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Crop Establishment, Residue Retention and Nutrient Management Influence the Phenology-mediated Greenhouse Gases Emission in an Intensive Rice-wheat System

Suborna Roy Choudhury [a], Chandan Kumar Panda [b], Devashish Kumar [a], Pravesh Kumar [a] and Anupam Das [c*]

[a] Department of Agronomy, Bihar Agricultural University, Bhagalpur, Bihar -813210, India.
[b] Department of Extension Education, Bihar Agricultural University, Bhagalpur, Bihar -813210, India.
[c] Department of Soil Science and Agricultural Chemistry, Bihar Agricultural University, Bhagalpur, Bihar - 813210, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The impact of management practices (i.e. crop establishment, tillage, residue addition etc.) on the global warming potential (GWP) and greenhouse gas intensity (GHGI) in rice-wheat cropping system accounting the economic viability is sparsely documented. A field experiment was

**Corresponding author: E-mail: anupam0281@bausabour.ac.in;*

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established in 2020 to gain insight crop phonology mediated greenhouse gas emission into GWP, GHGI and economic viability on crop seasonal scale over three cycles (2020, 2021 and 2022) of rice-wheat rotations under subtropical climatic condition. Treatments were three planting techniques viz., System of rice intensification (SRI) followed by conventional wheat without residues (SRI-CW), Puddle Transplanted rice (TPR) followed by CW with 30% rice residue incorporation (TPR-CW_{Ri}) and zero-till direct sowing of rice (ZT-DSR) followed by ZT wheat with 30% rice residue retention (ZTDSR-ZTW_{Rr}) and four different nutrient management practices viz., 100% NPK (as per recommended dose) through mineral fertiliser (100% NPK_i), 75% NPK through mineral fertiliser with 25% N trough organics (75% NPK_i + 25%$N_{Org.}$), 50% NPK through mineral fertiliser with 50% N trough organics (50% NPK_i + 50% $N_{Org.}$) was followed in both rice and wheat crop and 100% NPK through mineral fertiliser (100% NPK_i) along with mung bean (*Vigna radiata*) green manure in rice and 100% NPK through mineral fertiliser in wheat (100% NPK_i + GM). All treatments were established in a split-plot design and repeated three times; where three planting techniques were arranged in main plots and four different nutrient management practices were arranged in sub-plots. The highest system productivity was obtained under ZTDSR-ZTW_{Rr} treatment. Moreover, this system reduced the CH_4 and N_2O emission by 62.7 and 48% respectively over TPR-CW_{Ri}, hence, the Global Warming Potential (GWP), as well as gaseous intensity (GHGI), were reduced by 2.0-2.18 and 2.13-2.20 times, respectively than the traditional technique of cultivation. Green manure behaves differently by increasing the system productivity by 4.27% was and reducing the GHGI 4.56% over 100% NPK_i. Thus, ZTDSR-ZTW_{Rr} along with 100% NPK_i and green manuring in rice could be an economically viable opportunity for maintaining future yield standard of the system with lower emission scenario.

Keywords: Direct seeded rice; zero-tillage; rice; wheat; greenhouse gas intensity.

1. INTRODUCTION

Global environmental changes have exposed our food supply chain to an intricate situation [1] especially for South Asian countries, where the rice-wheat system prevailed centuries together. Although, the Green revolution undoubtedly promotes our food grain production but blanket fertilizers' application especially nitrogenous fertilizer, which caused an unprecedented decline in rice and wheat production ~1% at present days [2] and most perilously affected the environment with higher greenhouse gases (GHGs) concentration. Irrigated transplanted flooded rice system predominates over the globe that contributes 75% of rice consumed [3], is the most preferable cultivation system towards farmers, which is water expensive [4,5] and GHGs productive. Economic utilization of water and labour is boon for today's cultivation but in near future, these two will be the scarcest resources [6].

Another important aspect is the anthropogenic GHGs emission that alley the major contributor to global climate change [7,8]. Nitrous oxide (N_2O) emission in the agricultural system is mainly of soil origin that accounts for ~20% of global N_2O emission [9] which is about 60% of total anthropogenic N_2O emissions. Soil and root respiration accounted for 20% of the total emission through CO_2 and 12% through CH_4 emission [10]. Although, CO_2 is considered as one of the GHGs, but it used to counter balance by CO_2 fixation in the terrestrial ecosystem as net primary productivity and thus its effective contribution in global warming potential (GWP) is less than 1% [11]. CH_4 and N_2O having global warming potential 25 and 298, respectively than that of CO_2 over century's time span [10]. Thus, they are primarily responsible for global warming. Global warming mostly influences the carbon cycle, and thus the structures and functions of the ecosystem are changing [12] that are designated as climate change. Soil and environmental factors are mostly governing the GHGs emission and those factors are mostly influenced by the management practices in agriculture.

But, drastic change in cultivation technique raises an issue of adaptability. Little Modification in crop establishment method and tillage becomes effective to address the issue. System of rice intensification (SRI), direct-seeded rice (DSR) along with succeeding zero-till wheat crop is some common modifications in management practices under rice-wheat cropping system. The effect of these planting methods and tillage on crop performance, water productivity was evaluated by many researchers [13,14]. Environmental impact of these management practices especially GHGs emission was scanty. Another important aspect of crop production is nutrient management especially nitrogen. Application of nitrogenous fertilizers and organic manures augment the emissions of N_2O, CO_2 and CH_4 from soils [15-17]. But the impact of the conjoint application of mineral fertilizer and organics on GHGs emission together with crop planting techniques at different crop phenological stage in rice-wheat cropping system is very sparse. Rice straw incorporation in wheat crop now becomes a common farmer's practice but, its impact on CH_4 and N_2O dynamics is insufficient. Interaction among establishment method/tillage, nutrient and residue management on greenhouse gas emission and greenhouse gas intensity is not yet well-understood. Keeping these in view, this study was conducted to examine the effect of planting technique and nutrient management on phenology mediated emissions at different crop growth stages and its relation to agronomic productivity, profitability and greenhouse gas intensity.

2. MATERIALS AND METHODS

2.1 Site Description

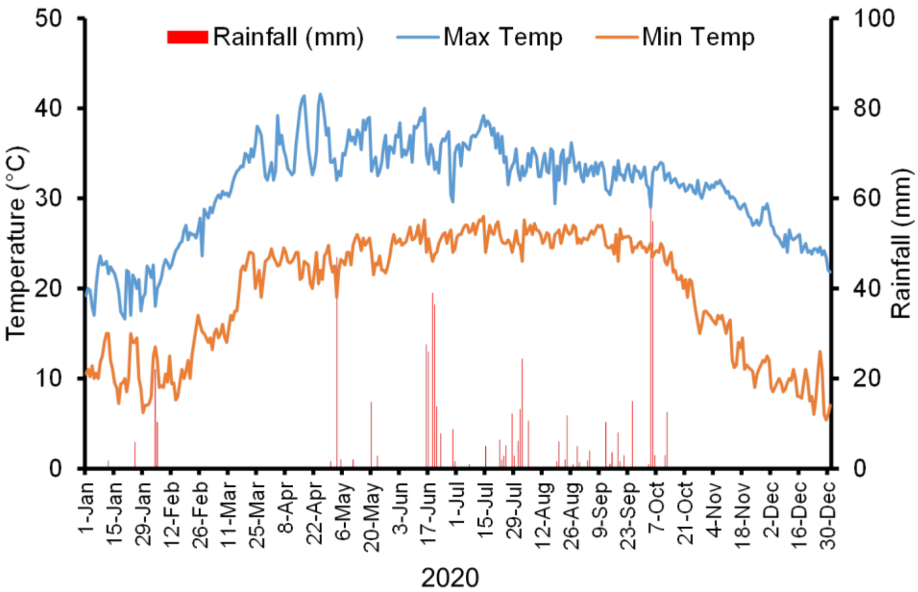
A field experiment was conducted for three consecutive years during 2020-2022 at the Research field of Bihar Agricultural University (BAU) (25°23'N, 87°07'E, 37.19 m MSL), Sabour, Bihar-India. Before the initiation of the experiment, a uniformity trial was done with wheat crop during rabi 2019. The initial characteristics of soil in the experimental site were loamy textured (Sand-50%, Silt-28% and Clay-22%), having $pH_{1:2.5}$ 7.3, electrical conductivity ($EC_{1:2}$) 0.25 dS m^{-1}, organic carbon 4.9 g kg^{-1}, available nitrogen 168.5 kg N ha^{-1}, available phosphorus 35.2 kg P_2O_5 ha^{-1} and available potassium 135.4 kg K_2O ha^{-1}.

2.2 Agro-climatic Condition

The experimental site was situated under the sub-tropical climate with desiccating summer and cool winter. The mean maximum temperature was 35-39^{0}C and minimum temperature 5-10^{0}C. The annual rainfall was about 1250 mm but 80% of the rainfall precipitated between mid-June and mid-October. Daily mean values of the weather parameters during the experimentation (Fig. 1) were obtained from university's meteorological observatory.

2.3 Experimental Details and Crop Management

The field experiment was conducted in split-plot design keeping planting technique as the main plot treatment and nutrient management as sub-plot treatment with three replications. The planting techniques were: the system of rice intensification (SRI) followed by conventional wheat (SRI-CW), Puddle Transplanted rice (TPR) followed by conventional wheat with 30% rice residue incorporation (TPR-CW_{Ri}) and zero-till direct-seeded rice (ZT-DSR) followed by zero-till wheat with 30% rice residue retention (ZTDSR-ZTW_{Rr}). Four different nutrient management practices were followed in the



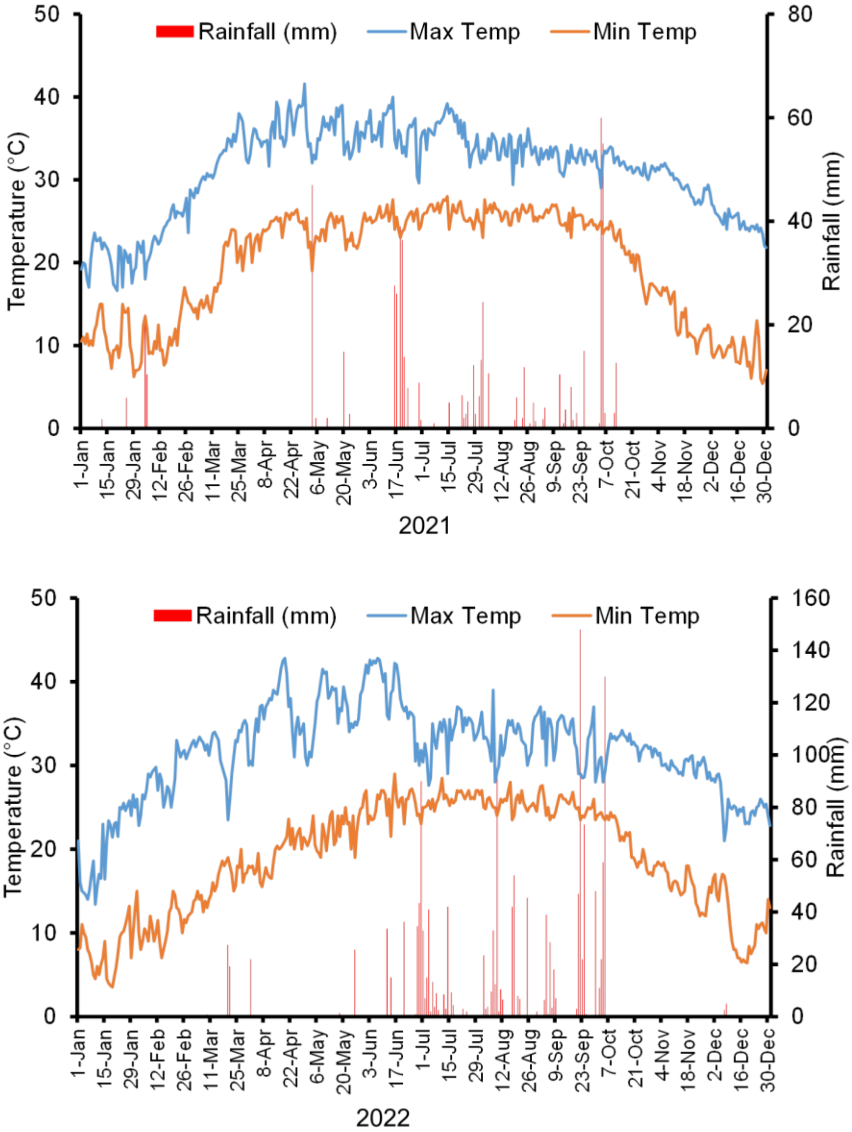


Fig. 1. Meteorological data of the experimental Years 2020, 2021, 2022

study. These were 100% NPK (as per recommended dose) through mineral fertiliser (100% NPK_i), 75% NPK through mineral fertiliser with 25% N trough organics (75% NPK_i + 25%$N_{Org.}$), 50% NPK through mineral fertiliser with 50% N trough organics (50% NPK_i + 50% $N_{Org.}$) was followed in both rice and wheat crop according to their recommended dose of fertilizer i.e. 100 kg N + 40 kg P_2O_5 + 20 kg K_2O ha^{-1} in rice and 120 kg N + 80 kg P_2O_5 + 60 kg K_2O ha^{-1} in wheat. In forth treatment, green gram (*Vigna radiata*) was used as a green manure crop in rice along with the 100% NPK, whereas in wheat simply 100% NPK was applied as mineral fertilizer (100% NPK_i +GM). Vermicompost was used as an organic supplement (N content 1.20%). The amount of rice residue applied in the subsequent wheat crop was 30% of the total rice straw yield either applied on to the field for residue incorporation (Ri) or kept as such on the soil surface after rice harvest for residue retention (Rr). Best management practices were adopted during experimentation as described in Table 1.

2.4 Crop Harvest and Yield

Mature crops from entire plots were harvested and threshed separately by manually. Yield was converted to t ha^{-1}. The grain yield of rice and wheat is reported at14% and 12%, grain moisture, respectively. The productivity of different treatments was compared using system

Table 1. Crop management during the experiment

Crop	Variety	Spacing	Seed rate (kg ha^{-1})	Fertiliser management	
				Type	Time of application
Rice	Rajendra Suwashini	SRI- 25 x 25 cm TPR-20 x 15 cm DSR-Manual line sowing	SRI- 5 kg ha^{-1} TPR- 50 kg ha^{-1} DSR- 30 kg ha^{-1}	Urea Diammonium phosphate (DAP) Muriate of potash (MoP)	Full dose phosphorus and potassium were applied as DAP and MoP respectively as basal and along with 1/3 of the N through DAP and urea and remaining N was top-dressed through urea in two equal splits at maximum tillering and panicle emergence)
Wheat	HD-2967	Row to Row- 22 cm	100 kg ha^{-1}	Urea Diammonium phosphate (DAP) Muriate of potash (MoP)	Full dose phosphorus and potassium were applied as DAP and MoP respectively as basal and along with 1/3 of the N through DAP and urea and remaining N was top-dressed through urea in two equal splits at maximum tillering and ear head emergence)

productivity as rice equivalent yield (t ha^{-1}) and was calculated using the following equation:

$$\text{Rice equivalent yield } (\text{t ha}^{-1}) = \frac{\text{Wheat yield } (\text{t ha}^{-1}) \text{ X Minimum support price of wheat } (\text{INR t}^{-1})}{\text{The minimum support price of Rice } (\text{INR t}^{-1})} \quad \text{(Eq. 1)}$$

2.5 Greenhouse gases (GHGs) Collection and Analysis

The gas samples i.e. CH_4, N_2O and CO_2 were collected using closed Pyrex glass gas chamber (volume- 0.32 m^3) using 50 mL disposable syringe with leur lock at 0, 30 and 120 minutes interval from each plot. The Gas samples were analyzed for CH_4, CO_2 and N_2O concentrations through gas chromatography (Model: Trace GC 1110, Make: Thermofisher) built with electron capture detector (ECD) and flame ionization detector (FID). Methanizer was used for the reduction of CO_2 to CH_4 using a nickel catalyst. Nitrogen was used as carrier gas at a flow rate of 35 mL min^{-1}. The column and detector were maintained at 60°C and 300°C, respectively. The gaseous flux was measured at different crop growth stages viz., maximum tillering, panicle initiation (rice) or ear head emergence (wheat) and physiological maturity stage of the crops. The fluxes were calculated using the following [18]:

$$F = \rho H \left(\frac{dC}{dt}\right) 273\,(273 + T)^{-1} \quad \text{(Eq. 2)}$$

where 'F' is the emission flux (mg m^{-2} hr^{-1}), 'ρ' is the density of gas at STP, 'H' is the height of chamber above the soil surface (m), 'C' is the gas concentration (mg m^{-3}), 't' is the time intervals of each time (hr), and 'T' is the air temperature in absolute scale inside the chamber during sampling.

2.6 Global Warming Potential (GWP) and GHGs Intensity (GHGI)

GWP was calculated by the following formula (Eq. 3) [19] after converting individual emission to their respective CO_2 equivalents.

$$\text{GWP } (CO_2\text{equivalent Kg ha}^{-1}) = (CO_2) + (CH_4 \text{ x } 25) + (N_2O \text{ x } 298) \quad \text{(Eq. 3)}$$

The equivalent GWP coefficients for CO_2, CH_4 and N_2O were 1, 25 and 298, respectively considering their emission potential in the 100-year time frame as described in IPCC, 2007.GHGI was estimated based on grain produced [19,20]:

$$\text{GHGI } \left(\text{Kg } CO_{2\text{ eq.}}\text{Kg}^{-1} \text{ grain yield}\right) = \frac{\text{GWP}}{\text{Grain yield}} \quad \text{(Eq. 4)}$$

2.7 Statistical Analysis

Data were analyzed through split-plot design as followed during the field experiment. The treatment influence was calculated using analysis of variance (ANOVA) at 5% probability levels ($p \leq 0.05$) [21]. Duncan's multiple range test (DMRT) was carried out using SAS 9.2 (SAS Institute, Cary, NC) [22] where ANOVA was significant.

3. RESULTS

3.1 Methane Emission

Methane (CH_4) emission was mostly influenced by the crop growing season and planting technique as compared to nutrient management. But the emission behaviour at different crop phenology was mostly governed by their planting techniques [p (PT*PS)=<0.0001] rather than nutrient management [p (NM*PS)= 0.325] (Table 2; Figs. 2 and 3). Although the methane emission was highest at the maximum tillering stage and gradually declined as the maturity progress, but the extent of the decline was the highest in ZTDSR and least in TPR. Amusingly, the magnitude of methane emission was highest in TPR (26.3 mg m^{-2} hr^{-1}) followed by SRI (20.7 mg$m^{-2}hr^{-1}$) and lowest in ZTDSR (9.8 mg$m^{-2}hr^{-1}$). Methane emission was almost negligible in wheat as compared to rice and key contributor of total GWP in rice ecology.

3.2 Carbon Dioxide Emission

Carbon dioxide (CO_2) emission was significantly influenced by planting technique and nutrient management practices. ZTDSR imparted highest CO_2 emission (20.1-24.0 mg m^{-2} hr^{-1}) followed by SRI-CW (13.0-15.8 mg$m^{-2}hr^{-1}$) and TPR-CWRi (11.7-14.3 mg$m^{-2}hr^{-1}$) (Figs. 2 and 3). Phonological emission of CO_2 was similar to the CH_4 emission in both the crop. Nutrient management also significantly influenced CO_2 emission. Application of organics (50% NPK_i + 50% $N_{org.}$) augmented the CO_2 emission by ~31% as compared to 100% NPK_i. There were about 2.5 times more CO_2 emission was recorded in wheat than rice, however; the emission trend was similar for both the crops.

3.3 Nitrous Oxide Emission

Nitrous oxide emission is the key contributor of the total GWP in aerobic ecosystem alike the wheat in our experiments (Figs. 2 and 3). Among the different crop phenology, maximum tillering stage of wheat emitted highest N_2O (0.89 $mgm^{-2}hr^{-1}$) and reduced gradually at ear head emergence (0.68 $mgm^{-2}hr^{-1}$) and at harvesting (0.39 $mgm^{-2}hr^{-1}$) which was about 8-15 times higher than the nitrous oxide emission in rice. Interestingly, ZTDSR-ZTW_{Rr} attributed lowest N_2O emission in both the crops which were 54.5% lower than the TPR-CW. Nitrous oxide emission was aggravated by the extent of mineral nitrogenous fertilizer used. Thus, 100% NPK_i recorded the highest N_2O emission as compared to other nutrient management practices. This ill effect could be compensated either by green manure with 100% NPK_i (~13.4%) application or conjoint application of organic and mineral fertiliser (29-34%). Interaction of planting technique and nutrient management had a profuse influence on N_2O emission. Thus, ZTDSR-ZTW_{Rr} along with 50% NPK_i + 50% $N_{org.}$lower down the N_2O emission by ~73.5% compared to conventional production practice in the rice-wheat system (TPR-CW along with 100% NPK_i) (Fig. 2).

3.4 GWP and GHGI

The emission behaviour of the greenhouse gases (GHGs) was enormously varied with the cropping season as well as the management practices and their cumulative impact could be capture by the GWP. Rice attributed 1.6-2.6 times higher GWP than the wheat crop. This was mainly due to the higher total methane emission in rice. TPR-CW_{Ri} attributed the highest GWP (28262 Kg $CO_{2\ eq}$ ha^{-1}) followed by SRI-CW (26065 Kg $CO_{2\ eq}$ ha^{-1}) and ZTDSR-ZTW_{Rr} (12979 Kg $CO_{2\ eq}$ ha^{-1}) contributed lowest GWP (Table 3, Fig. 3). In addition, the nutrient management practices also had a significant impact on GWP (Table 3). Greenhouse gas intensity (GHGI) signifies the relative impact of GWP as a function of crop yield. The result showed that ZTDSR-ZTWRr system contributed least GHGI among the planting techniques (1.42 Kg $CO_{2\ eq}kg^{-1}$ grain yield) and among the nutrient management practices 100% NPK_i + GM possessed lowest GHGI (2.32 Kg $CO_{2\ eq}$ ha^{-1}).

3.5 Grain Yield and Economics

Rice and wheat grain yield were significantly influenced by their planting technique and nutrient management practices (Table 4). ZTDSR-ZTW_{Rr} attributed the highest system productivity (9.13 t ha^{-1}) followed by TPR-CWRi (9.04 t ha^{-1}) and SRI-CW (8.60 t ha^{-1}). Rice grain yield was excelled in SRI (4.87 t ha^{-1}) and wheat grain yield performed better under ZTW_{Rr} (4.70 t ha^{-1}). Basically, the zero till wheat with residue retention gained advantage when sown after the zero till direct seeded rice. Further, the nutrient management practices exerted a similar influence on grain yield of rice and wheat, although, the inclusion of green manure crop had an excel over in rice grain yield by 4.32% over 100% NPK_i that eventually increased the system productivity by 4.27%. The interaction of planting techniques and nutrient management showed no any significance influence on grain yield of both the crops and system productivity [(p=0.8358 (rice), p= 0.9832 (wheat), p= 0.9012 (system)]. A similar influence was depicted in system profitability (B:C ratio). ZTDSR-ZTW_{Rr} recorded the highest net B:C ratio (1.92) followed by SRI-CW (1.53) and TPR-CW_{Ri} (1.41) (Table 4).

4. DISCUSSION

4.1 Effect of Planting Techniques and Nutrient Management Practices on CH_4 Emission

Rice is the major of atmospheric CH_4 (Tables 2 and 3; Figs. 2 and 3) emitter. Submerged conditions favour CH_4 emission resulted from the carbon mineralization [23]. The higher CH_4 emission was found at maximum tillering stage. Jia et al. [24] articulated a higher CH_4 emission occurs at this stage mostly due to the lower rhizospheric CH_4 oxidation. ZT showed significantly lower methane emissions than CT (Table 3) because, in ZT, there was no disturbance of soil caused less exposure of organic matter as caused by the tillage operation [25]. Organic manure application was further augmented the CH_4 emission by providing labile carbon sources [26-28]. A significant impact of tillage operation was observed during rabi seasons on the emission of methane. We found that the ZT system applied to wheat resulted in significantly higher CH_4 emissions than the conventional tillage (CT) systems. Previous studies [29,30] also confirmed that zero tillage attributed higher SOC and moisture content in the surface layers than CT. Methane emission might be influenced by a higher level of organic carbon content and comparatively anaerobic condition of soil microsites under ZT during the rabi - season [31].

Table 2. Two-way ANOVA for the effects of the crop planting technique (PT), nutrient management (NM) and the crop phenological stage (PS) on the CH_4, CO_2 and N_2O emissions during the two annual rice-wheat rotations of 2013 and 2014

Season	Factor	df	CH_4 (mg m^2 hr^{-1})			CO_2 (mg m^2 hr^{-1})			N_2O (mg m^2 hr^{-1})		
			SS	**F**	**P**	**SS**	**F**	**P**	**SS**	**F**	**P**
Rice	PT	2	50.55	5270.85	<0.0001	56.22	3600.89	<0.0001	0.049	8911.70	<0.0001
	NM	3	2.06	143.36	<0.0001	3.90	166.66	<0.0001	0.004	503.48	<0.0001
	PT*NM	6	0.42	14.59	<0.0001	0.11	2.26	0.0485	0.0001	6.21	<0.0001
	PS	2	2.82	294.31	<0.0001	1.79	114.39	<0.0001	0.003	562.44	<0.0001
	PT*PS	4	1.94	100.93	<0.0001	0.07	2.47	0.0529	0.0005	50.37	<0.0001
	NM*PS	6	0.03	1.19	0.3251	0.40	8.47	<0.0001	0.0001	9.88	<0.0001
	PT*NM*PS	12	0.16	2.75	0.0044	0.25	2.71	0.0050	0.0004	12.90	<0.0001
	Model	41	58.04	295.19	<0.0001	62.76	196.08	<0.0001	0.058	510.10	<0.0001
	Error	66	0.32			0.515			0.0002		
			SS	**F**	**P**	**SS**	**F**	**P**	**SS**	**F**	**P**
Wheat	PT	2	0.62	3290.35	<0.0001	478.97	6595.34	<0.0001	4.24	1300.78	<0.0001
	NM	3	0.07	253.09	<0.0001	60.07	551.45	<0.0001	1.38	283.56	<0.0001
	PT*NM	6	0.005	10.20	<0.0001	0.79	3.65	0.0034	0.03	3.41	0.0054
	PS	2	0.057	304.29	<0.0001	7.32	100.82	<0.0001	4.50	1381.97	<0.0001
	PT*PS	4	0.0009	2.44	0.0555	2.26	15.62	<0.0001	0.15	22.66	<0.0001
	NM*PS	6	0.0014	2.61	0.0248	0.28	1.29	0.2733	0.08	7.84	<0.0001
	PT*NM*PS	12	0.0043	3.87	0.0002	0.37	0.84	0.6082	0.21	11.01	<0.0001
	Model	41	0.758	197.26	<0.0001	550.31	369.64	<0.0001	10.61	158.83	<0.0001
	Error	66	0.006			2.39			0.107		

Table 3. Effect of planting technique and nutrient management on total GHGs emission in the rice-wheat cropping system

Treatments	Total emission (Kg ha^{-1})						GWP (Kg $CO_{2\ eq}$ ha^{-1})		GHGI (Kg $CO_{2\ eq}$kg^{-1} Grain yield)		
	CH_4		CO_2		N_2O						
	Rice	Wheat	Rice	Wheat	Rice	Wheat	Rice	Wheat	Rice	Wheat	System
Crop Planting Technique											
SRI-CW	627.98b	4.94b	442.51b	1193.47b	1.56b	27.32a	16608b	9457a	3.41b	2.71a	3.03b
TPR-CWRi	795.31a	7.56a	394.13c	1900.08a	0.84c	18.95b	20526a	7736b	4.42a	1.88b	3.13a
ZTDSR-ZTWRr	297.36c	2.12c	675.36a	342.72c	2.41a	12.60c	8829c	4150c	2.15c	0.88c	1.42c
Nutrient Management											
100% NPK_i	515.59b	3.93d	340.70c	902.16c	1.86a	24.80a	13784b	8390a	2.98d	1.99a	2.43c
75% NPK_i + 25%N_{Org}	590.89a	5.14b	413.28b	1205.57b	1.48b	17.24c	15627a	6471b	3.52b	1.64b	2.55b
50% NPK_i + 50% N_{Org}	629.09a	5.85a	491.90a	1485.79a	1.37b	16.03c	16629a	6408b	3.90a	1.67b	2.76a
100% NPK_i +GM	557.42b	4.44c	366.91c	988.85c	1.70a	20.66b	14810ab	7258ab	3.07c	1.65b	2.32d
P-Value	**	**	**	**	**	**	**	**	**	**	**

Values within a column, followed by different letters are significantly different at $p < 0.05$ by Duncan's multiple range test

Table 4. Effect of planting technique and nutrient management on grain yield and economics in a rice-wheat cropping system

Treatments	Yield (Mg ha^{-1})		REY (Mg ha^{-1})	B:C ratio
	Rice	Wheat		
Crop Planting Technique				
SRI-CW	4.87a	3.49c	8.60b	1.53b
TPR-CW_{Ri}	4.64b	4.12b	9.04a	1.41c
ZTDSR-ZTW_{Rr}	4.11c	4.70a	9.13a	1.92a
Nutrient Management				
100% NPK_i	4.63b	4.21a	9.13c	1.68b
75% NPK_i + 25%N_{Org}	4.44c	3.95b	8.66b	1.56c
50% NPK_i + 50% N_{Org}	4.26d	3.83b	8.35b	1.48c
100% NPK_i +GM	4.83a	4.39a	9.52a	1.84a
P-Value	**	**	**	**
M*S	0.8358	0.9832	0.9012	0.3135

Values within a column, followed by different letters are significantly different at $p < 0.05$ by Duncan's multiple range test

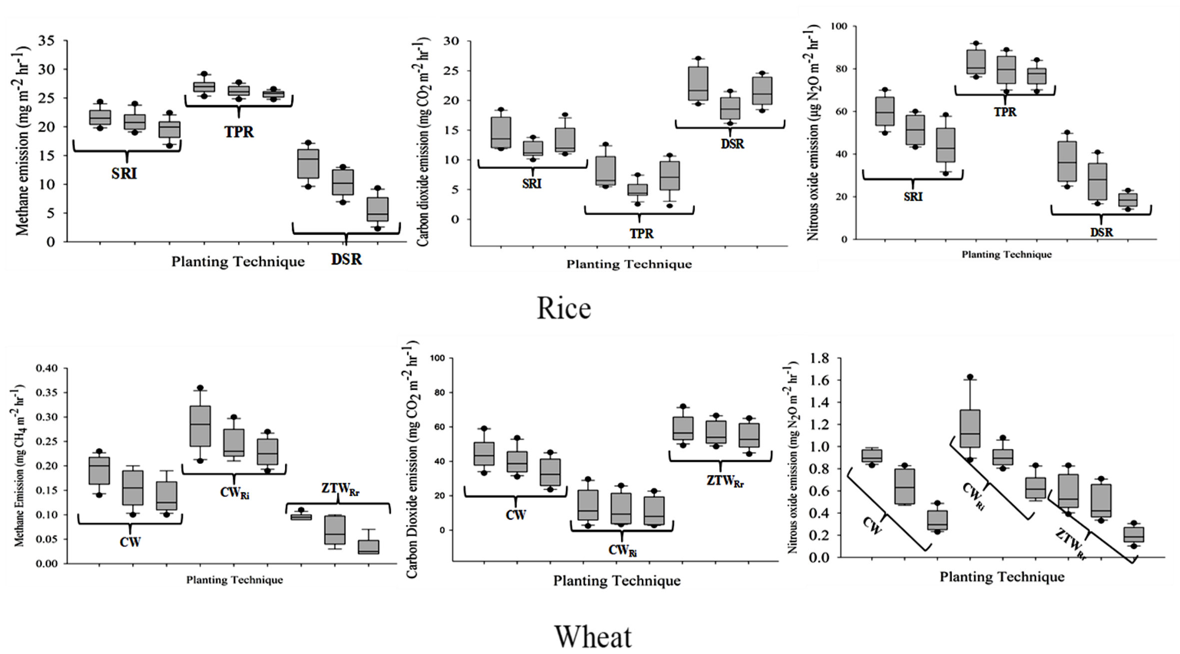


Fig. 2. Seasonal emission of GHGs emission in various Crop Growth Stages of rice and wheat as influenced by planting technique [The boxes in the above figure in each cluster indicate the different crop growth stage (From left maximum tillering, Panicle initiation (rice)/Ear Head emergence (wheat) and maturity stage)]

4.2 Effect of Planting Techniques and Nutrient Management Practices on CO_2 Emission

GHGs emission from agricultural soil is a result of a complex interaction between climate and soil physical, chemical and biological environment. Tillage impinges on biological, chemical and physical soil properties and therefore influences the release of the greenhouse gases [32]. Tillage enhances the surface roughness and void spaces that iterate the CO_2 emission to the atmosphere [33,34]. In our study, we have found less CO_2 emission under ZTDSR as compared to SRI and TPR (Tables 2 and 3; Fig. 2). Plant acquires highest root biomass during its maximum tillering stage, simultaneously, the microbial and root respiration also enhanced; hence, higher CO_2 emission was observed. This could be due to the higher availability of root exudates and organic matter facilitates heterotrophic decomposition [34].

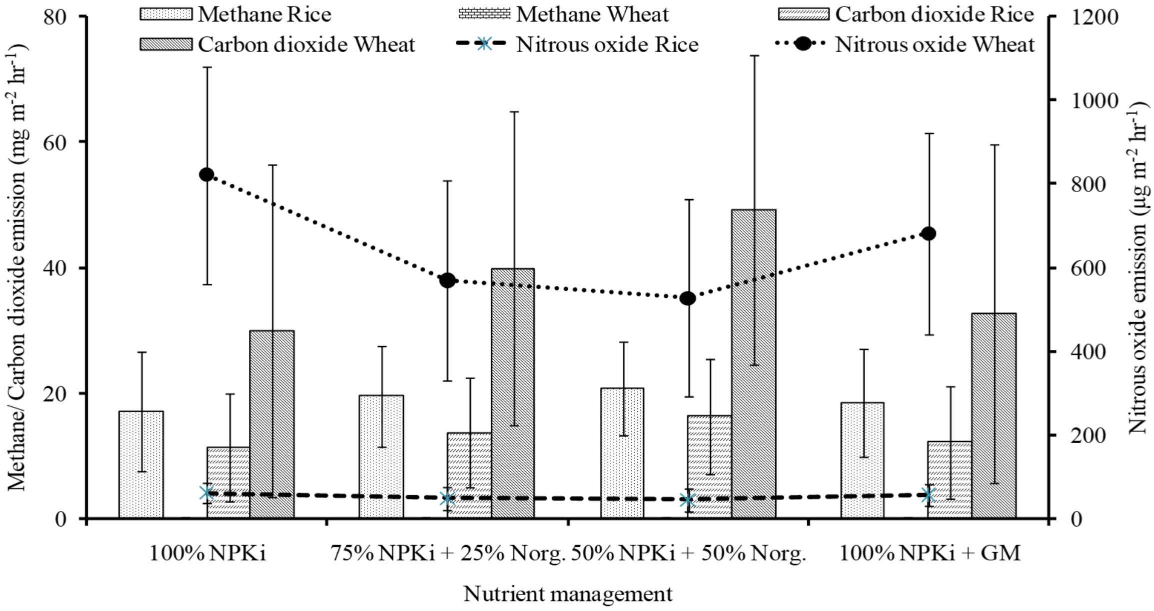


Fig. 3. Seasonal emission of GHGs emission in various Crop Growth Stages of rice and wheat as influenced by nutrient management

4.3 Effect of Planting Techniques and Nutrient Management Practices on N_2O Emission

N_2O produced in soils is mainly by dual microbial processes i.e., nitrification and denitrification [35]. Tillage influences physical, chemical and biological soil properties and therefore influences the emission of the greenhouse gases [32]. But there is large uncertainty regarding the higher N_2O emissions from zero tillage than conventional tillage soils [36,37] or N_2O emissions diminish after the long-term practice of no-tillage [38-40]. In our study, we have found a significant reduction in N_2O emission under ZTDSR-ZTW_{Rr} as compared to conventional practice (Tables 2 and 3). Residue addition in zero tillage had increased carbon: nitrogen ratio associated with this combination caused temporary immobilization of nitrogen which may act as a substrate for further nitrification and denitrification process, be the cause of reduced N_2O emission [41]. Mineral fertilization further augmented the N_2O emission because nitrogen fertilizer application provides the substrate for the processes driving the soil N_2O emissions [42,43], resulted in higher emissions of N_2O to the extent of 73% of the total annual emission [44].

4.4 Global Warming Potential and Greenhouse Gas Intensity

The impact of different management practices on CH_4 and N_2O emissions estimated through GWP for a 100-year horizon. Rice systems have been identified as a substantial source of CH_4 emissions [45]. Water management in rice systems is the prime factor for methane emission [46], in addition to carbon input (i.e. residue addition) [12,25] and fertilizer management [47-49] because methane is the end product of organic matter decomposition under anaerobic condition [50]. Intermittent wetting and drying during the rice-growing season (in SRI) substantially reduced the GWP by emitting a lesser amount of CH_4 as compared to TPR. Sander et al. [51] also found that periodical drying and wetting condition had reduced the GWP during the cropping season by 26% relative to continuous flooded condition. The rice rhizosphere at the maximum tillering stage is subjected to intense reducing conditions among the all phonological stages of rice, prop up the formation of CH_4 [46,52], emission hike could also be due to anaerobic decomposition of root exudates and decomposed rice roots biomass [23]. Declined CH_4 emission at crop maturity may result in due to less C input into the soil from below-ground crop biomass, assimilates for methane production [53]. Methane and nitrous oxide emission are the key regulating factor for GWP and they bear a trade-off relationship. GWP in wheat was 2.28 times less under the ZT system as compared to the conventional one. This may be due to higher mineralization of nitrogen caused higher substrate availability for denitrification. This observation was consistent with the other studies carried out by [54 and 33].

Conventional tillage attributed higher gas diffusion rates than ZT and made an impossible barrier for further reduction of N_2O to N_2 by the denitrifying organisms [55].

GHGI appraises the agronomic efficiency of management practices that begins to address both climate change and future food supply concerns [56]. ZTDSR-ZTW_{Rr} reduced the GHGI by 2.13-2.20 times than SRI-CW and TPR-CW_{Ri} (Table 3). Our experiment attains lower yield in ZTDSR, however, long term study showed that the ZTDSR excel over the TPR [57]. To our knowledge, these are the first instances where yield, profitability, GWP and GHGI are taken into account together for assessing the best management practices in rice-wheat systems. Consistent with our hypothesis, these results suggested the modification in planting techniques and nutrient management strategies bring into maximum produce at the same time reduce GWP and maximize profitability in the intensive rice-wheat production system [56,58].

5. CONCLUSIONS

We analyzed the results from our field studies and found that the planting techniques and nutrient management practices had an immense influence on GHGs emissions, productivity and profitability in the rice-wheat system. The cost incurred in all of these options must be taken into consideration while assessing the economic viability of any system. SRI had increased the grain yield by 18.5% over ZTDSR, whereas ZTW_{Rr} attributed 34.7% higher grain yield over CW. However, the highest system productivity (REY) was obtained under ZTDSR-ZTW_{Rr} system. This system also curtailed down CH_4 and N_2O emission by 62.7 and 48% respectively over TPR-CW_{Ri}, consequently, the GHGI and GWP were reduced by 2.13-2.20 and 2.0-2.18 times, respectively. Green manure behaves differently than other nutrient management practices. It did not influence the GWP but, the significant reduced the GHGI by increasing the system productivity by 4.27% was and reducing the GHGI 4.56% over 100% NPK_i. Thus, ZTDSR-ZTW_{Rr} along with 100% NPK_i and green manuring in rice could be an economically feasible option to retard greenhouse gas emission and uphold future food supply. However, the trade-off relationship between CH_4 and N_2O must be taken under consideration while adopting any mitigation strategies to reduce GWP in rice-wheat systems.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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