transplanted rice-TPR and Wet direct seeded rice-WDSR) and Fertilizer factor (F0, F1, and F2). The experimental design had two factors with three replications as a split plot design (Figure 2). The crop establishment and fertilizer application methods adopted in this experiment followed the local farmers' practices of rice cultivation.

As of crop establishment factor, the TPR was cultivated under wet condition and made puddling.

Twenty day-old seedlings of SinThuKha (IRYn1068-7-1 (Manawthukha/IRBB21) were transplanted and kept in flooded water as deep as 10 cm until one week before maturity but irrigated again whenever water reached 1 cm above soil level. The WDSR was grown under wet condition and made puddling and leveling. The same variety of rice, 70 kg/ha seed rate was sown with sprouted seeds through manual line sowing after thorough land leveling and draining water. Water was irrigated when seedlings were well survived and kept water level at about 3-5 cm. Flooded water was kept at about 10 cm depth and irrigated again when ever water reached 1 cm above soil level.

Regarding fertilizer factor, there were three treatments: Control (1) F0=No nitrogen + 63 kg TSP/ha (28 kg P_2O_5/ha) + 63 kg MOP/ha (37 kg K_2O/ha); (2) F1=Urea alone 189 kg urea/ha (86 kg N/ha) + 63 kg TSP/ha (28 kg P_2O_5/ha) + 63 kg MOP/ha (37 kg K_2O/ha); and (3). F2=124 kg/ha compound fertilizer (15:15:15), NPK were supplemented with 145 kg urea/ha (67 kg N/ha), 20 kg TSP/ha (9 kg P_2O_5/ha) and 30 kg MOP/ha (18 kg K_2O/ha).

TPR Plot	WDSR Plot
F1	F2
F0 (Control)	F1
F2	F0 (Control)

TPR Plot	WDSR Plot
F0 (Control)	F2
F1	F0 (Control)
F2	F1

TPR Plot	WDSR Plot
F1	F0 (Control)
F2	F2
F0 (Control)	F1

Figure 2. Field layout of experimental design

2.3 Sampling and measurement

Collected soil, plant, and gas samples were analyzed at the soil science research section and water utilization research section laboratories from the Department of Agricultural Research (DAR), Yezin, Nay Pyi Taw (ISO No. 90012015) under the Ministry of Agriculture, Livestock and Irrigation (MOALI) in Myanmar. Soil sample collection was made before and during field experimentation. Ten composite soil samples (0-15 cm) which had been randomly collected were taken at the experimental site before tillage preparation and at a depth of plow layer from each treatment one day after fertilizer split application at recovery, tillering, early panicle initiation (EPI), and booting stages to be analyzed for pH, EC, available N, P, K, and soil texture for expressing site characterization and to check for soil property changes. The Tyurin's method was used to determine the organic carbon using these soil samples and the result was expressed as percent.

Regarding grain yield of TPR treatments, rice plants were harvested from areas of 5 m^2 (2.74 m × 1.82 m) by rejecting two border rows and a sampling row to avoid interfering border effects. In WDSR treatments, since rice seeds are direct seeded into 20 cm rows, a 25 m linear row was harvested to be the same as 5 m^2 harvested areas. The rice grains were allowed to dry under sunshine to have restored seed moisture from about 16-17% to 14% which was checked by grain moisture meter. According to the guidance of laboratory of Department of Agricultural Research (DAR) DAR, the rice grain yield and biomass of each treatment was expressed as kg/ha.

$$\text{Adjusted rice grain weight (kg/5 m}^2\text{) at 14\% moisture} = (100 - M/86) \times W$$

Where; M=moisture content of grain, W= weight of harvested grain from 5 m^2

For on-site data, soil pH, soil temperature and Oxidation-Reduction Potential (ORP) by portable pH/ORP/ISE (HANNA Model-HI98191), and air temperature, water depth and irrigation frequency were recorded at weekly intervals throughout the experiment. Soil temperature was also recorded at the same time of pH measurement.

2.4 Gas sample and analysis

In this study, a closed chamber was used to collect the gas emitted from the rice field (Yuesi and Yinghong, 2003; Zou et al., 2005). There are two parts, a chamber base with a size of 30 cm width × 40 cm length × 15 cm height made of aluminum, and a 30 cm width × 40 cm length × 60 cm or 120 cm height chamber cover made of acrylic. The chamber base was immersed 7.5 cm into the soil throughout cultivation period and the joints of the chamber were sealed by water. There are two holes on the top surface of chamber cover, one is for gas collection and the other one is used for measuring inside air temperature. Two covers having different heights of 60 and 120 cm, respectively, were used depending on plant height. The 60 cm cover was used for early stage while the 120 cm cover was utilized in the older stage of rice plants.

Fifty four (54) gas samples were collected on a weekly basis throughout the growing period from six treatments in three replications at intervals of 0, 10, and 20 min in the morning from 09.00 am to 12.00 am as adapted from several references (Huang et al., 2017; Liu et al., 2014; Venterea et al., 2011). Gas samples were collected into Aluminum foil multi-layer bag-ABS valve (Cap. 0.5 L) through suction with portable battery driven air pump (SB-980). Air temperature inside the chamber was also measured by thermometer with temperature sensor-tip and recorded at the time of gas collection. Collected gas samples were analyzed for CH_4 and N_2O using gas chromatography-GC (SHIMADZU-Model-2010 Plus). An SH-Rt-Q-BOND column (Serial No. 1357883) was used with a flame ignition detector (FID) for CH_4 and electron captured detector (ECD) for N_2O fluxes analysis. CH_4 and N_2O fluxes were calculated according to the following equation;

$$E = \frac{\text{Slope (ppm/min)} \times VC \times MW \times 60 \times 24}{22.4\,(273 + T/273) \times Ac \times 1{,}000}$$

The emissions as kg CH_4 (or kg N_2O)/ha were derived from the slope of the linear regression curve of gas (CH_4 and N_2O) concentrations against the chamber closing time. The slope was referred to as mass per unit area per unit time (mg/m^2/h) (Gaihre et al., 2013), where VC is the volume of the gas chamber in liters (L), MW is the molecular weight of the respective gas, 60 is minutes per hour and twenty four is hours of the day. The volume of 1 mol of gas in L at standard temperature and pressure is 22.4. T is the temperature inside the chamber (°C) while 273 is the standard temperature of °K. AC is the chamber area (m^2) and 1,000 is μg/mg (Islam et al., 2020).

According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (AR5) CO_2 equivalents are used as 1 kg N_2O = 265 kg CO_2, and 1 kg CH_4 = 28 kg CO_2 (Myhre et al., 2013). GHG intensity (GHGI) (kg CO_2-equivalent/kg) was computed by dividing GWP of CH_4 and N_2O emissions by rice grain yield (Haque and Biswas, 2021).

$$\text{Total GWP (kg } CO_2 \text{ equivalent/ha)} = (CH_4 \text{ emission} \times 28) + (N_2O \text{ emission} \times 265)$$

$$\text{GHGI} = \text{Total GWP/Grain yield}$$

2.5 Statistical analysis

This is performed to compare seasonal value of CH_4 and N_2O gases emission, grain yield as affected by treatments (two factors: fertilizer factor and crop establishment factor) either individually or its interaction by using two way analysis of variances (F-test; ANOVA). Correlation coefficient (r) is used for indicating the relation between dependent variances; CH_4 and N_2O emission, grain yield and independent variances, such as fertilizer factor and crop establishment factor. Moreover, the statistical analysis was made between environmental factors such as pH, Eh, water depth and soil temperature and their influence on the fluxes of CH_4 and N_2O. The statistical significance was tested at (α=0.05) by statistical software SPSS (Statistical Package for Social Science) V.18.

3. RESULTS

3.1 Methane emission

Regarding weekly flux changes, TPR generally produced more CH_4 emissions as compared to WDSR throughout the rice growing period (Figure 3). CH_4 emissions are found to be relatively lower (2.15-5.03 mg/m^2/h) during the 30-48 days after seeding (DAS) but gradually increased and maximized (20.23-24.04 mg/m²/h) at EPI (90 DAS). After that, emissions gently decreased and minimized at maturity stage (132 DAS).

As far as fertilizer effect is concerned, flux change patterns throughout the growing period is observed to have similar trends as crop establishment (Figure 4). The emissions of CH_4 for F0, F1, and F2 are more or less minimum between 30-48 DAS but slowly elevated and peaked at EPI (90 DAS). After that, emissions tended to sharply decline up to maturity stage with minimum fluxes.

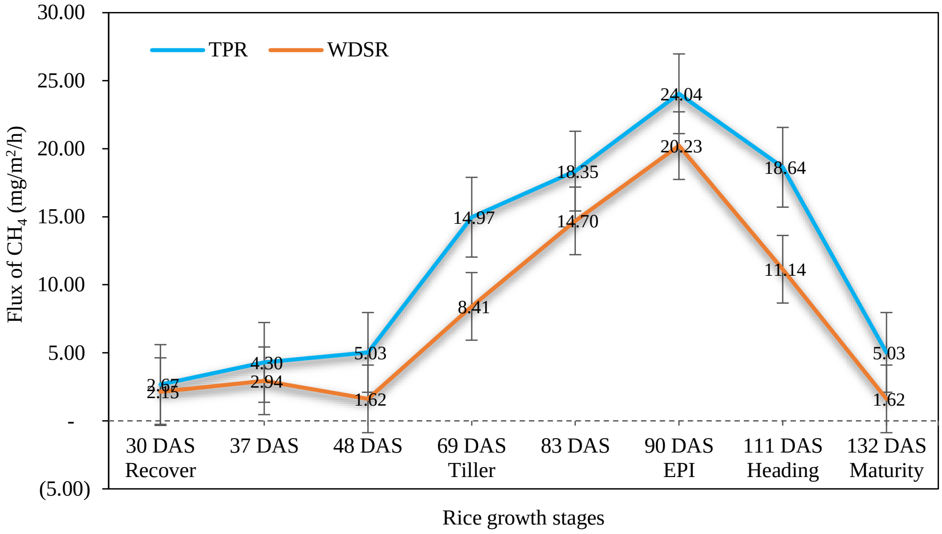

Figure 3. CH_4 fluxes of crop establishment methods (mg/m²/h) by rice growth stages

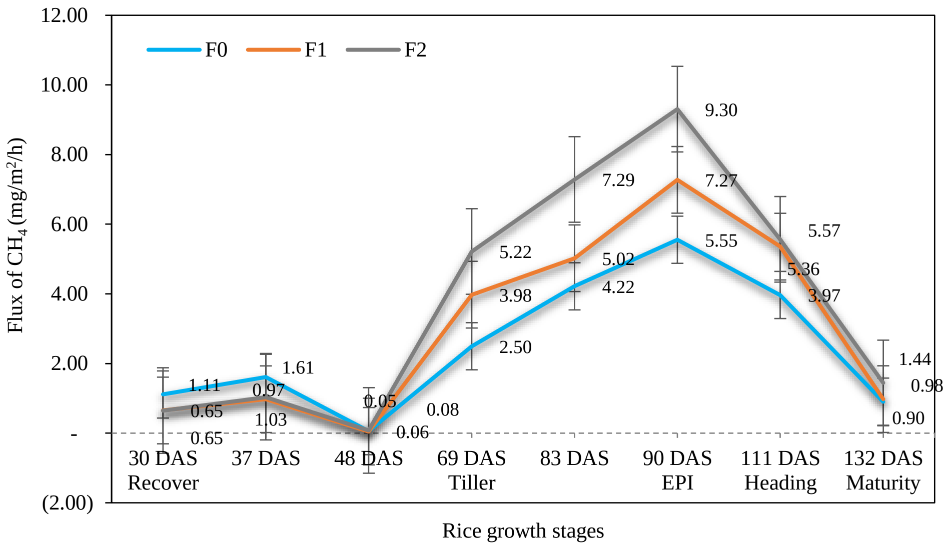

Figure 4. CH_4 fluxes of N fertilizer application methods (mg/m²/h) by rice growth stages

3.2 Nitrous oxide emission

Regarding weekly N_2O flux changes by rice growth stages as affected by crop establishment, TPR produced slightly more N_2O than that of WDSR throughout the rice growing period, but they are not statistically different (Figure 5). In both TPR and WDSR, N_2O emissions are relatively higher during early stages of 30-37 DAS, unlike CH_4 emission in which fluxes are noticed as minimum during 30-37 DAS (Figure 3 and Figure 4). The N_2O emissions again declined and minimized at the tillering stage (69 DAS). After that, emissions slowly increased and was found to be highest at EPI stage (90 DAS). After EPI stage, N_2O fluxes slightly decreased but remained at levels similar to 30-37 DAS. The trend of all fertilizer treatments were more or less the same throughout the growing period and F2 produce more N_2O than the others (Figure 6). The emissions of N_2O for F0, F1, and F2 were showed minimum fluxes between 48-83 DAS but slowly elevated and become stable after EPI (90 DAS). According to fluxes of CH_4 and N_2O result, the trade-off effect between CH_4 and N_2O occurred throughout the growth stages of rice cultivation.

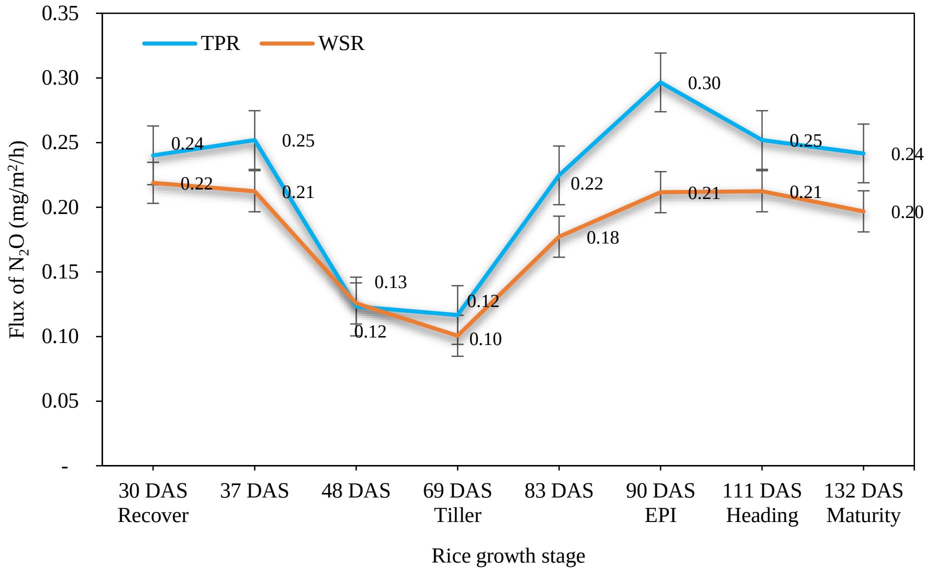

Figure 5. N_2O fluxes of crop establishment methods (mg/m²/h) by rice growth stage

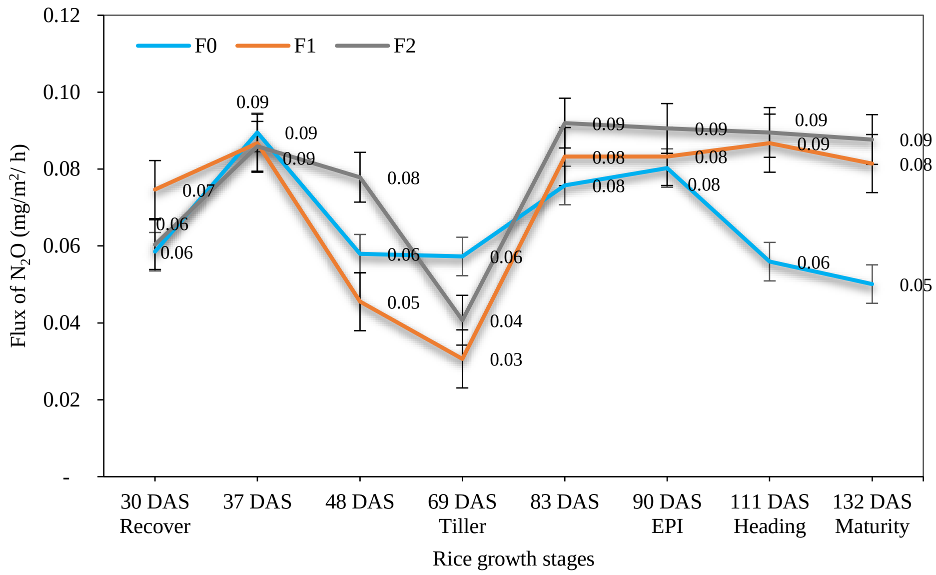

Figure 6. N_2O fluxes of N fertilizer application methods (mg/m²/h) by rice growth stages

3.3 Rice grain yield

Rice grain yield and fluxes of CH_4 and N_2O as affected by crop establishment and fertilizer are shown in Table 1.

These data revealed that any two combination of crop establishment and fertilizer tested in this experiment (TPR, WDSR, and F1, F2) grain yields are not statistically different from each other (Table 1). Rice grain yields between TPR and WDSR are not significantly different across the fertilizers at the 5% probability level, while among F0, F1, and F2, grain yields are found to be significantly different using F0 (without N), but F1 and F2 were not different from each other.

3.4 Global worming potential (GWP) and greenhouse gas intensity (GHGI)

In Table 2, all fertilizer treatments with TPR contributed more GWP as compared to that of with WDSR indicating again TPR produced more GHG emissions than WDSR. As for GHGI, GHGI, of TPR with all fertilizer treatments were found to be generally higher than that of WDSR. According to (Song et al., 2021b) WDSR practice indicated 75% lower GHGI than flooded TPR. It is noticeable that WDSR planting method is likely to be acceptable when compared with TRP across the fertilizer treatments owing to lower GHGI. When looking at WF1 (WDSR with urea) and WF2 (WDSR with compound fertilizer), GHGI is similar but WF1 had a 7% higher yield compared to WF2. Thus, based on GWP and GHGI analysis, WF1 (WDR with urea) is noticed to be suitable for cost efficient GHGs mitigation strategy.

Table 1. Rice grain yield (kg/ha) and fluxes of CH_4 and N_2O as affected by crop establishment and fertilizer

No	Treatment		Grain yield (kg/ha)	Average flux (mg/m^2/h)	
	Crop establish	Fertilizer		CH_4	N_2O
1	TPR	F0	5,370.39	3.27198	0.1348830
2	TPR	F1	6,846.36	3.58669	0.0976081
3	TPR	F2	6,868.53	4.68619	0.0683357
4	WDSR	F0	5,283.60	1.83577	0.0738248
5	WDSR	F1	6,527.40	2.71568	0.0844403
6	WDSR	F2	6,100.08	3.29895	0.0778937
5% LSD			**8,91.276**	**1.65580**	**0.1003500**
1	TPR		6,361.76	3.84828	0.1002760
2	WDSR		5,970.36	2.61680	0.0787196
5% LSD			783.367 NS	0.95597*	0.0579372 NS
1		F0	5,327.00	2.55378	0.1043540
2		F1	6,686.88	3.15119	0.0910242
3		F2	6,484.30	3.99257	0.0731147
5% LSD			640.357*	1.17083 NS	0.0709582 NS
C,V%			12.90	28.20	61.60

TPR=transplanted rice, WDSR=wet direct seeded rice, F0=no N, F1=urea, F2=compound fertilizer, LSD=the least significant difference, NS=not significant, *=significant at 5% probability level

Table 2. Average GWP kg CO_2eq/ha and GHGI of six treatments

No	Treatment		Rice grain yield (kg/ha)	CH_4 (kg/ha)	N_2O (kg/ha)	GWP (kg CO_2eq/ha)	GHGI (kg CO_2eq/kg)
	Crop establish	Fertilizer					
1	TPR	F0	5,370.39	109.93	4.53	4,238.48	0.79
2	TPR	F1	**6,846.36**	120.51	3.27	4,213.94	0.62
3	TPR	F2	**6,868.53**	157.45	2.29	4,996.56	0.73
4	WDSR	F0	5,283.60	61.68	2.48	2,362.09	0.45
5	WDSR	F1	**6,527.40**	91.24	2.83	**3,281.23**	**0.50**
6	WDSR	F2	**6,100.08**	110.84	2.61	3,773.66	0.62

TPR=transplanted rice, WDSR=wet direct seeded rice, F0=no N, F1=urea, F2=compound fertilizer

3.5 Environmental factors and GHGs emission correlation

Since the soil is calcareous, the average pH of all experimental units (EU) are kept higher at 8.5-8.6 in early stage during 30-37 DAS but gradually decreased after 37 DAS and maintained 7.05-7.55. The methane emissions in this study are negatively correlated with average soil pH (-0.35*, N=18) (Table 4) as the higher the average soil pH, the lower the CH_4 emission, as found in early growth stages (Table 3). Although soil pH was fairly stable around neutral after 48 DAS, CH_4 emissions are not consistent (Figure 3 and Figure 5). The N_2O emissions in this study did not correlatd with soil pH value (-0.04 ns N=18) (Table 4).

In this study, CH_4 emission are significantly correlated with average soil water depth of all plots (Table 4). The CH_4 emissions are noted as lower when average ORP -110.25 mV to -125.75 mV during 30-48 DAS under the water depth of 1.0-1.5 cm but gradually increased and peaked at -184.84 mV

(90DAS-EPI stage) under the average water depth of 5.8-6.0 cm, after that it sharply decreased when water depth was 0.0-0.5 cm and ORP was -123.64 mV to -125.25 mV at heading and maturity stages. In relation with N_2O emissions, it is relatively higher when ORP was -110.25 mV to -121.6 mV under the presence of water depth 1.0 cm during 30-37 DAS whereas CH_4 emissions are lower at that time. The ORP are noted to be lower (-189.74 mV to -189.84 mV) when water depths were under 5.6-6.0 cm during 69-90 DAS. However, correlation coefficient (r) of ORP between CH_4 and N_2O are 0.08 ns, N=18 and 0.05 ns, N=18, respectively. Thus, it implies that GHG emission (CH_4 and N_2O) is not correlated with ORP in this study.

At the time of 30 DAS, the average soil temperature was 27ºC and gently increased with growth stages, thereby CH_4 emissions are lower at early stages, but it slowly increased with increasing soil temperature. Average CH_4 emission peaked at 90 DAS, EPI when soil temperature reached its highest temperature at 34.84ºC. The correlation coefficient (r) between CH_4 emission and soil temperature is 0.48*, N=18 (Table 4). However, correlation between N_2O emission and soil temperature was not observed during this field experiment.

Table 3. Average soil pH, soil temperature, oxidation reduction potential (ORP), and water depth by rice growth stages

No	Growth stages	Soil pH	Soil temperature (ºC)	ORP (mV)	Water depth (cm)
1	30 DAS	8.60	27.00	-110.25	1.5
2	37 DAS	8.50	27.31	-121.60	1.5
3	48 DAS	7.55	29.30	-125.75	1.0
4	69 DAS Tiller	7.05	29.72	-189.74	5.8
5	83 DAS	7.73	29.91	-187.60	6.5
6	90 DAS EPI	7.50	34.87	-189.84	6.0
7	111 DAS Heading	7.52	29.76	-123.64	0.5
8	132 Maturity	7.52	27.00	-125.23	0.0

DAS=days after seeding

Table 4. Correlation coefficient (r) of GHGs emissions (CH_4 and N_2O) against the environmental factors

GHG (mg/m^2/h)	Environmental factors			
	pH	ORP (mV)	Water depth (cm)	Soil temperature (°C)
CH_4	-0.36*	0.08 NS	0.45*	0.48*
N_2O	-0.04 NS	0.05 NS	-0.14 NS	0.07 NS

NS=not significant, *=significant at 5% probability level

4. DISCUSSION

4.1 Emissions pattern of CH_4 and N_2O

Although the measurement of GHGs emissions from rice cultivation have been systemically researched by a number of regional countries in South East Asia, there is no reliable information available from Myanmar, especially CH_4 and N_2O emissions, from existing farmers' adopted fertilizer application under different rice establishment methods (Win et al., 2021). Further, the insight upon the consequences of the local farmers' adopted agricultural practices on CH_4 and N_2O emissions from rice cultivation was gained from this study. In this study, the trade-off effect between CH_4 and N_2O occurred which agreed with other research findings (Janz et al., 2016; Kong et al., 2021; Song et al., 2021b).

Along with the rice growth throughout the season, CH_4 fluxes increase continuously until 90 DAS (EPI stage) and after that descended rapidly, which were similar with the results of the previous studies (Gaihre et al., 2013). This may be due to crop residue accumulation which favors the emission of CH_4 (Janz et al., 2019). Moreover, the period between 83 DAS and 90 DAS (EPI stage) had the highest water depth (Table 3 and Figure 7). The effect of continuously flooded rice fields on CH_4 emission in assisting CH_4 production through creating anaerobic situation has been well documented (Gupta et al., 2016; Song et al., 2021a; Vo et al., 2018; Zhou et al., 2018). The anaerobic situation of soil aids the methanogenic bacteria which are the major source of CH_4 in the atmosphere (Haque and Biswas, 2021; Islam et al., 2020; Kong et al., 2021).

On the other hand, the trends of N_2O emission were not similar with CH_4 trend. The N_2O flux was higher at the 30 DAS and gradually reduced to the minimum rate at the 69 DAS or the tiller stage. Furthermore, the curve of N_2O emissions increased again until the EPI stage which was the highest stage of N_2O, while CH_4 fluxes decreased again from its highest point. According to the data of N_2O emission, the rate of N_2O positively responded to low water depth situation and N fertilizer application. The dry situation and N fertilizer are perfect boosters to generate the nitrification and denitrification process in the soil and that knowledge clearly explains the reason why N_2O emission becomes higher during low water depth and N fertilizer application (Granli, 1994; Janz et al., 2016; Kong et al., 2021).

4.2 Effect of environmental factors on CH_4 and N_2O emission

Over all rice growing stages of this study, TPR always emitted higher CH_4 and N_2O than WDSR. This matches the report that mentioned WDSR could reduce CH_4 emissions significantly over conventional transplanting method (Sandhu et al., 2021) and it showed WDSR can reduce at least 8% GHG emission as compared to TPR. There were numerous causes for higher CH_4 emissions in TPR. Mainly, the water depth of rice field is one of the main influencing factors on CH_4 emission. The minimum irrigation of WDSR produced an aerobic soil environment which depresses emission of CH_4 (Islam et al., 2020; Kumar and Ladha, 2011; Liu et al., 2014) while the TPR always maintains at least 1 cm of water depth (Figure 7).

There was a negative correlation between CH_4 emission and average soil pH (Table 4). Higher average soil pH was recorded while the CH_4 emission reached the lowest rate in early growth stages (Figure 3). This result corresponds with previous research that the impact of pH on the soil organic matter decomposition and the activity of microorganism sometimes retards the growth of methanogens (Tang et al., 2016). The continuous flooding for appropriate amounts of time normally causes the soil pH to approach a neutral level (around 7) which enhances the CH_4 production. Most of the methanogens are neutrophilic and usually active in neutral pH level, thus CH_4 production is most efficient in the pH range between 6.5 and 7.5 under neutral or slightly alkaline conditions (Wang et al., 2018). The N_2O emissions in this study did not statistically correlate with soil pH values in this study since the relationship between pH and N_2O emissions are complex (Smith, 2010; Tang et al., 2016). Although (Wang et al., 2015) mentioned that increasing soil pH inhibits N_2O production, both average soil pH and N_2O emissions were simultaneously higher at the early stage of rice growth (30-48 DAS).

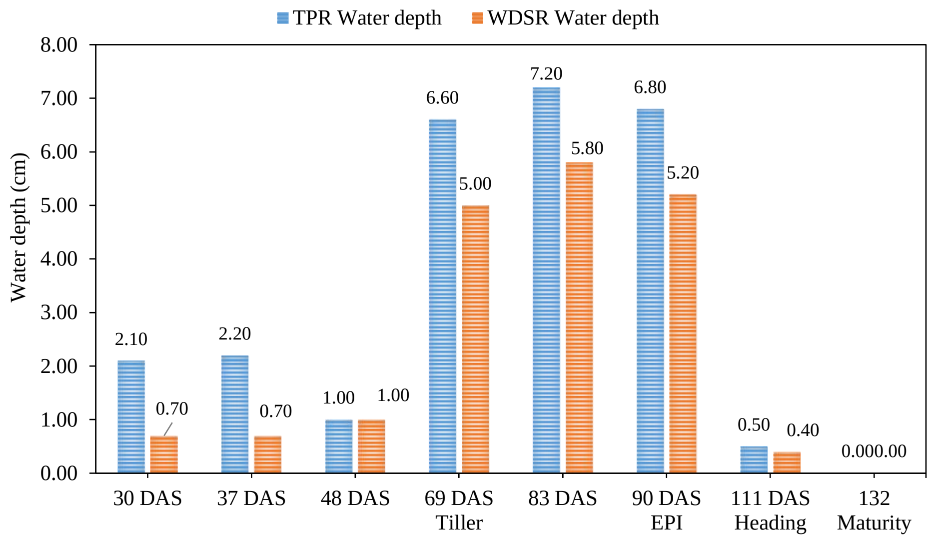

Figure 7. Water depth of TPR and WDSR by rice growing stages

Although no correlation of the soil temperature with N_2O fluxes was observed, there was a positive correlation between soil temperature and average CH_4 emission. Average CH_4 emission peaked at 90 DAS, EPI when soil temperature was highest (34.84°C). In addition, the differences in CH_4 and N_2O emission between two crop establishment methods and N fertilizer application relatively depends on abiotic factors, precipitation, and soil properties (including soil temperature) that can affect activities of microorganisms such as oxidation and reduction (Liu et al., 2014; Sandhu et al., 2021; Venterea et al., 2011; Vo et al., 2018)

4.3 Cost efficient GHGs mitigation strategy for Myanmar

In this study, several of the results explain how crop establishments and nitrogen fertilizer influence GHG emissions and also global warming potential (GWP), and greenhouse gases intensity (GHGI). The overall findings of this study indicate the pair of wet bed direct seeded rice and urea fertilizer application (WDSR+F1) is the most appropriate agricultural practice for GHG mitigation technique in sustainable rice production profile, which gives relatively less methane and nitrous oxide emissions in term of lower GWP and GHGI with acceptable rice yield.

According to the statistical analysis, the grain yield of TF1, WF1, TF2 (TPR with compound fertilizer), and WF2 (WDSR with compound fertilizer) are not statistically different to each other at 5% probability level in this study (Table 1). This makes sense because the local farmers obviously select the agricultural practices which ensure productivity and profit. The rice grain yield of TPR and WDSR were more or less the same and this finding was supported by (Liu et al., 2014; Sandhu et al., 2021). As rice plants can be either transplanted or direct seeded, depending on locality, labor availability and initial investment, the yield potential is often the same. The methane flux was 47% higher in TPR compared to WDSR, while there are no significant difference among F0, F1, and F2 in the average flux of CH_4. With regard to average nitrous oxide fluxes, neither crop establishment (TPR, WDSR) nor fertilizers (F0, F1, and F2) were found to be significantly different. In addition, TPR produced more CH_4 and N_2O than WDSR across fertilizers in almost each growth stage throughout the growing period.

Regarding Global Warming potential (Table 2), GWP of both TF1 and TF2 were higher than the WF1 and WF2 as the result of producing more GHG emissions than WDSR. Furthermore, GHGI of WDSR with all fertilizer treatments were found to be generally lower than that of TPR. It is noticeable that WDSR planting method is likely to be acceptable when compared with TRP across the fertilizer treatments owing to lower GHGI. Thus, based on GWP and GHGI analysis, the pair of wet bed direct seeded rice and urea fertilizer application (WDSR+F_1) practices is noted to be suitable for GHG mitigation.

5. CONCLUSION

Currently, several studies highlighted that changing the cultivation practice from TPR to WDSR makes sense to resolve the high cost of farming inputs, water, and labor scarcity. This change has been adapted by farmers themselves based on their experiences and indigenous knowledge (Janz et al., 2016; Pathak et al., 2013). This study indicates a pair of practices (WDSR+F_1) has great potential in mitigating GHGs emission from the agricultural sector since it creates lower GWP and GHGI with acceptable productivity. However, the finding of this study may not be used to generalize the feature of all small farmers in the central dry zone of Myanmar, since it was a pioneer field experiment in Myanmar with limited equipment, facilities, budget and time. Further studies should be done to identify the flexibility (wiggle room) in practices to fulfil the cost efficient GHGs mitigation strategy for Myanmar.

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