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Agronomic Management Strategies for Yield-Scaled Global Warming Potential under Rice-Wheat Cropping System

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Authors' contributions

This work was carried out in collaboration among all authors. Author SRC conceptualized the work, analysis of Greenhouse gases and prepared the final draft. Author AD performed the statistical analysis and manuscript writing and authors SKG, SEEMA, RPS, SKP conducted field experiment and helped in literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Greenhouse gas emissions have an indirect impact on crop production and are primary sources of the global warming. A field experiment was carried out to examine the effect of management practice (i.e. culmination of tillage and nutrient management) on GHGs emission and its subsequent effect on agronomic productivity and subsequent impact on global warming. There were three different crop establishment methods as main plot treatments: M_1 (Rice: SRI, Wheat: Conventional tillage), M_2 (Rice: Transplanted Puddle rice, Wheat: Conventional tillage + 30% residue incorporation), M_3 (Rice: DSR, Wheat: Zero tillage + 30% residue retention) and four nutrient management as sub plot treatments viz. S_1(100% of Recommended dose of fertilizer (RDF) through inorganic sources), S_2 (75% of RDF through inorganic sources + 25% N of RDF through organic sources), S_3 (50% of RDF through inorganic sources + 50% N of RDF through organic sources), S_4 (S_1 + mung bean as green-manure). After conducting three year of experiment (2013-2016), it has been found that the DSR emitted lower CH_4 (1.39 mg m^{-2} hr^{-1}), CO_2 (0.57 mg m^{-2} hr^{-1}) and N_2O (0.36 mg m^{-2} hr^{-1}) at the maximum tillering stage of rice. The same trend was followed under zero tillage with30% residue retention in wheat with lower emission range of all three gases i.e. 0.95, 1.29 and

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0.58 mg m^{-2} hr^{-1} respectively. Lowest emission of CH_4 and CO_2 with the values of 1.87 and 1.24 mg m^{-2} hr^{-1} respectively from rice and 1.57 and 3.23 mg m^{-2} hr^{-1} from wheat was observed under 100% RDF through inorganic fertilization, whereas, N_2O emission was just reverse to emission pattern of CH_4 and CO_2. Crop establishment through minimum soil disturbance with residue retention under rice- wheat cropping sequence along with 100% RDF through mineral fertiliser along with green manure could be one of the stable agronomic strategies under lower GHGs emission scenarios.

Keywords: Greenhouse gases; Global warming; Climate change; DSR; Zero tillage.

1. INTRODUCTION

Long-term changes in average temperatures, precipitation, and climate variability threaten agricultural production, food security, and the livelihoods of farming communities globally [1]. Due to greenhouse effect the global mean annual temperature was increased by 0.40-0.76°C at the end of 20th century over end of 19th century and also projected a rise of 1.1 to 6.4 °C at the end of 21st century [2]. India is the fourth largest GHG emitter in the world where agriculture is responsible for 18% of total national emissions [1].The net GHGs emission were 1727.7million tons of CO_{2eq} from India in 2007 [3]. Anthropogenic GHGs emission, including rice residue burning has become major contributors to global climate change [4,5] which have made food security complicated, fragile and vulnerable in South Asia [6] where, rice-wheat rotation is one of the largest agricultural production systems. Green Revolution technologies achieved a hike in growth rates of food grain production through indiscriminate use of fertilisers' especially nitrogenous fertilisers, which not only caused a declined in rice and wheat yield by 1% in recent year [7] and but also created serious environmental problem i.e. burning of crop residue instead adopted the concept of no-till farming which enhanced greenhouse gas concentration especially CO_2. Agricultural soil is the major emitter of nitrous oxide (N_2O) contributing 20% of the total global N_2O emission [8] i.e. 60% of anthropogenic N_2O emissions followed by CO_2 paying 20% to the total emission through soil and root respiration and methane emitting 12% of total CH_4emission [2]. Although carbon dioxide (CO_2) is considered as most important GHG but CO_2 fluxes are counter balanced by atmospheric CO_2 fixation in crop plants as net primary productivity and thus contribute less than 1% to the global warming potential (GWP) of agriculture [9]. Methane (CH_4) and nitrous oxide (N_2O) is primarily responsible for global worming because their global warming potential (GWP) are 25 and 298 times greater respectively, than that of CO_2 over a time span of 100 years [2].Global warming may distorted global carbon cycle, thereby structures and functions of ecosystem [10]. Therefore, GHGs emission from agricultural soil depends on soil and environmental factors that includes precipitation amount and timing, soil texture, soil organic carbon and pH, soil water regime, which get influenced by the management practices like tillage management, residue management, water management, fertilizer management etc. [11,12,13,14,15].The anoxic soil environment (i.e. flood irrigated rice production) is one of the main sources of CH_4 emission [11], whereas aerobic crops intensify N_2O production [16]. This trade off relationship between CH_4 and N_2O need to be considered when developing GHGs mitigation strategies.

Tillage systems with residue retention/ residue incorporation have significant influence on CH_4 and N_2O emission. Several field studies proved that zero-tillage (ZT)/ no-tillage (NT) results in lower CH_4 emission than conventional tillage (CT) [17,18] through preserving a CH_4oxidation potential that would get disturbed by tillage [19]. Impact of tillage on N_2O emission is quite uncertain. Several studies have revealed that N_2O emissions from ZT can be less than [20,21], equal to [22,23] or higher than [24,25,26] conventional tillage systems. But, Six et al. [27] concluded that the higher soil N_2O emissions under NT will be decreased with time.

It has been also well documented that applications of fertilizers and organic manures increase the emissions of N_2O, CO_2 and CH_4 from soils [28,29]. But impact of combined application of fertiliser and organic manure on GHGs emission together with tillage management with residue retention/ residue incorporation during the wheat-growing season subsequent to rice-growing season in rice-wheat cropping system is scanty. Keeping these in view, the objectives of our study are (1) to examine the effect of management practice (i.e. culmination of tillage and nutrient management) on GHGs emission and (2) to evaluate the effect of GHGs on agronomic productivity and subsequent impact on global warming.

2. MATERIALS AND METHODS

2.1 Site Description

A field experiment was conducted during 2013-16 at the Research Farm of Bihar Agricultural University (BAU), Sabour, Bihar. Before 2013, the field was under Rice-Wheat cropping system with recommended dose of mineral fertiliser. A uniformity trial on wheat was undertaken during Rabi 2012–2013 to ensure uniform soil fertility in the entire field. The research farm is under subtropical climatic condition with hot desiccating summer, cold winter and moderate rainfall. The average maximum temperature is 35-39°C whereas, minimum temperature 5-10°C. The mean annual rainfall is around 1250 mm and precipitated during mid June to mid October. The meteorological parameters were recorded at Meteorological Observatory of BAU. Monthly mean values of meteorological parameters during crop growth period from 2013–2014 to 2015-16 were presented in Fig. 1.

The soil (0–15 cm layer), taken after the uniformity trial, of the experimental site was silty clay loam in texture, with pH 7.3, Walkley-Black C (oxidizable SOC) 4.9 g kg^{-1}, EC 0.25 dS m^{-1}, $KMnO_4$oxidizable N 168.5 kg ha^{-1}, 0.5 M $NaHCO_3$extractable P 35.2 kg P_2O_5ha^{-1} and 1 N NH_4OAc extractable K 135.4 kg K_2Oha^{-1}.

2.2 Experimental Details

The field experiment was conducted with three treatment combinations [conventional tillage (M_1); conventional tillage with (wheat)/without (rice) residue incorporation (M_2) and zero tillage with (wheat)/without (rice) residue retention (M_3) as main plot treatment and four treatment combinations100% Recommended dose of fertilizer (RDF) through mineral fertiliser (S_1), 25% N of RDF substituted through organic sources +75% RDF through mineral fertiliser(S_2), 50% N of RDF substituted through organic sources + 50% RDF through mineral fertiliser (S_3) and 100% RDF as mineral fertiliser + Mung bean (*Vigna radiata*) as green-manure crop(S_4) arranged in split plot design with three replication. The treatment details are given in Table 1. Individual plot size was 8m x 4m. It was observed that 30% rice residue (straw yield) was applied to wheat crop only. Residues of the rice crop were retained on the soil surface at harvest under all residue retention plots.

2.3 Crop Management

Rice variety 'Rajendra Suwashini' was sown in mid of June and transplanted in mid of July using seed rate 50kg ha^{-1}, although, directed seeding was done in mid of June with the seed rate of 30 kg ha^{-1}. Rice was planted in three different methods describe in Table 1. Rice under SRI system was planted in 25x25 cm spacing, whereas 20x15 cm spacing was given in

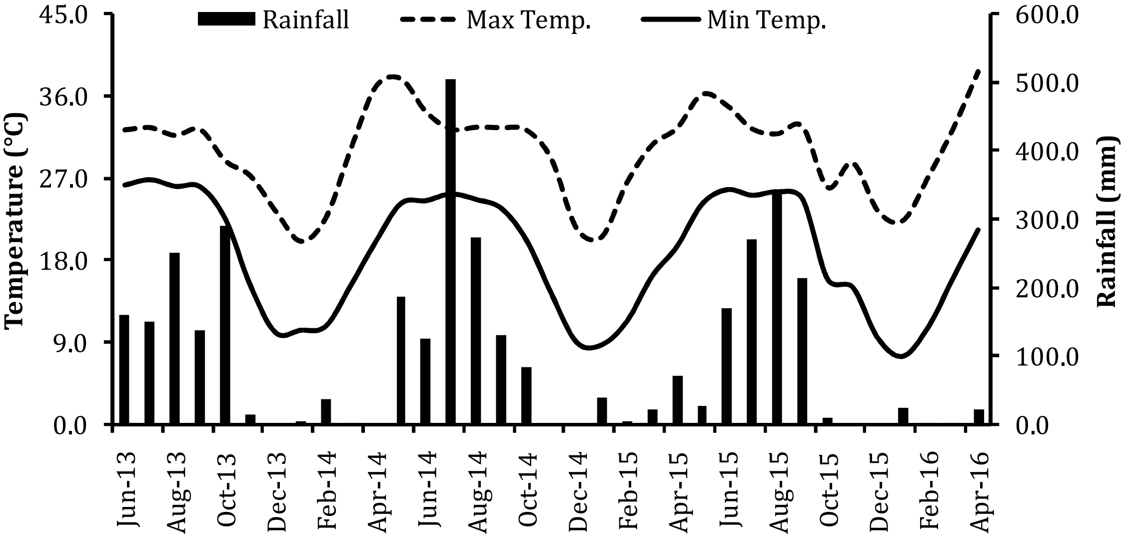

Fig. 1. Monthly mean values of meteorological parameters

Table 1. Treatment details

Treatment notation	Rice	Wheat
	Crop establishment method/Tillage	
M_1	System of rice intensification (SRI)	Conventional tillage
M_2	Transplanted puddled rice (TPR)	Conventional tillage + 30% rice residue incorporation
M_3	Direct seeded rice (DSR)	Zero tillage + 30% rice residue retention
	Nutrient management practices	
S_1	100% of Recommended dose of fertilizer (RDF) through inorganic sources	100% of Recommended dose of fertilizer (RDF) through inorganic sources
S_2	75% of RDF through inorganic sources + 25% of RDF through organic sources	75% of RDF through inorganic sources + 25% of RDF through organic sources
S_3	50% of RDF through inorganic sources + 50% of RDF through organic sources	50% of RDF through inorganic sources + 50% of RDF through organic sources
S_4	100% of RDF through inorganic sources + mungbean as green manuring	100% of RDF through inorganic sources

transplanted rice. Manual sowing of DSR was carried out in the plot. A recommended dose of fertilizers 120 kg N + 60 kg P_2O_5 + 40 kg K_2O ha^{-1} was applied in rice in which full P and K was applied in form of di ammonium phosphate and muriate of potash respectively as basal and along with 1/3 of the N while, the remaining N was top-dressed in two equal splits (after first and second irrigation).Vermicompost (1.5% N) was used as an organic source. During top dressing, fertilizers were broadcasted and care was taken so that the fertilizers were mainly targeted on the crop rows.Similarly for wheat, 'HD-2967' variety was sown manually in the mid of November through hand plough with row to row distance 22 cm using seed rate of 100 kg ha^{-1}. A common recommended dose of 150 kg N + 60 kg P_2O_5 + 40kg K_2O ha^{-1} were applied as in the case of wheat.

2.4 Greenhouse gas (GHG) Collection and analysis

Various green-house gases were collected from both rice and wheat field through gas chamber with the help of 50 mL disposable injection syringe with three (3) way leur lock. At each sampling date GHG samples were collected at 0, 30, 60 and 120 minutes interval from each gas chamber. The GHGs were estimated through Gas chromatography (Tracer 1100 GC; Make-Thermo Fisher). The fluxes of the gases were calculated at three key stages like maximum tillering stage, panicle initiation or ear head emergence stage and maturity stage of crops. The gas emission flux was calculated from the difference in gas concentration according to the equation of Zheng et al. [30] :

$$F = \rho h\left(\frac{dC}{dt}\right)273(273+T)^{-1}$$

where F is the gas emission flux (mg m^{-2} h^{-1}), ρ is the gas density at the standard state, h is the height of chamber above the soil (m),C is the gas mixing ratio concentration (mg m^{-3}), t is the time intervals of each time (h), and T is the mean air temperature inside the chamber during sampling.

2.5 Global Warming potential (GWP) and GHGs intensity (GHGI)

GWP is a measure of how much a given mass of greenhouse gas (GHG) is estimated to contribute to global warming. Gaseous emissions were converted to CO_2 equivalents using GWP. The GWP of different treatments were calculated using the following equation [31]:

$$\text{GWP } (CO_2\text{-equivalents, kg } ha^{-1}) = (CO_2) + (CH_4 \times 25) + (N_2O \times 298)$$

Based on a 100-year time frame, the GWP coefficients for CH_4 and N_2O are 25 and 298, respectively, when the GWP value for CO_2 is taken as 1 [2].

Grain yield were recorded using 1 m^2 quadrate from three places in each plot and converted it to t ha^{-1} and GHGI was estimated on the basis of grain yield produced [32,33]:

$$\text{GHGI (kg } CO_2\text{eq kg}^{-1}\text{ grain yield)} = \text{GWP/Grain yield.}$$

2.6 Statistical Analysis

Analysis of variance (ANOVA) was done to determine treatment effects [34]. Duncan's multiple range test (DMRT) was used as a post hoc mean separation test (P=0.05) using SAS 9.2 (SAS Institute, Cary, NC) [35]. The DMRT procedure was used where the ANOVA was significant.

3. RESULTS AND DISCUSSION

3.1 Grain Yield and Economics

Yield of rice and wheat ranged from 4.11-4.87 t ha^{-1} and 3.49-4.70 t ha^{-1}, respectively (Fig. 2). Highest rice grain yield was obtained under SRI (4.87 t ha^{-1}) which was ~5% higher than the transplanted rice. Yield under DSR (4.11 t ha^{-1}) reduced by ~11% as compared to TPR. But, there was ~35% increase in grain yield under Zero tilled wheat (4.70 t ha^{-1}) than conventional wheat (3.49 t ha^{-1}) that eventually increased the rice equivalent yield (REY) by 6.16% over conventional tillage practices both in rice and wheat crop. Residue incorporation had significant influence on wheat grain yield that enhanced 18% yield over conventional wheat. Application of sole mineral fertiliser resulted higher yield (4.63 t ha^{-1}) than combined application of mineral fertiliser and organic manure (4.26-4.44 t ha^{-1}). However, inclusion of green manure had significantly increased the rice yield by 4.32% over sole mineral fertiliser application that ultimately increased system productivity (REY). Exclusion of tillage drastically reduced cost for tillage operation and also saved water, labour and other inputs, altogether total cost of cultivation was lowered down. In addition to that there was a yield advantage under zero tillage as compared to the conventional tillage practices. Highest B: C ratio was found under the treatment DSR followed by zero tilled wheat. Inclusion of green manure along with 100% mineral fertiliser had increased the rice yield, hence higher B: C ratio was obtained in this treatment over 100% mineral fertiliser application.

3.2 Carbon Dioxide Emission

Carbon dioxide (CO_2) flux was significantly influenced by the management practices (Table 2). Conventional tillage management practices were imparted highest CO_2 flux (2.01-2.40 mg m^{-2} hr^{-1}) irrespective of all the crop growth stages followed by SRI and DSR emitted lowest CO_2 which was ~12 and 71% lower than the SRI and puddle rice respectively. Maximum tillering stage contributed highest CO_2 flux among the other phenological stages of rice i.e. panicle initiation, maturity (1.56-1.80 mg m^{-2} hr^{-1}) irrespective of management practices. Nitrogen management also significantly influenced the CO_2 flux. Substitution of half of the inorganic nitrogen (50% N of RDF) through organic manure (i.e. vermicompost) emitted highest

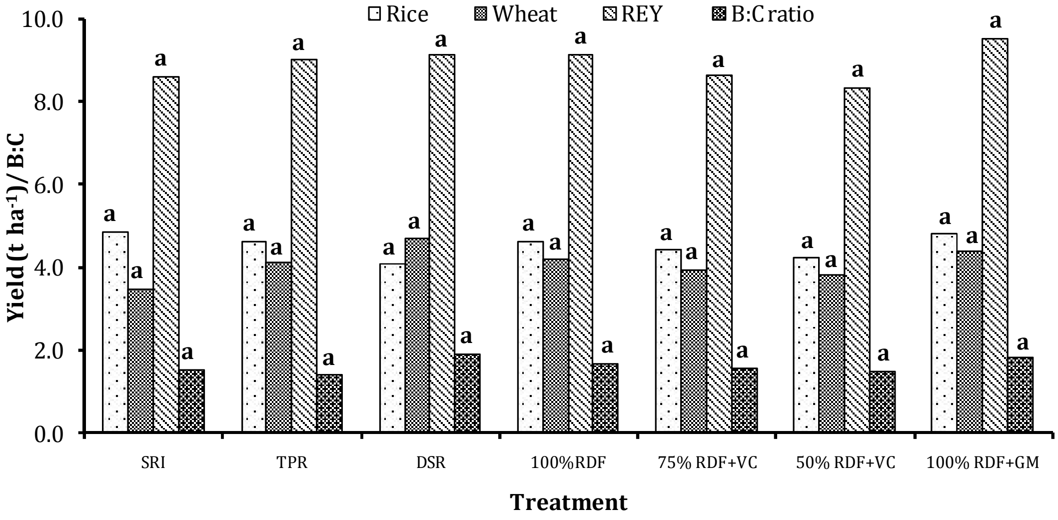

Fig. 2. Effect of management practices on grain yield and economics in rice-wheat cropping system *(Bar with the different letters are significantly different at p=0.05)*

Table 2. Effect of tillage and nutrient management on GHGs emission in various crop growth stages of rice

Treatment	**CH_4 (mg m^{-2} hr^{-1})**			**CO_2 (mg m^{-2} hr^{-1})**			**N_2O (µg m^{-2} hr^{-1})**		
	Maximum Tillering	**Panicle Initiation**	**Maturity**	**Maximum Tillering**	**Panicle Initiation**	**Maturity**	**Maximum Tillering**	**Panicle Initiation**	**Maturity**
Crop Establishment method/ Tillage									
M_1	21.6b	21.0b	19.7b	15.8b	15.1b	13.0b	59.8b	51.5b	43.8b
M_2	27.0a	26.2a	25.7a	14.3b	13.1b	11.7b	36.5c	27.9c	18.5c
M_3	13.9c	10.2c	5.4c	24.0a	22.9a	20.1a	82.7a	79.5a	77.3a
Nutrient Management									
S_1	18.8c	17.3d	15.1d	12.5c	11.2d	10.1a	69.6a	60.9a	53.7a
S_2	21.3b	20.0b	17.3b	14.8b	14.2b	12.0b	55.1c	48.4c	43.5c
S_3	22.7a	20.9a	18.8a	18.8a	16.6a	13.4a	51.6d	44.1d	40.7d
S_4	20.6b	18.3c	16.4c	12.6c	12.8c	11.0c	62.2b	58.4b	48.2b
***p* Value**									
M*S	0.0064	0.0003	0.0001	0.1040	0.0298	0.1314	0.0001	0.0090	0.0001

Table 3. Effect of tillage and nutrient management on GHGs emission in various crop growth stages of wheat

Treatment	**CH_4 (mg m^{-2} hr^{-1})**			**CO_2 (mg m^{-2} hr^{-1})**			**N_2O (mg m^{-2} hr^{-1})**		
	Maximum Tillering	**Ear head Emergence**	**Maturity**	**Maximum Tillering**	**Ear head Emergence**	**Maturity**	**Maximum Tillering**	**Ear head Emergence**	**Maturity**
Crop Establishment method/ Tillage									
M_1	0.19b	0.16b	0.14b	44.8b	40.0b	33.6b	1.16a	0.91a	0.64a
M_2	0.28a	0.24a	0.23a	65.3a	62.6a	60.6a	0.91b	0.64b	0.33b
M_3	0.10c	0.07c	0.04c	12.9c	11.3c	9.8c	0.58c	0.48c	0.19c
Nutrient Management									
S_1	0.16d	0.12d	0.11d	32.4d	30.7c	26.4d	1.10a	0.84a	0.52a
S_2	0.20b	0.17b	0.14b	43.5b	39.6b	36.5b	0.78c	0.58c	0.35c
S_3	0.22a	0.19a	0.17a	53.0a	48.8a	45.6a	0.75c	0.55d	0.29d
S_4	0.18c	0.14c	0.12c	35.2c	32.8c	30.1c	0.91b	0.74b	0.40b
***p* Value**									
M*S	<0.0001	0.0784	0.0819	0.4775	0.2601	0.0003	0.0006	<0.0001	0.0224

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

M_1- System of Rice Intensification (SRI) and Conventional tillage in Wheat; M_2- Transplanted Rice and Conventional tillage with residue incorporation in Wheat; M_3- Direct seeded rice (DSR) and zero tillage with residue retention in wheat; S_1-100% Recommended dose of fertilizer (RDF) through mineral fertilizer; S_2- 25% N of RDF substituted through organic sources + 75% RDF through mineral fertilizer; S_3- 50% N of RDF substituted through organic sources + 50% RDF through mineral fertilizer; S_4- 100% RDF as mineral fertiliser + Mung bean (Vignaradiata) as green-manure crop in rice and 100% RDF as mineral fertilizer in wheat.

CO_2flux (~1.63 mg m^{-2} hr^{-1}) than the full inorganic nitrogen application (1.13 mg m^{-2} hr^{-1}). Wheat crop emitted ~2.5 times more CO_2 than rice irrespective of tillage and fertilization (Fig. 3). Zero tillage with residue retention emitted lowest CO_2 flux (1.13 mg m^{-2} hr^{-1}) as compared to the conventional tillage in wheat (3.95 mg m^{-2} hr^{-1}). Conventional tillage with 30% residue incorporation contributed highest (6.28mg m^{-2} hr^{-1}) CO_2 emission flux among all the tillage and/or residue management practices. Tillage increases the surface roughness and void spaces that aggravated the CO_2 evolution and subsequent emission to the atmosphere [36]. Besides this, higher carbon dioxide release was found in response to tillage that means the ploughing operation breaks down of soil aggregate and exposure of soil organic matter for microbial decomposition under conventional tillage system. Furthermore, soil pore character i.e. total porosity and pore size of the soil are stronger envisages of carbon dioxide flux than soil organic matter and presence of microbial biomass carbon [1]. Conventional tillage increases the porosity of the soil which favours the respiration of aerobic microorganism by recovering movement of water and air within the soil that augment carbon dioxide emission [37].

3.3 Methane Emission

Methane (CH_4) emission fluxes in all treatments were increased gradually, and then peaks at maximum tillering stage. Thereafter, CH_4 emission fluxes declined gradually and kept relatively low levels at harvesting. Conventional tillage (puddle rice) recorded highest CH_4 emission (2.63 mg m^{-2} hr^{-1}) followed by SRI (2.07mg m^{-2} hr^{-1}) and DSR (0.98 mg m^{-2} hr^{-1}) (Table 2). CH_4 emission had significantly (p=0.05) influenced by the fertilizer management practices. CH_4 emission flux increased with increasing amount of organic manure added to the soil. Highest CH_4 emission flux (2.08 mg m^{-2} hr^{-1}) was recorded in the treatment where 50% N was supplemented with organic manure and that emitted ~22% more CH_4 than the sole mineral fertiliser treatment (1.71 mg m^{-2} hr^{-1}). Tillage and fertilization both had significant (p=0.05) effect on CH_4 emission. Across the three years, the averaged CH_4 fluxes were negligible (2.49–9.84 kg C ha^{-1}) during the wheat growing season (Fig. 4). Hence, zero tillage emitted lower CH_4 as compared to the conventional tillage whereas residue incorporation was further enhanced the CH_4 emission (Fig. 3). Generally rice cultivation responsible for anthropogenic methane emission anaerobic conditions are prerequisite for activities of methanogenic bacteria that enhance methane production. Adding to this methane oxidation potential would get disturbed by tillage operation. Thus under zero tillage no disturbance of the soil causes less exposure of soil organic matter resulted in lower chance of methane emission.

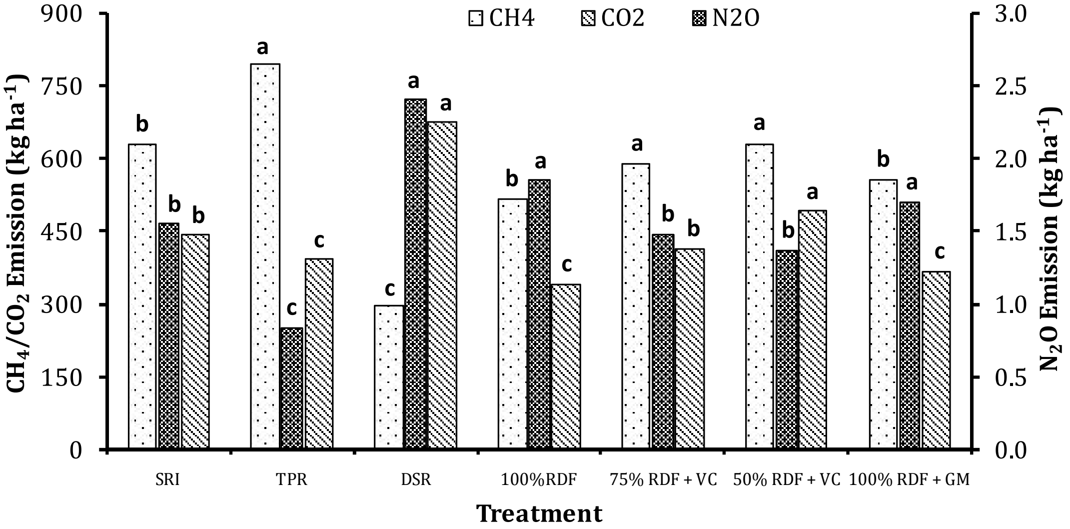

Fig. 3. Effect of crop establishment method and nutrient management practices on total greenhouse gas emission in rice *(Bar with the different letters are significantly different at p=0.05)*

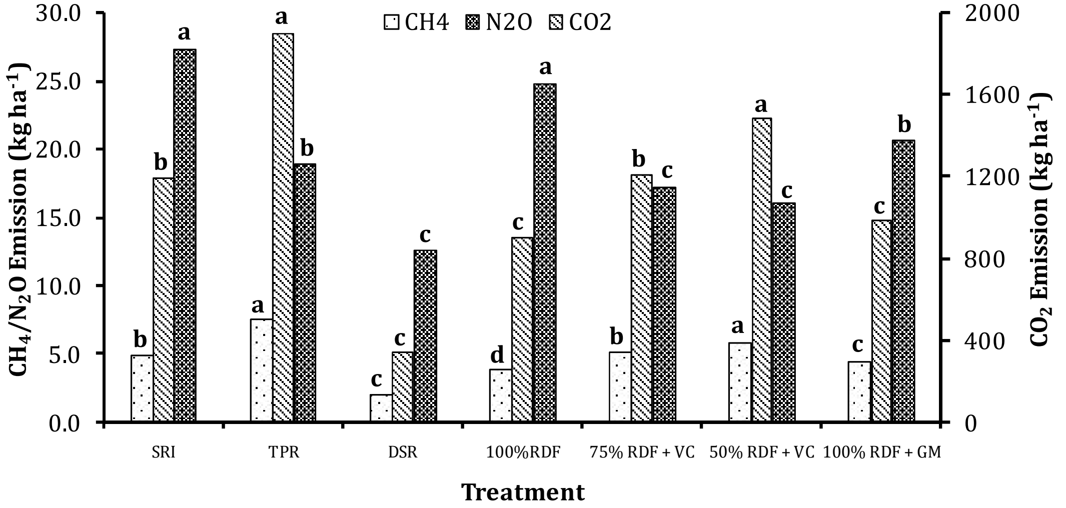

Fig. 4. Effect of crop establishment method and nutrient management practices on total greenhouse gas emission in wheat *(Bar with the different letters are significantly different at p=0.05)*

Moreover, under zero tillage system soil has high bulk density as because of reduced porosity (total porosity and pore size) that enhances retention of methane in soil and prevents the flow of methane in soil. It may improve oxidation of methane by methanotrophs resulting in lower methane emission. Under aerobic condition, non-microbial methane emission is common from wheat crop. Three factors are responsible for non-microbial methane emission, those are temperature fluctuation during *rabi* season, application of irrigation water through alternate wetting and drying and UV radiation. Application of organics was further aggravated the CH_4 emission flux by providing predominant carbon sources [38, 39].

3.4 Nitrous Oxide Emission

During the three cropping cycle of rice-wheat annual rotation, highest nitrous oxide (N_2O) emission took place during wheat season as compared to the rice crop season (Table 2 and 3). Unlike CO_2 and CH_4, maximum N_2O emission flux was observed in maximum tillering stage (rice-0.06 mg m^{-2} hr^{-1}, wheat-0.89mg m^{-2} hr^{-1}) followed by panicle (0.053 mg m^{-2} hr^{-1})/ ear head emergence (0.68 mg m^{-2} hr^{-1}) and maturity (rice-0.047 mg m^{-2} hr^{-1}, wheat-0.39 mg m^{-2} hr^{-1}) irrespective of management practices (Table/Fig). DSR followed by zero till wheat with 30% residue retention augmented N_2O emission flux by ~54.5% over transplanted rice followed by conventional wheat system (Fig. 4). Mineral fertilization significantly (p=0.05) increased N_2O flux by 29-34% as compared to combined application of organics and mineral fertilization in both the crops. A synergistic effect of green manuring was found to combat N_2O flux (Fig. 4). There was 13.4% reduction in N_2O emission flux found in 100% RDF with green manuring as compared to 100% RDF throughout the cropping season. Tillage and fertilization had significant interaction effect on N_2O flux in both the crops. Although, there is a large ambiguity regarding the higher nitrous oxide emission from zero tillage system than conventional tillage system but after long term practice of zero tillage may reduce the nitrous oxide emission [17](Ahmed et al. 2009). The nitrification and denitrification process both are responsible for nitrous oxide emission [40]. Actually nitrous oxide is produced under reducing condition or poorly aerated soil. Under zero tillage condition the soil is wetter and denser and having more soil microbial biomass. 30% residue retention is a practice in zero tillage system that supplies adequate labile substrate to denitrifying bacteria for nitrous oxide emission. The rate of oxygen diffusion into soil might be lower in soils with high water content under NT, thereby creating anaerobic conditions that are conducive to denitrification and N_2O emissions [41, 42]. Mineral fertilisation further augmented the N_2O emission because the application of the nitrogen fertilizer to the soils would have further increased the substrate availability for the processes driving the soil N_2O emissions [26, 43], resulted in enormous pulse emissions of N_2O, accounting for 73% of the annual emissions [44](Cui et al., 2012).

Under maximum tillering stage lower rhizospheric methane oxidation is occurred which most effectively transport reconciled by crop produce higher methane emission which is successively decreased to panicle initiation (rice) or ear head emergence (wheat) followed by harvesting stage. The reason behind such event may be due the fact that crop can utilize more nutrient in a better at prime vegetative phase for manufacturing more biomass exclusively for generating healthy reproductive parts in later crop growth stage. Maximum tillering stage attributed to highest root biomass enhanced microbial and root respiration; hence, increased CO_2 emission was found. This may be either decomposition of in-situ organic matter or root exudates by heterotrophic microorganism [36] (Robertson et al.,2000). Moreover, shallow submergence comparatively no ponding is found during later stage of growth.

3.4 GWP and GHGI

There were significant differences of the total global warming potential (GWP) of emitted CH_4, CO_2 and N_2O across all treatments, ranging from 4150 to 20526 kg CO_{2eq} ha^{-1} in whole cropping seasons (Fig. 5). Total global warming potential (GWP) of rice crop was 1.64-2.65 times higher than the GWP of wheat. Highest GWP was recorded in transplanted rice (20526 Kg $CO_{2\ eq}$ ha^{-1}) followed by SRI (16608 Kg $CO_{2\ eq}$ ha^{-1}) and lowest in DSR (8829 Kg $CO_{2\ eq}$ ha^{-1}) in rice season, whereas conventional wheat recorded highest GWP (9457 Kg $CO_{2\ eq}$ ha^{-1}) followed by conventional wheat with residue incorporation (7736 Kg $CO_{2\ eq}$ ha^{-1}) and lowest in zero till wheat with residue retention (4150 Kg $CO_{2\ eq}$ ha^{-1}). Significant variation in GWP was found under nutrient management practices. S_3 recorded highest GWP in rice which is at par with S_2 followed by S_1 and S_4, whereas S_1 recorded highest GWP in wheat. Extent of substitution of mineral fertiliser through organic manure did not show any significant variation in GWP in both the crops. N_2O emission is the key regulating factor for GWP in wheat growing season, because absence of anaerobiosis retards CH_4 emission. GWP under wheat growing season was 46-56% lower under zero till system as compared to conventional tillage system. This may be due to more nitrogen mineralisation rate increased the substrate availability for soil nitrification and denitrification. This observation is consistent with other studies carried out by [21,42]. Conventional tillage in well aerated soil possesses higher gas diffusion rates than zero tillage made impossible for further reduction of N_2O to N_2 by denitrifying organism [45].

Assessment of global warming potential as a function of crop yield (i.e. GHGs produced per unit of grain yield) is designated as greenhouse gas intensity (GHGI). Tillage showed more prominent impact on GHGI as compared to the nutrient management practices. Conventional tillage with continuous submergence (transplanted rice) (4.42 Kg $CO_{2\ eq}$ kg^{-1} grain yield) showed highest GHGI followed by SRI (3.41 Kg $CO_{2\ eq}$ kg^{-1} grain yield) and lowest in DSR (2.15 Kg $CO_{2\ eq}$ kg^{-1} grain yield). Whereas, conventional wheat (2.71 Kg CO_{2eq} kg^{-1} grain yield) recorded highest GHGI followed by

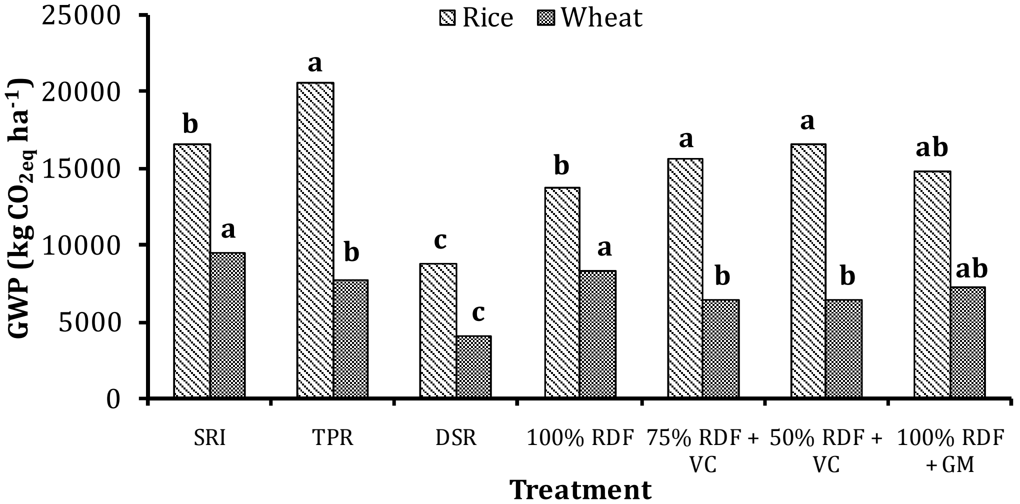

Fig. 5. Effect of tillage and nutrient management on global warming potential (GWP) in rice-wheat cropping season *(Bar with the different letters are significantly different at p=0.05)*

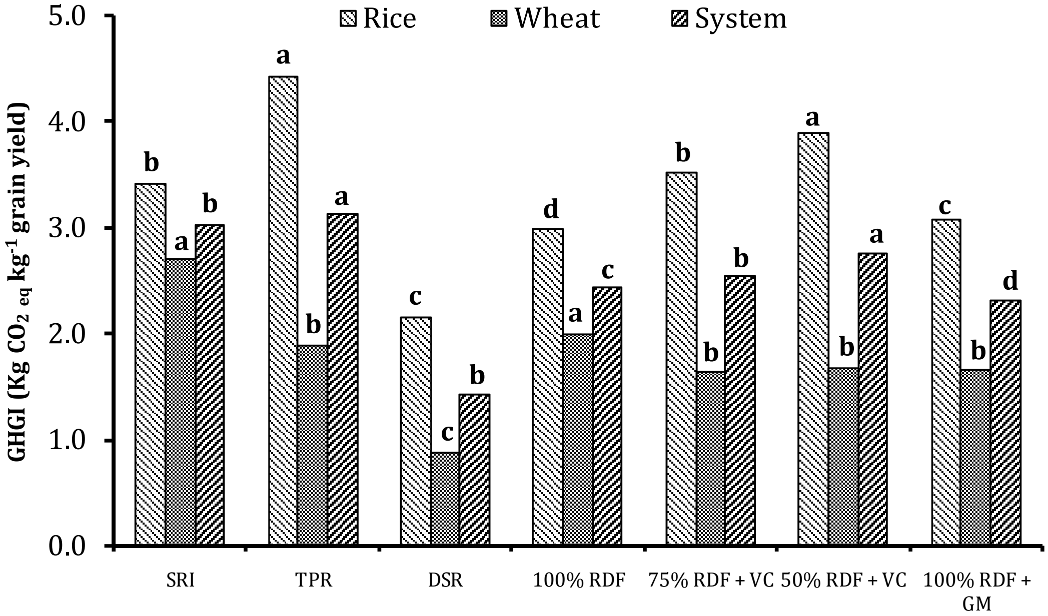

Fig. 6. Effect of tillage and nutrient management practices on GHGI in rice wheat cropping system *(Bar with the different letters are significantly different at p=0.05)*

conventional wheat with residue incorporation (1.88 Kg CO_{2eq} kg^{-1} grain yield) and lowest in zero till wheat with residue retention (0.88Kg $CO_{2\ eq}$$kg^{-1}$ grain yield). Nutrient management showed significant variation on GHGI. Direct seeded rice followed by zero till wheat with residue retention reduced the GHGI by a factor of 2.13-2.20 than conventional rice and wheat (Fig. 6). Although DSR obtained lower yield, but in long run DSR performed better than TPR [46] (Jat et al., 2014).This may be due to favourable soil environment enhanced system productivity and augment annual GWP by reducing CH_4 emission through moist irrigation or alternate wetting and drying in rice [47,48] and N_2O during wheat season to a lesser extent (Fig. 3 and 4). Consistent with our hypothesis, these results suggested that modification of management practices produced maximum yields while reducing GWP and maximised profitability in intensive rice-wheat production system [49,50] (Grassini and Cassman, 2012, Pittelkow et al., 2013).

4. CONCLUSIONS

Three year studies showed the positive effect of management options on GHGs emissions and agronomic productivity. The cost for all of these options had to be taken into account when assessing the economic viability of a system. SRI system had increased rice grain yield by 18.5% over DSR, whereas zero till wheat with residue retention had recorded 34.7% higher yield over conventional wheat. But highest system productivity was obtained under direct seeded rice followed by zero till wheat with 30% residue retention treatment. This system had reduced the CH_4 and N_2O emission by 62.7 and 48% respectively over conventional rice and wheat system, hence the GWP and GHGI was reduced by a factor 2.0-2.18 and 2.13-2.20, respectively. Although addition of green manure did not influenced the GWP but significant impact was found in GHGI. Because 100% RDF through mineral fertiliser along with green manure increased the system productivity by 4.27%, therefore GHGI was reduced by 4.56% over 100% RDF through mineral fertiliser. Direct seeded rice followed by zero till wheat with 30% residue retention along with 100% RDF through mineral fertiliser along with green manure could be an economically viable yield-scaled agronomic management strategy for future food supply under lower emission scenarios.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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