Adaptation approaches for direct seeded rice to reduce greenhouse gas emission in the perspective of climate change

ABSTRACT

A field experiment was conducted at research farm, Bihar Agricultural University, Sabour during 2017 and 2018 to gain insight crop phonology mediated greenhouse gas emission under different tillage and nitrogen management practices in direct seeded rice (DSR). The experiment was conducted in split plot design with two tillage viz. zero tillage (ZT) and conventional tillage (CT) as main plot and four nitrogen management practices viz. 100% nitrogen through neem coated urea (S_1), SPAD based nitrogen management (S_2), 75% through neem coated urea + 25% nitrogen through Vermicompost,(S_3) and ¼ nitrogen as basal and rest in equal three splits at 20, 40, 60 DAS (S_4) as sub plot, in three replication. The highest yield (4.69 t ha^{-1}), net return (46440 Rs ha^{-1}) and B:C ratio (1.44) were recorded from zero tilled DSR. Further, highest yield (4.82 t ha^{-1}), net return (44880 Rs ha^{-1}) and B:C ratio (1.36) was obtained under split application of nitrogenous fertilizers among other subplot treatments. The range of methane (0.57- 1.47 mg m^{-2} hr^{-1}) carbon dioxide (0.32- 0.61 mg m^{-2} hr^{-1}) and nitrous oxide (19.58- 38.79 µg m^{-2} hr^{-1}) emission was recorded lowest in zero tilled plots and split application of nitrogenous fertilizer also emitted lowest values of 1.59 mg m^{-2} hr^{-1} methane, 0.86 mg m^{-2} hr^{-1} carbon dioxide and 46.76 µg m^{-2} hr^{-1} nitrous oxide at maximum tillering stage of crop growth. Moreover, methane and nitrous oxide emission was gradually decreased from maximum tillering to harvesting stage. Zero tilled DSR with split nitrogen fertilizer application ascribed lowest greenhouse gas intensity among the other crop establishment and nitrogen management options. Thus, zero tilled method of crop establishment with split application of nitrogenous fertilizer could be a remunerative and environmentally stable method for direct seeded rice cultivation.

Keyword: Direct seeded rice, Greenhouse gas intensity Nitrogen management, Zero tillage.

1. Introduction

Traditional rice establishment technique i.e. massive puddling followed by transplanting is not only exhaustive water user but also burdensome, energy consuming, and laborious process [1].

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Conventionally, rice is established by repeated wet tillage (Puddling) followed by transplanting of the seedlings in the puddled soil while wheat established (in rice residue burned fields) by broadcasting/drilling seed after disking, tilling and planking operations [2]. Seed bed preparation operations oxidises the hidden organic matter, break the macro-aggregates into the micro-aggregates which adversely affect the soil properties [3,4]. Besides, soil perturbation by conventional tillage makes the soil to serve as a source rather than a sink of atmospheric pollutants [5]. About 20-40% of entire water required for growing crops is utilized in preparation of land for transplanting paddy. The situation could be further aggravated with degradation of soil fertility, declining underground water level and lesser per capita land availability and water productivity which ultimately are threat in front of sustainable rice production system. In addition, contribution of agriculture in total N_2O, CH_4 and CO_2 emission are 60%, 39%, and 1% respectively with rice based cropping system playing a principle role in global warming. Global CH_4 emission from rice paddies was estimated to be 20–40 Tg yr^{-1} which accounted for approximately 5–19% of annual CH_4 emission to the atmosphere [6]. Nitrous oxide (N_2O) emission from cultivated area of low land rice was much lower ranging from 1.7–4.8 Tg N_2O N yr^{-1} (Yao *et al*., 2013). Therefore, direct seeded rice (DSR) is the only probable alternative by offering certain advantages like saving irrigation water, labour, energy time [7] for better growth of succeeding crops as well as by reducing emission of greenhouse gases [8] and fruitless water flows. Zero tillage or reduce tillage establishment which is extensively used for many crops around the world and this technology when used in rice cultivation has potential to allow saving in time, energy, water and labour during rice establishment. Moreover, Zero tilled or no tilled system of crop establishment not only reduce soil disturbance but also increases soil organic matter accumulation and can also increase crop yield [9, 10, 11]. Consequently, application of appropriate quantity of N at the right time to restrict rapid mineralization losses through different pathways before it is utilized by the crop is, therefore, one of the most important factors to realize high yield and N use efficiency in DSR. Thus, there is an urgent need to focus on input management practices for improving use efficiency and sustaining the rice based production system under lower emission scenarios. To address the issues of sustainability of food production on account of changing climate, a combination of tillage and nutrient management practices were tested aimed at (1) to gain insight crop phonology mediated greenhouse gas emission under different crop establishment and

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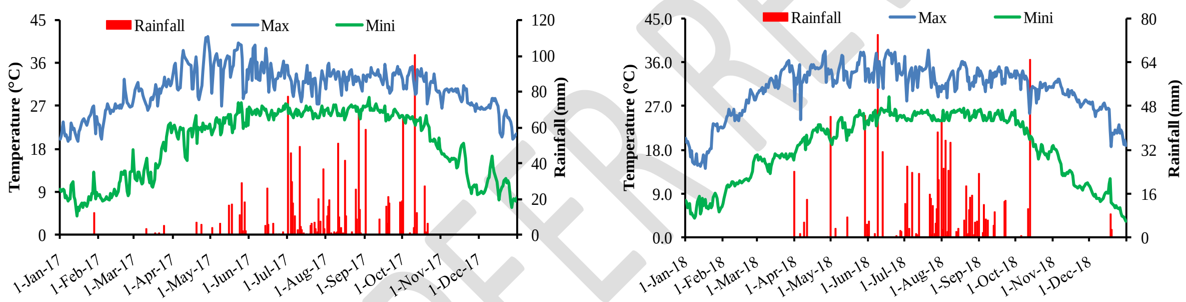
nitrogen management practices and (2) to evaluate the effect of GHGs on productivity, profitability and subsequent impact on global warming.

2. MATERIALS AND METHODS

2.1 Experimental details

The field study was carried out at experimental farm of at Bihar Agricultural College Farm, Sabour during kharif season of 2017 and 2018. The climate of Sabour, Bhagalpur is sub-tropical having moderate annual rainfall, hot and dry summer and cold winter. Maximum and minimum temperature recorded for the same period varied in between 30.7 to 34.9 °C and 20.0 to 26.8 °C, respectively. Wind speed was varied from 1.2 to 5.0 km hr^{-1}. The average annual rainfall of this place is about 1150 mm. Monthly average values of weather Parameters of 2017 and 2018 were presented in fig. 1(a) and (b).



(a) (b)

Figure 1: Monthly mean weather parameter of 2017 and 2018

The initial status of sol was clay- loam with pH- 7.4, Electrical Conductivity- 0.29 dSm^{-1}, organic carbon- 4.6 g kg^{-1}, Available N – 228.5 Kg N ha^{-1}, Available P- 19.22 Kg P_2O_5 ha^{-1}, Available K- 210.4 Kg K_2O ha^{-1} . The experiment was laid out in split plot design with 8 treatment combination and replicated thrice having two crop establishment method i.e. zero tilled DSR (M_1), and conventional DSR (M_2) and with four nitrogen Management Practices viz. S_1 as 100% nitrogen through neem coated urea where half was applied as basal and rest in two equal splits at active tillering and panicle initiation stage, S_2 SPAD based nitrogen management where SPAD threshold was 36 for rice whenever the SPAD reading was below critical value the N Fertilizer was applied (20 kg ha^{-1}) in form of Urea, S_3 with 75% through urea +25% nitrogen through vermicompost applied 15 days before sowing. And S_4 in which ¼ Nitrogen as basal and rest 3 in equal splits at 20, 40, 60 DAS. , Each plot having dimension of 4.0X5.0 m^2 The plots were given uniform recommended dose of

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phosphorus and potassium @ of 60 and 40 kg P_2O_5 and K_2O ha^{-1} respectively, during the crop season.

Rice variety Rajendra Sweta was sown in mid June with seed rate of 50 kg ha^{-1} at a row spacing of 20 cm. The recommended dose of fertilizer of rice was 120 kg N + 60kg P_2O_5 + 40 Kg K_2O ha^{-1} in which full P and K was applied in form of diammonium phosphate (DAP) and muriate of Potash (MOP) respectively as basal and nitrogen (Urea and DAP) was applied as per the treatment. Source of organic fertilization was Vermicompost with 1.5%N. Rice crop was harvested and threshed manually. Yield of rice was estimated by harvesting the entire plot and converted it to t ha^{-1}. The grain yield of rice was recorded at 14% moisture.

2.2 Greenhouse gas (GHG) collection and analysis

The greenhouse gases i.e. CH_4, N_2O and CO_2 were collected from each plot through closed chamber method with the help of 50 mL disposable injection syringe with three way leur lock. At each sampling date, GHG samples were collected at 0, 30 and 60 minutes interval from each plot. The Gas samples were analyzed by a gas chromatograph (Trace GC 1100, Thermo Fischer) equipped with electron capture detector (ECD) and flame ionization detector (FID) for analysing N_2O and CH_4 respectively. CO_2 was reduced to CH_4 with hydrogen in a nickel catalytic methanizer at 350°C and then detected by the FID. The carrier gas was nitrogen at a flow rate of 35 mL min^{-1}. The temperatures for the column and ECD detector were maintained at 60°C and 300°C, respectively. The oven and FID were operated at 60°C and 300°C, respectively. The gas emission flux was calculated from the difference in gas concentration according to the equation of Zheng [12]

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

where F is the gas emission flux (mg m^{-2} hr^{-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.

2.3 Statistical analysis

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Analysis of variance (ANOVA) was done to determine treatment effects [13]. 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) [14]. The DMRT procedure was used where the ANOVA was significant.

3. RESULTS AND DISCUSSION

3.1 Grain yield and economics

Different crop establishment and nitrogen management practices had significant impact on grain yield. Maximum grain yield (4.69 t ha^{-1}) was obtained from plots sown under zero tilled condition. Rice sown under zero tilled condition experienced reduced soil disturbance, resulting in increase in soil organic matter accumulation in top soil [15] which enhanced tillering capacity, lodging tolerance, greater stress resistance and wide ecological adaptability of rice crop [16]. Further, in zero tilled DSR there was more root length density of the crop which produces greater xylem exudates and transport these towards shoot at faster rates and thus helps in maintenance of higher chlorophyll level and photosynthetic rates of leaves resulting in more yield. The same was also confirmed by Jat et al [17]. Besides, there was also low sterility percentage resulting in more number of filled grains per panicle [18]. Significantly higher grain yield (4.82 t ha^{-1}) was recorded under split application of nitrogenous fertilizer compared to other sub plot treatments which gives adequate nutrient quickly as compared to organic substitute to the crop [19]. This is because of the fact that split application promotes higher leaf area index and dry matter production as well as effective tillers per meter square with more portioning of nutrients from source to sink and also due to lower weed infestation and higher nutrient utilization by efficient nitrogen management. Similar results were reported by [20]. Moreover, due to the fact that less nitrogen before anthesis and more nitrogen application at or after anthesis increase the post anthesis dry matter accumulation and grain filling [21]. The yield ascribing character was the maximum under the three split nitrogen treatment resulting higher grain yield [21]. This may be attributed to the adequate N availability, at required crop growth stage which facilitates tillering, and develops more and heavier grains in rice crop. Additionally, cell elongation, cell enlargement and cell division due to proper utilization of nitrogenous fertilizer application under split nitrogenous fertilizer application, activates meristematic tissues which remain functional for longer periods resulting in better expression of yield and yield attributes and resulting in more yield of the crop. This result is in close agreement with those reported earlier [22, 23].

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There was reduction in cost of cultivation in zero tilled DSR (M_1) as compared to conventional DSR (M_2), probably due to the fact that in zero tilled plot less labours were required in addition with less cost in land preparation due to no tillage operation which declined cost of cultivation [24] (Kumar et al. 2009). Similarly, highest gross returns of 78690 Rs.ha^{-1},net return (46440 Rs.ha^{-1}) and B: C ratio (1.44) was recorded from treatment zero tilled DSR mainly because in Zero tilled DSR both of grain and straw yield was high [25]. Among nitrogen management practices lowest cost of cultivation was incurred in SPAD based nitrogen management (32125 Rs.ha^{-1}) compared to other treatments. It may be due to the fact that in SPAD based nitrogen Management less amount of fertilizer was given to the soil. About 24% less nitrogen was given in as compared to other nutrient management practices. The maximum gross return of 78005 Rs.ha^{-1}, net return (44880 Rs.ha^{-1}) and benefit cost ratio of 1.36 was recorded from the crop raised with three split application of nitrogen fertilizer. This is due to the fact that split fertilizer application increases the nutrient use efficiency resulting in increased nutrient uptake which influences various growth and yield attributing characters which attributes to higher gross return.

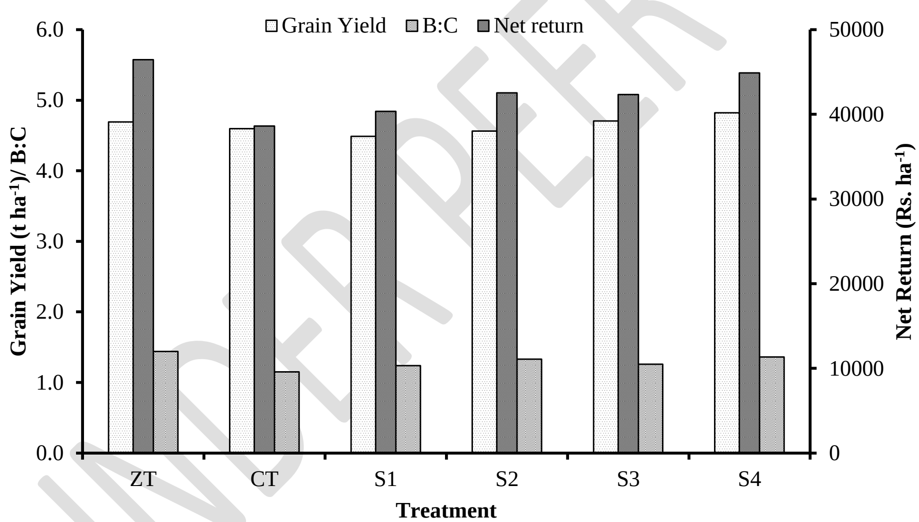

Figure 2: Effect of tillage and nitrogen management on Grain yield, net return and B:C ratio

3.2 Greenhouse gas emission

Rice cultivation is an important anthropogenic source of methane emission. The statistical analysis revealed that lowest greenhouse gas emission was found in zero tilled plots irrespective of nitrogen management practices (Table 1). However, significant variation was found in methane emission at different stages of crop growth while there was no significant variation in nitrous oxide emission in

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different crop growth stages. Lowest methane emission was under Zero tilled DSR (1.47,1.08 and 0.57 mg m^{-2} hr^{-1} at maximum tillering, panicle initiation and harvesting stage respectively) as compared to Conventional tilled DSR. Although the emission followed decreasing trend from maximum tillering stage of the crop to later on. Generally, methane emission from rice field mostly depends on input and soil management practices. Anaerobic conditions are prerequisite for activities of methanogenic bacteria that enhance methane production. Several studies proved that zero tilled DSR resulted in lower methane emission than conventional DSR (Ahmed et al.2009) through preserving methane oxidation potential that would get disturbed by tillage operation [26]. Basically, under zero tillage there is no disturbance of soil cause less exposure of organic matter as caused by tillage operation [27]. Higher methane emission was recorded at maximum tillering stage is due to lower rhizospheric methane oxidation and more effective transport mediated by rice plants [28], which was successively decreased to panicle initiation and harvesting stage. The same trend of emission pattern was also observed for CO_2 and N_2O. Lower C_2O emission of 0.61, 0.57, 0.32 mg m^{-2} hr^{-1} from maximum tillering, panicle initiation and harvesting stage respectively under zero tilled condition. The emission of N_2O

Table 1: Effect of tillage and nitrogen management on greenhouse gas emission

Treatment	CH_4 Emission (mg m^{-2} hr^{-1})			CO_2 Emission (mg m^{-2} hr^{-1})			N_2O Emission (µg m^{-2} hr^{-1})		
	Max. Till	PI	Harvest	Max. Till	PI	Harvest	Max. Till	PI	Harvest
ZT	1.47b	1.08b	0.57b	0.61b	0.57b	0.32b	38.79b	29.42b	19.58b
CT	2.24a	2.20a	2.09a	1.52a	1.39a	1.24a	63.46a	54.78a	46.54a
S_1	1.92a	1.74b	1.37b	1.07b	1.01b	0.82b	62.37a	51.85a	41.71a
S_2	1.84ab	1.54c	1.25c	0.84c	0.75c	0.71c	40.69d	32.41c	27.11c
S_3	2.08a	1.89a	1.61a	1.49a	1.27a	0.92a	54.67b	47.44b	35.41b
S_4	1.59b	1.39d	1.08d	0.86c	0.90b	0.66d	46.76c	36.72c	28.02c

Values with different letters in the same column are significantly different at P=0.05 in DMRT

ZT-Zero tillage, CT- Conventional Tillage, S_1: 100% N through neem coated urea, S_2: SPAD based N management, S_3: 75% N through urea + 25% N through organic, S_4: ¼ of N as basal and rest in 3 equal split at 20,40 and 60 DAS

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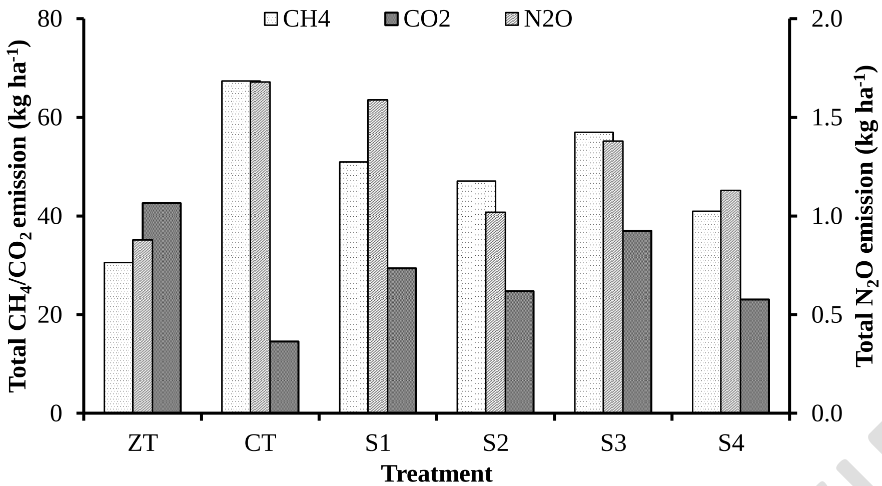

Figure 3: Total greenhouse gas emission from rice crop

ranged from 19.58 to 38.79 µg m^{-2} hr^{-1} from zero till and from 46.54 to 63.46 µg m^{-2} hr^{-1} from conventional tillage. Plots with 100% nitrogen through neem coated urea emitted more nitrous oxide that also lowers the methane and carbon dioxide emission, however, split of nitrogenous fertilizer made lower emission irrespective of all three gases. Addition of organic matter to the soil increased the decomposition rate of soil organic content which resulted in higher emission of methane [8]. Nitrous oxide emission from soil is mainly by microbial process of nitrification and denitrification also [29]. Tillage may affect the biological, chemical and physical property of soil as well as influence the greenhouse gas emission like nitrous oxide [30]. Although there is large uncertainty regarding higher nitrous oxide emission under zero tilled DSR than conventional DSR [31] or nitrous oxide emission diminishes after long term practices of zero tilled DSR. Under nitrogen management practices, split doses of fertilizer application emitted lower ranged of all three greenhouse gases i.e. 1.59, 1.39, 1.08 mg m^{-2} hr^{-1} for CH4 and 0.86, 0.90, 0.66 mg m^{-2} hr^{-1} for CO_2 and 46.76, 36.72, 28.02 µg m^{-2} hr^{-1} for N2O. It was also found that emission of nitrous oxide varied from 41.71 to 62.37 µg$m^{-2}$$hr^{-1}$ from 100% nitrogen through neem coated urea i.e. maximum nitrous oxide emission was formed from this treatment as under such conditions there are chances of rapid mineralization and prone to loss through different pathways before it is utilized by crop. Fundamentally, application of nitrogenous fertilizers as basal to the soil would have further increased the substrate availability for soil nitrous oxide emission. Likewise, use of nitrogenous fertilizer is directly linked quantum of with nitrous oxide

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(Smith and Conen 2004). Split application of nitrogenous fertilizer had lowest nitrous oxide emission at each stage of crop growth, as application of adequate quantity of nitrogen at right time is one of the most important factors for highest nitrogen use efficiency and lower loss as denitrification. Exclusion of tillage (ZT) caused drastic reduction in total CH_4, CO_2 and N_2O emission, whereas split application of N fertilizers also resulted lowest emission (Fig. 3). Relative contribution in global warming potential (GWP) was highest in CH_4 (68-75%) followed by N_2O (23-30%) and least in CO_2 (1-4%) (Fig. 4). GWP was highest in CT-DSR (1931 kg CO_{2eq} ha^{-1}) which was double than ZT-DSR (949 kg CO_{2eq} ha^{-1}). Among the nitrogen management strategies, splitting of N-fertilizer reduced the GWP by 22 and 26% as compared to the 100% N through neem coated urea and 75% N through Urea + 25% N through vermicompost, respectively.

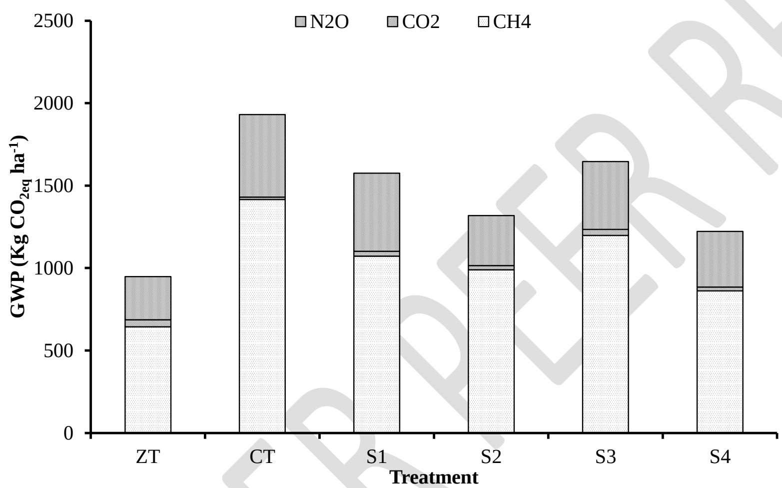

Figure 4: Relative contribution of GHGs in GWP

CONCLUSIONS

Above study concluded that Zero tilled method of crop establishment along with split application of nitrogenous fertilizer would not only boost the yields but also decrease the greenhouse gas emission as well as global warming potential. Thus, the wider adoption of resource conservation approaches in direct seeded rice has long run benefits in terms of conserving natural resources, saving energy, higher production and cost effectiveness in the perspective of climate change.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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