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Greenhouse Gas Mitigation Strategies for Lowland Rice Cultivation under Common Farm Practices, and Accompanying Influencing Factors for Acceptability among Local Farmers in Myanmar

Myo Thet Tin[1], Amnat Chidthaisong[2], Nathsuda Pumijumnong[1], Noppol Arunrat[1], and Monthira Yuttitham[1*]

[1]Faculty of Environment and Resource Studies, Mahidol University, Nakhon Pathom, Thailand
[2]The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, 126 Prachauthit Rd, Bangmod, Tungkru, Bangkok, Thailand

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*** Corresponding author:**
E-mail:
monthira.yut@mahidol.ac.th

ABSTRACT

The main purpose of the study was to determine agricultural rice establishment options with specific fertilizer application methods which produce less methane, and lower nitrous oxide emissions (Lower Global Warming Potential. Greenhouse Gases Index and Abatement cost) while still maintaining an acceptable rice yield. To do so, methane (CH_4) and nitrous oxide (N_2O) emissions, and grain yields from rice fields were explored, under different farmer fertilizer application methods and two different crop establishment options currently practiced by local farmers, namely transplanted rice (TPR) and wet bed direct seeded rice (WDSR). Both were measured in field experiments. In this study, it was found that rice cultivation emitted CH_4 and N_2O at the rate of 3.23±0.94 mg/m^2/h (ranging from 1.83-4.68) and 0.089±0.024 mg/m^2/h (ranging from 0.073-0.135), respectively. In addition, TPR produced more CH_4 and N_2O than WDSR did across the different fertilizer methods at almost each growth stage throughout the growing period. Finally, the result was a pair of rice cultivation practices-including WDSR with urea nitrogen fertilizer application (WF1)-which show great potential for mitigating GHG emissions in the Myanmar agricultural sector. Lower GWP, GHGI, and AAC with acceptable productivity were all seen. Moreover, this study was designed to investigate influencing factors on acceptability of local farmers upon WF1. Some 36% of respondents among local farmers were willing to accept WF1 with conditions, while 30% acceptability was found in neutral respondents, not yet decided on practices of rice cultivation for coming seasons. According to multiple regression analysis, the influencing factors of farmers' acceptability towards WF1 were their rice cultivation experience, the number of available agriculture information sources, and the total quantity of cultivated land for rice growing.

1. INTRODUCTION

Agriculture contributes around 10-12% of the world's total human-caused greenhouse gas (GHG) emissions, and is responsible for 60% of global nitrous oxide (N_2O) and 50% of methane (CH_4) emissions (Smith et al., 2008). Carbon dioxide is also a greenhouse gas, and globally, CO_2 emissions from soil are largely balanced by the net primary productivity and CO_2 absorption by crops, resulting in a total contribution of less than 1% to agriculture's global warming potential (GWP) (Smith et al., 2007). Nitrous oxide is a significantly more potent greenhouse gas, with a radiative forcing potential about 12 times greater than that of methane (Shukla et al., 2019).

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Upland agricultural systems are predominantly responsible for the emission of N_2O, whereas flooded rice (Oryza sativa) systems emit a combination of CH_4 and N_2O (Song et al., 2021a). An earlier study has documented that the GWP of GHG gas emissions originating from rice cultivation is approximately four times greater than either wheat or maize (Linquist et al., 2012). Therefore, the majority of strategies aimed at mitigating overall GWP from rice cultivation primarily concentrate on the reduction of CH_4 emissions. Nonetheless, it is imperative to acknowledge that these mitigation approaches should encompass not only CH_4 but also N_2O emissions, given that certain strategies designed to decrease CH_4 emissions may inadvertently lead to an increase in N_2O emissions (Klüber and Conrad, 1998).

The primary cause of methane (CH_4) emissions from agricultural land stems from biologically mediated processes involving methanogenic bacteria and resulting from organic matter decomposition, particularly under anaerobic soil conditions (Conrad, 2002; Sass et al., 2002). Simultaneously, emissions of nitrous oxide (N_2O) are influenced by nitrification and denitrification processes in the soil (Smith, 2010). Various studies indicate that lowland flooded fields play a crucial role in CH_4 emissions, while making a minor contribution to N_2O emissions (Ly et al., 2013). Furthermore, the release of N_2O is linked to the application of nitrogen fertilizers and dry soil conditions (Linquist et al., 2012; Linquist et al., 2015). The results of these studies highlight the significant association between farming practices, such as water management and fertilizer application methods, and the emissions of CH_4 and N_2O.

An effective approach for mitigating CH_4 emissions involves mid-season drainage, which in turn entails the temporary removal of irrigation water, as demonstrated in various field experiments (Arunrat et al., 2018; Nayak et al., 2015). The outcomes of these field experiments indicated that mid-season drainage substantially reduces CH_4 fluxes while enhancing rice yields (Islam et al., 2020; Liu et al., 2014; Song et al., 2021c; Tang et al., 2016). However, this practice may lead to increased N_2O emissions due to the creation of relatively saturated soil conditions, which are positively correlated with N_2O production, revealing a trade-off effect between CH_4 and N_2O (Arunrat et al., 2018; Islam et al., 2020; Liu et al., 2014; Song et al., 2021c; Tang et al., 2016).

The interaction of CH_4 with the atmosphere in croplands is subject to the influence of nitrogen fertilizer application (Cai et al., 1997). Various impacts from CH_4 emissions have been observed as a result of nitrogen fertilizer applications (Kong et al., 2021; Linquist et al., 2012; Liu et al., 2012b). The stimulation of CH_4 emissions has been documented in certain instances following nitrogen fertilizer applications (Liu and Greaver, 2009; Shang et al., 2011), whereas in other experimental settings, they have been found to hinder CH_4 production (Venterea et al., 2005). Additionally, there are scenarios where no significant correlation is established between nitrogen fertilizer application and methane emission rates (Mosier et al., 2006). Nitrogen fertilizer has the capacity to undergo either nitrification or denitrification in soil, and then subsequently be released as N_2O (Smith, 2010). Moreover, the application of nitrogen fertilizer stands out as a critical practice with direct or indirect implications on N_2O emissions (Nayak et al., 2015; Venterea et al., 2011). Numerous field studies focusing on N_2O emissions and the effects of nitrogen fertilizer application have been conducted, further identifying correlated influencing factors-such as crop type, application rate, and timing-all of which have been extensively documented (Linquist et al., 2012; Venterea et al., 2005). The timing and method of nitrogen fertilizer application, whether split or not, has been advocated for both upland and lowland crops in terms of greenhouse gas fluxes. Split application of N fertilizer has proven to be an effective approach in reducing N_2O emissions from potatoes, especially under conditions of adequate rainfall and reduced aeration (Kong et al., 2021). Furthermore, the timing of early and late spring fertilization in maize has shown a significant impact on greenhouse gas fluxes (Venterea et al., 2005). Additionally, managing fertilizer application through the split method can influence methane and nitrous oxide emissions in both upland and lowland rice cultivation, as detailed by Kong et al. (2021) and Linquist et al. (2012). The impact of compound fertilizers, typically containing nitrogen (N), phosphorus (P), and potassium (K), on enhancing fertilizer efficiency has been noted, albeit with potential environmental repercussions due to mismanagement in application practices (Gupta et al., 2016; Haque and Biswas, 2021).

Myanmar is traditionally an agricultural country and this sector contributes approximately 20.1% of national Gross Domestic Product (GDP). Rice is a major crop of the country within this sector (MoALI, 2019). The majority of rice farming systems employ transplanted rice (TPR) and wet bed direct seeded rice (WDSR) for local farmers. Generally, the TPR method utilizes intensive inputs, namely water and labor, with a high cost of production (Chauhan et al., 2017; MoALI, 2019) while the WDSR method, seeded directly on non-puddle soil, has become very common especially among local farmers since it can help solve water shortage and labor scarcity problems, while also producing a high cost-benefit ratio (Janz et al., 2016; Pathak et al., 2013). Several pieces of research have indicated that crop establishment with WDSR and appropriate water management is potentially a better CH_4 mitigation strategy than the TPR method (Liu et al., 2014). It has also been highlighted that the average CH_4 emissions from TPR were more than 80% of the emissions produced by WDSR in two-year experiments (Gupta et al., 2016). Additionally, WDSR with midseason drainage likely diminishes the CH_4 emission rate by up to 50%. Thus, WDSR may be easily accepted by different levels of rice farmers because of its reduced requirements for water, and its lower cost of production. The capacity of adaptation to climate change may also be better for WDSR, which has a relative tolerance to both drought and water stress (Pathak et al., 2013).

The understanding of climate change and GHG emissions related to rice cultivation in Myanmar is currently in its early stages among policymakers, farmers, and researchers. Additionally, there is a lack of existing research on GHG emissions from rice fields (Oo et al., 2015).

Both the private and public sectors have failed to recognize the potential negative impact of the agricultural sector on the environment. The Ministry of Natural Resources and Environmental Conservation (MONREC) enacted the Environmental Conservation Law in 2012. However, this legislation neglected to address GHG emissions from the agricultural sector, focusing instead on the industrial sector, urban development, tourism, and mining. Additionally, the System of Rice Intensification (SRI) policy was introduced in 2018 as part of the national plan by the Ministry of Agriculture, Livestock, and Irrigation (MOALI) and the Department of Planning (DoP). This policy aimed to enhance national food security and boost rice exports by advancing agricultural economics, without taking environmental concerns into account. Consequently, it is imperative for Myanmar to conduct primary field experiments that specifically address GHG emissions from the agricultural sector.

The escalating demand for rice production has raised significant environmental concerns regarding the rise in GHG emissions (Lubbers et al., 2013). Consequently, there is a crucial need to comprehend the trade-offs between enhancing rice yield and minimizing GHG emissions, and to further facilitate the formulation of effective mitigation and adaptation strategies. Significant reductions in CH_4 and N_2O emissions from rice fields can be achieved by implementing various mitigation measures. Nonetheless, numerous substantial challenges exist, hindering the integration of these mitigation options into local rice cultivation practices. Hence, it is essential to identify opportunities for emissions reduction in rice production that align with the existing practices of farmers, thus ensuring their prompt acceptance in case of positive outcomes. Furthermore, a comprehensive understanding of farmers' decision-making processes regarding the adoption of mitigation strategies within their established practices is essential to pinpoint the barriers that impede adoption as determining factors.

The objectives of this study encompass quantifying the emissions of CH_4 and N_2O from rice utilizing two distinct fertilizer application methods within two differing farming systems. Furthermore, the study assesses global warming potential (GWP), greenhouse gas intensity (GHGI), and abatement costs associated with various combinations of fertilizers and farming systems. Lastly, the study identifies factors that influence the acceptability of farmers towards adopting mitigation techniques.

2. METHODOLOGY

2.1 Measuring GHG emissions

2.1.1 Study area

The field experiment was conducted at Kyaukse research station in Kyaukse Township, Mandalay region, located at 21º36′47″ N 96º7′49″ E and an elevation of 77 m.a.s.l. in Myanmar. This region has a history of diverse agricultural traditions practiced by local farmers. The soil characteristic of the area is classified as carbonated alluvial (gleysol) in the FAO/UNESCO system, featuring a fine texture and shallow soil profile. The soil exhibits good water drainage and high-water percolation rates, although it has a low capacity for retaining moisture. These soil conditions make it suitable for cultivating field crops using a paddy-upland cropping system, including green gram, chickpea, sesame, and sunflower as upland crops, and rice as a lowland crop (Tin et al., 2022).

2.1.2 Field experiment design, treatments and layout

Two factors were identified in accordance with the current practices of local farmers: crop establishment (Transplanted rice-TPR and Wet direct seeded rice-WDSR) and fertilizer (F0, F1, and F2). The experimental setup consisted of two factors with three replications, following a split plot design. The methods of crop establishment and fertilizer application utilized in this study were based on the traditional practices of rice cultivation by local farmers (Tin et al., 2022).

In terms of crop establishment factors, the TPR was grown in a wet environment and created by puddling. Twenty-day-old SinThuKha (IRYn1068-7-1 (Manawthukha/IRBB21)) seedlings were transplanted, and until one week before they matured, they were kept submerged in water up to 10 cm deep. However, they were irrigated once more as soon as the water level rose to 1 cm above the soil. The WDSR produced puddling and leveling when it was grown in damp conditions. Following thorough leveling of the land and water drainage, sprouted seeds from the same variety of rice, weighing 70 kg/ha, were manually sown in a line. When seedlings were thriving and the water level was between 3 and 5 cm, irrigation was started. Flooded water was maintained at a depth of roughly 10 cm, and irrigation was restarted as soon as the water rose 1 cm above the soil. There were three treatments for the fertilizer factor: urea, muriate of potash (MOP), triple super phosphate (TSP), and compound fertilizer (15:15:15) (Tin et al., 2022).

2.1.3 Gas sample and analysis

In this study, a closed chamber was utilized to gather the gas emitted from the rice field (Yuesi and Yinghong, 2003; Zhou et al., 2018). The chamber consisted of two parts: an aluminum base measuring 30 cm in width, 40 cm in length, and 15 cm in height, and an acrylic cover measuring 30 cm in width, 40 cm in length, and either 60 cm or 120 cm in height. The chamber base was embedded 7.5 cm into the soil throughout the cultivation period, with the joints sealed by water. The cover has two holes on its top surface-one for gas collection and the other for inserting a plug to measure the internal air temperature. Two cover heights were used depending on the growth stage of the rice plants: the 60 cm height for the early stage and the 120 cm height for the later stage (Tin et al., 2022).

Throughout the growing period, 54 gas samples were collected weekly from six treatments, each replicated three times. Sampling occurred at 0, 10, and 20-minute intervals between 9:00 am and 12:00 pm, based on methods adapted from multiple references. (Huang et al., 2017; Liu et al., 2012a; Venterea et al., 2011). Gas samples were drawn into aluminum foil multi-layer bags equipped with ABS valves (0.5 L capacity) using a portable battery-powered air pump (SB-980). The chamber's internal air temperature was measured with a thermometer featuring a sensor tip and documented at the time of sampling. The gas samples were then analyzed for CH_4 and N_2O using a gas chromatograph (GC) (SHIMADZU Model 2010 Plus). The analysis employed an SH-Rt-Q-BOND column (serial no. 1357883) with a flame ionization detector (FID) for CH_4 and an electron capture detector (ECD) for N_2O (Tin et al., 2022).

As per the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (AR5), equivalence values are applied where 1 kg of N_2O is equivalent to 265 kg of CO_2, and 1 kg of CH_4 is equivalent to 28 kg of CO_2 in terms of their impact on climate change (Myhre et al., 2013). The greenhouse gas intensity (GHGI) in kilograms of CO_2 equivalent per hectare was calculated by dividing the global warming potential (GWP) of CH_4 and N_2O emissions by the rice grain yield, as described by Haque and Biswas (2021). Total GWP (kg CO_2 eq/ha) = (CH_4 emission × 28) + (N_2O emission × 265).

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

2.2 Factors influencing local farmers' acceptability of GHG mitigation strategies

Personal interviews were conducted within a specific radius of 10 km around the field experiment location, targeting farmers selected purposively for a community-based survey. Two villages, Kula and Pyiban, situated within this radius, were included. Kula village, located southeast of the field experiment site, is approximately eight miles away, while Pyiban village, located south of the research farm, is approximately three miles away. Kula has 164 rice farmers, whereas Pyiban has 105 rice farmers (MoALI, 2019).

2.2.1 Sample size

The personal interviews were conducted at specific locations within a 15 km radius of the field experiment, with farmers purposively selected for a community-based survey. The two villages within this radius, Kula and Pyiban, have populations of 164 and 105 rice farmers, respectively. The total sample size was calculated using the formula of Yamane (1967).

$$n = \frac{N}{1} + N * e^2$$

Where; n=sample size, N=total number of rice farmer households, e=level of precision (10%)=0.1, N=269.

$$n = \frac{269}{1} + 269 * 0.1^2 = 72.9$$

n ≈ 73 (N=269, was taken from rice farmer households from two villages).

$$\text{Sample fraction } \frac{n}{N} = \frac{73}{269} = 0.27$$

According to the sample size calculation formula, a total of 73 sample farmers were randomly selected for the survey. This study included 73 farmers from a larger group of 269 farming households, representing 27% of the households in the two villages. Details of the sample size are provided in the following Table 1.

Table 1. Sample size calculation

Name of village	Total rice growing area (acres)	Total farming households	Sample size	% of total rice farming households
Ku La	421	164	45	27%
Pyiban	512	105	28	27%
Total	933	269	73	27%

2.2.2 Data collection method

Standardized questionnaires served as the primary tool for collecting both quantitative and qualitative data at the household level. The survey gathered background information on local farmers' experiences and knowledge related to agriculture and environmental impacts. Additionally, personal interviews were conducted to assess local farmers' perceptions and acceptance of selected methods for establishing crops with lower greenhouse gas emissions and alternative practices for applying nitrogen fertilizer.

All 73 respondents for the personal interviews were paddy farmers with a minimum of three years of experience in rice cultivation. The interviews were conducted within a 15 km radius around the field experiment (or research plots), specifically targeting farmers selected for a community-based survey. The two villages within this radius are Kula and Pyiban, in Kyaukse Township.

2.2.3 Data analysis

This study utilized factor analysis to identify factors influencing farmers' acceptability. Multiple regression analysis (using the least squares method) was employed to apply a model that determines the correlation coefficients (β values) of independent factors affecting farmers' acceptability. Additionally, t-values of individual independent factors, along with R-squared (R^2) and F-values, were computed to assess significance and interpret the relationships between independent variables (such as X1, X2, X3, etc., representing farmers' situations) and the dependent factor of farmers' acceptability.

A regression model was specified in explicit form as follows:

$$\text{Model: } Y = \alpha + \beta 1X1 + \beta 2X2 + \beta 3X3 + \beta 4X4 + \beta 5X5 + \beta 6X6 + U$$

Where: Y=acceptability scores of rice farmers, α=Constant term, β1-β7=regression coefficients, X1=Age, X2=education level, X3=experience in rice cultivation, X4=agricultural information sources, X5= profit from rice cultivation, X6=land cultivated for rice.

3. RESULTS

3.1 Rice grain yield and GHG emissions

In this research, rice cultivation emitted CH_4 and N_2O at rates of 3.23±0.94 mg/m^2/h (ranging from 1.83 to 4.68) and 0.089±0.024 mg/m^2/h (ranging from 0.073 to 0.135), respectively, as the average fluxes across the entire field experiment. Additionally, the Transplanting of Puddled Rice (TPR) method resulted in higher CH_4 and N_2O emissions compared to the Water-saving Direct Seeded Rice (WDSR) method across various fertilizer applications and growth stages throughout the growing season. Previous studies, (e.g. Sandhu et al., 2021), have demonstrated that Direct Seeded Rice (DSR) methods can significantly reduce

CH_4 emissions compared to conventional transplanting methods, potentially lowering GHG emissions by at least 8%.

Table 2 presents rice grain yields and fluxes of CH_4 and N_2O as influenced by crop establishment methods and fertilizer applications (Tin et al., 2022).

Table 2. 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 estb. method	Fertilizer		CH_4	N_2O
1	TPR	F_0	5,370.39	3.27198	0.1348830
2	TPR	F_1	6,846.36	3.58669	0.0976081
3	TPR	F_2	6,868.53	4.68619	0.0683357
4	WDSR	F_0	5,283.60	1.83577	0.0738248
5	WDSR	F_1	6,527.40	2.71568	0.0844403
6	WDSR	F_2	6,100.08	3.29895	0.0778937
	5% LSD		891.276	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		F_0	5,327.00	2.55378	0.1043540
2		F_1	6,686.88	3.15119	0.0910242
3		F_2	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, F_0=no nitrogen, F_1=urea, F_2=compound fertilizer, LSD=the least significant difference, NS=Not significant, *=significant at 5% probability level

The results indicated that across all combinations of crop establishment methods (TPR and WDSR) and fertilizer treatments (F0, F1, and F2) tested in this experiment, there were no statistically significant differences in rice grain yields (Table 3). Specifically, grain yields between TPR and WDSR did not differ significantly regardless of the fertilizer applied at the 5% significance level. Among the fertilizer treatments (F0, F1, and F2), grain yields were significantly different only when comparing F0 (without nitrogen) to the others. However, there were no significant differences in grain yields between F1 and F2 treatments (Tin et al., 2022).

3.2 Global warming potential (GWP) and greenhouse gas intensity (GHGI)

Table 3 shows that all fertilizer treatments applied with TPR resulted in higher greenhouse gas emissions compared to those applied with WDSR. This highlights that TPR consistently produces more GHG emissions than WDSR in the Myanmar agricultural fields of our study. In terms of GHGI, the values associated with TPR across all fertilizer treatments were generally higher than those for WDSR. According to Song et al. (2021c), WDSR practice can lead to a 75% reduction in GHGI compared to flooded TPR. This underscores that the WDSR planting method is likely more acceptable when considering lower GHGI across different fertilizer treatments, especially when compared to TPR. When focusing on WF1 (WDSR with urea) and WF2 (WDSR with compound fertilizer), GHGI values were similar, though WF1 yields were 7% higher compared to WF2. Therefore, based on the analysis of GWP and GHGI-WF1 (WDSR with urea) appears to be the most cost-effective strategy for mitigating GHG emissions (Tin et al., 2022).

3.3 Average abatement cost (AAC)

In Table 4, the calculated production cost of six treatments (two crop establishments paired with three fertilizer combinations) and average abatement cost (AAC) of four fertilizer treated treatments are mentioned. For production cost among the four-F1 (urea) paired with TPR, and WDSR, F2 paired with TPR and WDSR- the lowest calculated AAC were found to be F1 and WDSR. The major limitations of TPR are labor availability, a time-consuming pace, and high production costs. Total abatement costs (TAC) are calculated as the production cost of fertilizer, minus the production cost of control- whereas total abatement potential (TAP) is obtained by subtracting $GWP_{control}$ from $GWP_{treatment}$. Thus, average abatement cost (AAC) is determined through TAC divided by TAP. In that regard, TF1 (transplanted rice with urea fertilizer) is realized to be more acceptable than TF2 (transplanted rice with compound fertilizer) especially in term of mitigation, as TPRF1 gave (-4,004.219) AAC. When compared between WF1 and WF2, WF1 contributes lower AAC than WF2. This indicates a more suitable pairing for GHG mitigation. Also in the AAC assessment of this study, TF1 and WF1 were found to be relatively acceptable for GHG mitigation techniques to date.

Table 3. Average GWP (kg CO_2eq/ha) and GHGI of six treatments

No	Treatment		Rice grain yield	CH_4	N_2O	GWP	GHGI
	Crop estb. method	Fertilizer	(kg/ha)	(kg/ha)	(kg/ha)	(kgCO_2eq/ha)	(kgCO_2eq/ka)
1	TPR	F_0	5,370.39	109.93	4.53	4,238.48	0.79
2	TPR	F_1	6,846.36	120.51	3.27	4,213.94	0.62
3	TPR	F_2	6,868.53	157.45	2.29	4,996.56	0.73
4	WDSR	F_0	5,283.60	61.68	2.48	2,362.09	0.45
5	WDSR	F_1	6,527.40	91.24	2.83	3,281.23	0.50
6	WDSR	F_2	6,100.08	110.84	2.61	3,773.66	0.62

TPR=transplanted rice, WDSR=wet direct seeded rice, F_0=no nitrogen, F_1=urea, F_2=compound fertilizer

Table 4. Average Abatement Cost (MMK kgCO_2/eq)

No	Treatment		Production cost (MMK/ha)	Total abatement cost (MMK/ha)	Total abatement potential (kgCO_2eq/ha)	Average abatement cost (MMKkgCO_2/eq)
	Crop estb. method	Fertilizer				
1	TPR	F_0	1,047,220	-	-	-
2	TPR	F_1	1,145,500	98,280	-24.54	- 4,004.22
3	TPR	F_2	1,185,800	138,580	758.08	182.80
4	WDSR	F_0	1,010,170	-	-	-
5	WDSR	F_1	1,108,450	98,280	919.14	106.93
6	WDSR	F_2	1,148,750	138,580	492.43	281.42

TPR=transplanted rice, WDSR=wet direct seeded rice, F_0=no nitrogen/control, F_1=urea, F_2=compound fertilizer, MMK=Myanmar Kyat (1 USD=1,650 in 2019) *Fertilizer costs are calculated based on current relevant market price as of July 2019. Urea 50kg=MMK 26,000, TSP 50kg=MMK 25,000, MOP 50kg=MMK 22,000, 15:15:15 compound fertilizer 50kg=MMK 40,000

3.4 Mitigation technique selection

As indicated, the results of this study analyzed GHG emissions from different farming systems, crop establishment and nitrogen fertilizer practices, global warming potential (GWP), and greenhouse gas intensity (GHGI). Moreover, the production cost of rice cultivation and average abatement cost (AAC) were calculated to figure out the pairs of proper rice crop establishment methods and nitrogen fertilizer application practices which create less GHGs, while also still producing acceptable rice yields throughout the field experiments.

The overall findings of this study indicated the pairing of wet bed direct seeded rice (WDSR) and urea fertilizer application (WF1) was the most appropriate agricultural practice for GHG mitigation with a sustainable rice production profile. This pairing gives off relatively less methane and nitrous oxide than other techniques, while still providing acceptable rice yield, as well as lower GWP, GHGI and AAC.

According to the statistical analysis, the grain yields of TF1, WF1, TF2, and WF2 (WDSR with compound fertilizer) were not statistically different to each other at 5% probability level in this study. This finding made sense, as these crop establishment methods and fertilizer application practices are currently adopted by local farmers at the ground level, and the farmers frequently select agricultural practices which ensure both productivity and profit.

Regarding GHG emissions, 47% of methane flux was higher in TPR (as compared to WDSR) while there were no significant differences among F0, F1, and F2 in average flux of CH_4. With regard to average nitrous oxide fluxes, neither crop establishment (TPR, WDSR) nor fertilizer type (F0, F1, and F2) were found to be significantly different.

In the case of GWP (Table 4), both TF1 and TF2 were higher than WF1 and WF2, and the result of TPR produced more GHG emissions than WDSR. Furthermore, the GHGI of WDSR with all fertilizer treatments was found to be generally lower than that of TPR. It is noticeable that the WDSR planting method is likely to be more acceptable than TPR across the fertilizer treatments (owing to lower GHGI). Thus, within our GWP and GHGI analysis, WF1 (WDSR with urea) is noted to be most suitable for GHG mitigation.

Although the AAC analysis gave two options for transplanted rice cultivation-urea (TF1) and WF1, both relatively acceptable for environmental friendly agricultural practices-other aspects of GWP and GHGI were rendered with production rates. It then became clear that WF1 appeared to be the particular rice establishment option, or fertilizer application method, with the least CH_4 or N_2O emissions possible, without reducing rice yield.

3.5 Factors influencing acceptability among local farmers

3.5.1 Profile of respondents

The profile of respondents describes demographic and socio-economic characteristics of the respondents from the two villages of Pyiban and Kula. The demographic characteristics include age, education level, and experience in rice cultivation while the agricultural characteristics include current practices of fertilizer application, and crop establishment methods for rice cultivation systems (Table 5).

(1) Age

In the study area, the age of rice farmers was dispersed; ranging from 20 to 64. In Kula village, respondents' age groups were evenly dispersed between young (age 18 to 30) and middle (31 to 60) with 47% of each. Only 6% of respondents were in the group older than 60. In Pyiban village, the highest amount existed in the middle age group (57%) followed by older than 60 (25%), then the lowest amount of respondents was 18 to 30 (18%).

(2) Education level

Primary education was the most common level completed in Kula village (more than half of respondents; 53%), followed by secondary and high school education, which were 29% and 13%, respectively. Only 5% of respondents reached the college/university level of education in Kula village. However, respondents in Pyiban village noted 39% for secondary education, the highest group level for this village. In the case of university education level however, there was not a single graduate in Pyiban village.

(3) Experience in rice cultivation

Three groups were outlined for rice cultivation experience: low (3-9 years), medium (10-16) and high (above 16). Comparisons for the two villages are presented in Table 4. Most of the respondents for both villages had medium experience 62% of farmers in Kula village and 57% in Pyiban village. Low experience farmers were second most prevalent for both those villages.

(4) Agricultural information sources

The distribution of agricultural information is sorted by numbers of sources, with three groups outlined: low (1-3 sources), medium (4-6) and high (7-9) for the two villages (shown in Table 4). In Kula village, 51% of respondents access one to three sources of agricultural information, making it the largest group in this village. Whereas in Pyiban village, most of the farmers who responded access four to six sources of agricultural information (54%). However, few respondents in both Kula (18%) and Pyiban (7%) accessed high sources of information.

In the studied villages, there were nine main information sources. The most popular (and readily available) agricultural sources for this study area were other farmers/friends (71 respondents), social media (70 responds) and private fertilizer companies' sales-men (68 respondents). Moreover, government extension workers were also an important source of agricultural knowledge and information, as 52 respondents in the survey listed them as major sources of information. They are followed by television and newspapers, which some farmers still accessed as primary agricultural information sources. The least favorite information sources were radio and magazines, not more than four respondents accessed them regularly (Figure 1).

(5) Available land for rice cultivation

Farmers were categorized into three groups: small cultivated areas (lower than 5 acres), medium cultivated areas (6 to 10 acres) and highly cultivate areas (above 10 acres) based on rice cultivation of their own land (Table 5). Greater percentages of small, cultivated areas and medium cultivated areas were found in Kula village, and most farmers from Kula village (56%) cultivated rice plots smaller than 5 acres. However, the highest percentage was found in Pyiban village, where half of the respondents cultivated rice plots sized between six to 10 acres.

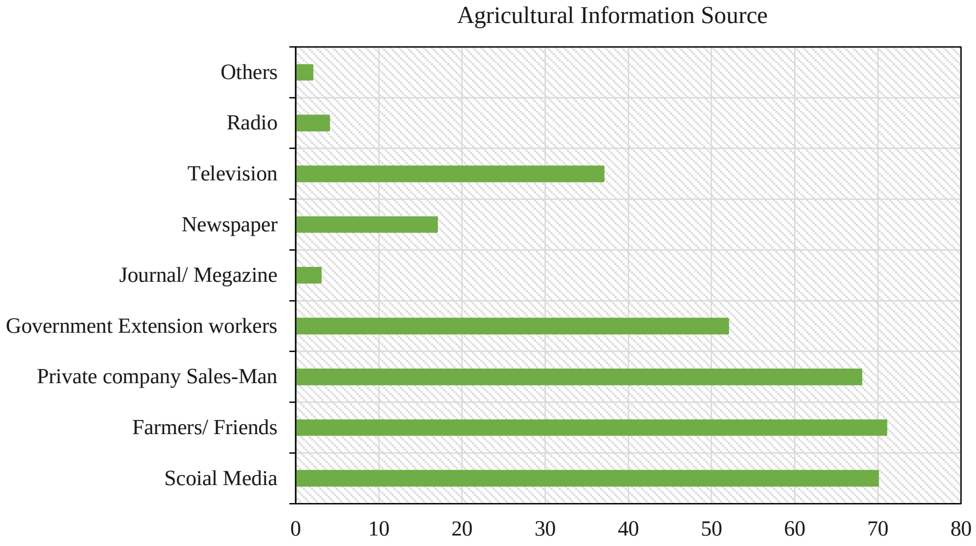

Figure 1. Sources of agricultural information used by farmers

Table 5. Characteristic profiles of farmers

Characteristic	Categorization	Kula village (n=45)		Pyiban village (n=28)	
		F	%	F	%
Age	Young (18-30)	21	47	5	18
	Middle (31-60)	21	47	16	57
	Old (61 and above)	3	6	7	25
Education level	Primary	24	53	9	32
	Secondary	13	29	11	39
	High School	6	13	8	29
	College/University	2	5	0	0
Rice cultivation experience (in years)	Low (3-9)	14	31	8	29
	Medium (10-16)	28	62	16	57
	High (16 and above)	3	7	4	14
Agri-information sources	Low (1-3)	23	51	11	39
	Medium (4-6)	14	31	15	54
	High (7-9)	8	18	2	7
Cultivated land (in acres)	Small (<5)	25	56	11	39
	Medium (6-10)	18	40	14	50
	High (>10)	2	4	3	11
N-fertilizer and crop establishment	TF1	10	22	9	32
	TF2	12	27	8	29
	WF1	11	24	9	32
	WF2	12	27	2	7

TF1-TPR with urea, TF2-TPR with compound fertilizer, WF1-WDSR with urea, WF2-WDSR with compound fertilizer

(6) Current rice cultivation practices

The distribution of respondents was based on the four major types of practice in the study area: transplanted rice with urea (TF1); transplanted rice with compound fertilizer (TF2); wet bed direct seeded rice with urea (WF1) and wet bed direct-seeded rice with compound fertilizer (WF2). All four were practiced by the two villages. This study highlighted that all four types were more or less equally distributed among respondents in the two villages (Figure 2).

In Figure 2, TF1=TPR with urea; TF2=TPR with compound fertilizer; WF1=WDSR with urea; WF2=WDSR with compound fertilizer Both TF2 and WF2 practices had 27% usage and these results were relatively higher than the other two practices in Kula village. In contract, TF1 (32%) and WF1 (32%) were practiced by most of the farmers in Pyiban village. The lowest amount was WF2, with 7% of Pyiban village's respondents. In this study of the two villages, the most commonly applied practice was TF2 (28% of all respondents), followed by WF1 with 27% (Figure 2).

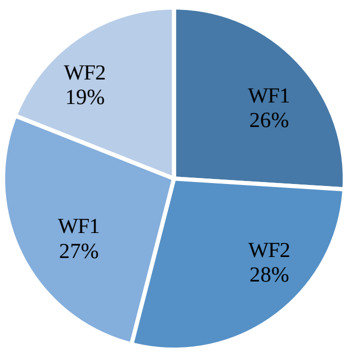

Figure 2. N-fertilizer application and crop establishment in rice cultivation

(7) Profit from rice cultivation

The grain yields and cost of rice cultivation (Supplementary data) data of this analysis were collected from a 2021 field survey, with a basis of 8,500 MMK per bucket of rice (Sin Thuka rice cultivar -IRYn1068-7-1, Manawthukha/IRBB21). The market price was derived from the yearly report of the Department of Agriculture Research, Kyaukse Township as secondary data. Concerning the net income (or profit) of rice production, farmers who practiced WF1 were higher than WF2. It also showed the least profit of any practice in Kula village, since the cost of production for WF2 was the second highest among the rice cultivation practices (Table 6). However, WF2 in Pyiban village showed moderate profit, more or less on par with TF1.The average grain yield of Kula village was also higher than Pyiban village, and Kula village's average profit (282,211 MMK) was less than the profit of the Pyiban village (306,129 MMK).

3.6 Acceptability of local farmers on GHG mitigation techniques

The acceptability of local farmers is shown in Table 7. There are five degrees of acceptability: willing to accept; willing to accept with conditions; neutral; not willing but not strongly rejecting; and not willing to accept. The greatest number of local farmers (drawn from overall respondents) were willing to accept WF1 with conditions (36%). The second highest percentage of acceptability was found to be neutral, with 30% of respondents still not yet decided on their practices for rice cultivation for the coming season.

Table 6. Grain yield and profit by different types of rice cultivation practice

Rice cultivation practice	Kula village (n=45)			Pyiban village (n=28)		
	Cost (Kyats)	Grain yield (basket/ac)	Profit (Kyats)	Cost (Kyats)	Grain yield (basket/ac)	Profit (Kyats)
TF1	489,000	90.36	279,060	473,300	91.48	304,280
TF2	547,800	96.53	272,705	521,300	93.27	271,495
WF1	486,000	93.40	307,900	462,900	95.34	347,490
WF2	522,000	93.08	269,180	498,600	94.10	301,250
Average	511,200	93.00	282,211**	489,025*	94.00	306,129**

*=Significant at 5% level, **=Significant at 1% level

Table 7. Acceptability of local farmers by villages on WF1

Acceptability of local farmers	Kula (n=45)		Pyiban (n=28)		Total (n=73)	
	f	%	f	%	f	%
Willing to accept (5)	3	7	5	18	8	11
Willing to accept with conditions (4)	12	27	14	50	26	36
Neutral (3)	17	38	5	18	22	30
Not willing, but not strongly rejecting (2)	9	20	4	14	13	18
Not willing to accept (1)	4	8	0	0	4	5

3.7 Factors influencing farmers' acceptability of WF1

In this study, age, educational level, experience in rice cultivation, agricultural information sources, profit from rice cultivation and land cultivated for rice were estimated to be the critical influencing factors, according to step-wise statistical analysis (Table 8). The standardized coefficient of all factors was statistically positive, which shows the influences and factors were positively related with farmers' acceptability. Meanwhile, the rice cultivation experience of farmers was 95% significant in determining farmers' acceptability. Here farmers with rice-growing experience were more willing to accept the WF1. Farmers with knowledge of multiple rice cultivation practices were also rarely hesitant to change their current practices. According to the multiple regression analysis, available information sources for agriculture was also significantly correlated with the acceptability of the local farmers, and its coefficient was positive as well. This finding can perhaps be interpreted as farmers who accessed more information sources related to agriculture then displayed greater acceptability of the WF1 practice in the study area. Moreover, available land for rice cultivation was also significant (90%) and positively correlated with farmers' acceptability since the agriculture practice-especially irrigation management and land preparation-cannot promptly be changed by individuals working in fields that are homogenously bonded to each other, and in environments where the farmers need to follow the practices of the majority.

Table 8. Influencing factors on farmers' acceptability (min=1, max=5)

Variables	Standard error	Coefficient (Standardized)	T-Value	Probability value
Age	0.131	0.163	0.778	0.446
Education level	0.026	0.170	0.852	0.405
Rice-growing experience	0.023	0.400	2.157	0.046**
Information sources	0.025	0.351	2.454	0.024**
Profit	0.130	0.142	0.178	0.482
Cultivated land	0.015	0.449	1.947	0.066*

*=Significant at 10% level, **=Significant at 5% level,

4. DISCUSSION

4.1 Emissions patterns of CH_4 and N_2O

Although measuring GHG emissions from rice cultivation has been systemically researched in a number of regional countries in Southeast Asia, there is little reliable information available in Myanmar. This is especially true of field experiments regarding CH_4 and N_2O emissions from existing farms, where farmers have adopted different fertilizer applications under different rice establishment methods (Win et al., 2021).

Thus, insights were gained from this study regarding the consequences of local farmers adopting agricultural practices related to CH_4 and N_2O emissions from rice cultivation. In this study, the trade-off effect between CH_4 and N_2O occurred, which in turn agreed with other previous research findings (Janz et al., 2016; Kong et al., 2021; Song et al., 2021b; Tin et al., 2022).

Alongside rice growth throughout the season, CH_4 fluxes in this study were found to increase continuously until 90 DAS; Day after seeding (EPI stage) and after that descend rapidly. This was in line with similar results in previous studies (Gaihre et al., 2013).

In all likelihood, this is due to crop residue accumulation which favors CH_4 emission (Janz et al., 2019). Moreover, the period between 83 DAS and 90 DAS (EPI stage) had the highest water depth (Table 3). The effect of continuous flooded rice fields on CH_4 emission has been well documented, and it has been found to assist CH_4 production by creating anaerobic situations (Gupta et al., 2016; Song et al., 2021a; Vo et al., 2018; Zhou et al., 2018). Anaerobic situations in soil aid methanogenesis bacteria, which are the major source of CH_4 concentrations in the atmosphere (Haque and Biswas, 2021; Islam et al., 2020; Kong et al., 2021).

On the other hand, trends in N_2O emission were not found to be similar with CH_4 trends. Namely, fluxes were higher at the 30 DAS mark, and were regularly reduced to the minimum rate at 69 DAS, or the tiller stage. Furthermore, the curve of N_2O emissions increased again till the EPI stage, this was the highest stage of N_2O, while CH_4 fluxes decreased again from the highest point.

According to N_2O emission data, the rate of N_2O positively responded to both low water depth situations and N fertilizer applications. Drier situations and N fertilizer are perfect boosters to generate the nitrification and denitrification process in the soil, and that knowledge clearly explains why N_2O emission become higher during low water depths and when applying N fertilizer (Granli, 1994; Janz et al., 2016; Kong et al., 2021).

4.2 Influencing factors on farmers' acceptability

The proper combination of rice crop establishment methods and nitrogen fertilizer application practices produces less greenhouse gas emissions accompanied by an acceptable rice yield. This appeared through the field experiments, as WF1 based on its grain yield GWP, GHGI and AAC results, and is currently also being practiced by some local farmers. Moreover, the WF1 group had the highest rate of net income according to the social survey. As per local farmers' perceptions, the highest rate (36% of respondents; from two villages, Kula and Pyiban) were willing to accept the pairing of WDSR and WF1 for their coming season of rice cultivation. In fact, some farmers well realized the value of WF1 and were willing to change to it. But many remained reluctant to promptly alter their strategies, due to obstacles on the ground level.

According to multiple regression analysis, the factors influencing farmers' acceptability of WF1 were: the rice cultivation experiences of farmers; the number of available information sources for agriculture; and land available for rice cultivation. The results of the analysis showed that even when farmer experiences varied, especially in rice cultivation, they were not hesitant to change their current practices, since they were confident they could handle varieties of cultivation methods, given enough knowledge and information. This also agreed with other previous research, as past rice cultivation experiences have shown to significantly influence acceptability regarding low-carbon agricultural practice (Hou and Hou, 2019). Besides, a case study in Thailand revealed that agricultural experience is the most significant determinant in farmers' adaptive capacity (Arunrat et al., 2017). Also, Hou and Ying (2014) observed that farmers' decisions regarding plantation methods largely depend on personal observation and experience in farm management, especially when they had no way to obtain comprehensive market information by themselves (Wang and Zhang, 2013).

This fact also linked with the second determining factor. The more farmers accessed information related to agriculture, the greater their acceptability of WF1 practices in the study area. Numbers in previous findings support this result, with Arunrat et al. (2017) defining institutional accessibility as attending training about agricultural practices, climate change, and adaptation strategies. Most were in turn found to affect farmers' adaption of practices positively.

The article of Ng et al. (2011) indicated that farmers who had sound communication and networking with other farmers showed a greater desire to practice new agricultural methods. Moreover, the availability of land for rice cultivation was positively correlated with farmers' acceptability-though cultivation systems were not easy to change individually when agriculture lands were adjacent each other. This was due to several factors, namely irrigation management and land preparation could not promptly be changed by individuals, when the fields were homogenously bonded to each other. Farmers still needed to follow the practices of the given majority. However, this result disagreed with the findings of J. Hou and Hou (2019) which mentioned that small production scale was more strongly correlated with farmers' acceptability and adoption decisions regarding environmental friendly agriculture practices than it was for farmers who had large production scale.

5. CONCLUSION

Today, several pieces of research have highlighted that changing the cultivation practice from TPR to WDSR has become a way to make sense of, and even resolve the high cost of farming inputs-namely water and labor scarcity and these changes have been adapted by farmers themselves based on their experiences and indigenous knowledge.

Fortunately, the findings of this study indicated that the pair of practices (WDSR+F1) has great potential in mitigating GHG emissions from the agricultural sector, since lower GWP and GHGI lead to acceptable productivity. Further, insights upon the consequences of local farmers adopted agricultural practices and its effects on CH_4 and N_2O emissions from rice cultivation were a large gain from this study. Here, the trade-off effect between CH_4 and N_2O occurred, and this result agreed with other research findings. Furthermore, the main results showed that the sociodemographic information of local farmers-such as the rice cultivation experience, numbers of available information sources, and the overall size of rice-cultivated land-were significantly and positively correlated with their intention to accept the WF1 practice as a GHG mitigation strategy in rice cultivation.

Much of the information from this study is useful scientific knowledge, which may be used for future research and further studies, especially in figuring out GHG mitigation strategies under the sustainable development umbrella. However, the findings of this study may not be used to generalize the features of all small farmers in the central dry zone of Myanmar, since it was a pioneer field experience in the region, with several limitations-including limited equipment and facilities, and restrictions on budget and time. Therefore, there may be wiggle room to fulfill cost efficient GHG mitigation strategies for Myanmar.

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