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Performance of rice-wheat cropping system under resource conservation and various nutrient management practices

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Abstract

A field study was conducted during three consecutive years of 2016-17, 2017-18 and 2018-19 at university farm at Bihar Agricultural University, to assess the impact of resource conservation and nutrient management on yield, economics, and energetics of rice-wheat cropping system. The experiment was conducted in split plot design replicated thrice with three cropping system establishment methods viz. system of rice intensification + conventional wheat, transplanted rice + conventional wheat with 30% rice residue incorporation and direct seeded rice + zero tilled wheat with 30% rice residue incorporation as main plot and with three nutrient management practices viz. 100% of Recommended dose of fertilizer (RDF) through inorganic sources, 75% of RDF through inorganic sources + 25% of RDF through organic sources (vermicompost), 50% of RDF through inorganic sources + 50% of RDF through organic sources (vermicompost) and 100% of RDF through inorganic sources + mungbean as green manuring. It was obvious from the result that highest rice yield (48.7 qha^{-1}) was from system of rice intensification + conventional wheat meanwhile highest wheat yield (47.0 qha^{-1}) and system productivity (rice equivalent yield) (91.3 qha^{-1}) was from direct seeded rice + zero tilled wheat with 30% rice residue incorporation. Moreover, the dominance of resource conservation practices on other practices was prevalent in the cropping system as highest B:C ratio (1.92) was obtained from direct seeded rice + zero tilled wheat with 30% rice residue incorporation. Lowest greenhouse gas emission i.e. CH_4 , CO_2 , N_2O was from direct seeded rice with zero tilled wheat and residue incorporation at different stages of crop growth. Among different nutrient management practices highest yield both for rice (48.3 qha^{-1}) wheat (43.9 qha^{-1}) and rice equivalent yield (95.2 qha^{-1}) was obtained from 100% of RDF through inorganic sources + mungbean as green manuring. Adding to this the B:C ratio was also least (1.84) from same, whereas lowest greenhouse gas emission (CH_4 , CO_2) was from 100% inorganic fertilizers. And lowest nitrous oxide emission was from 50% inorganic and 50% organic fertilizers.

Keywords: Energetics, green manuring, nutrient management, resource conservation, zero tillage.

Introduction

Among the world's major agriculture production system rice-wheat cropping sequence (RWCS) is the largest production system occupying around 12.3 M ha in India, 0.5 M ha in Nepal, 2.2 M ha in Pakistan and 0.8 M ha in Bangladesh and around 85 percent of this area falls in Indo-gangetic plains (IGP) (Ladha *et al.* 2003, Timsina and Connor 2001) [8, 17]. Conventionally, rice in these region is established by repeated 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 (Bhatt 2015) [2]. Seed bed preparation operations oxidizes the once hidden organic matter, break the macro-aggregates into the micro-aggregates which adversely affect the soil properties (Roper *et al.* 2013, Das *et al.* 2014) [12, 4]. Furthermore, soil perturbation by conventional tillage makes the soil to serve as a source rather than a sink of atmospheric pollutants and thus is not sustainable and environment friendly (Busari *et al.* 2015) [3]. Intensively cultivated rice field have been identified as major contributor of greenhouse gases (GHG) to the atmosphere. The transplanted rice which allows continuous flooding of soil up to six months creates an anoxic environment favorable for production of methane (CH_4). Global CH_4 emission from rice paddies was estimated to be 20-40 Tg yr^{-1} which accounted for

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approximately 5–19% of annual CH₄ emission to the atmosphere (IPCC 2007) [5]. Nitrous oxide (N₂O) emission from cultivated area of low land rice was much lower ranging from 1.7–4.8 Tg N₂O-N yr⁻¹ (Yao *et al.* 2013) [19]. However, studies show that substantial N₂O emission took place from rice fields due to mid season drainage and dry-wet episodes and with increasing rate of nitrogen (N₂) application, the N₂O emissions from rice fields are likely to be increased (Yao *et al.* 2013) [19]. Conventional transplanted rice that involves transplanting of 30 days old seedlings, followed by continuous flooding of 5–7 cm water throughout the growing season consumes about 1300–1900 mm of water. In the present scenario, increasing water scarcity has threatened productivity and sustainability of irrigated rice systems in Asia; direct seeded rice (both wet and dry) is considered to be alternative water saving rice production technique. Moisture regime is a key factor which influences the emissions of methane, nitrous oxide and carbon dioxide from soil. Water management practices like mid-season drainage and intermittent irrigation have been recommended as mitigation options for reduction of CH₄ emission from rice fields. Occurrence of wet and dry cycles in direct seeded rice fields affects the aeration status of soil, which in turn regulates nitrification and denitrification processes and can enhance N₂O emissions. Since, emission of CO₂ through soil respiration is a major pathway of carbon (C) efflux from terrestrial ecosystems and directly related to sequestration of C in soil, any alteration in soil respiration rate due to change in soil moisture regime may affect the global C budget. Rice is predominantly grown as puddled transplanted crop in India. The farmers transplant rice from 10 June when the daily evaporation rate is very high (8-10 mm/day). The underground water is being over exploited by excessive pumping to meet the water requirement of transplanted rice. As a consequence, it has been causing a sharp decline in ground water table. Therefore, need has been felt to develop technically viable and economically feasible alternate techniques for growing rice in this region. The preliminary research conducted at various agriculture universities indicated that dry direct seeded rice could be a viable alternative to transplanted rice.

Nitrogen is a vital nutrient element for rice plants, as 75 per cent of leaf N is allied with chloroplast which physiologically helps in dry matter production through photosynthesis. The low nitrogen use efficiency and recovery percentage is mainly due to its rapid mineralization and proneness to losses through different pathways before it is utilized by the crop. Application of appropriate quantity of N at the right time is, therefore, one of the most important factors to realize high yield and N use efficiency in DSR.

Materials and method

Site description

The field experiment was carried out at Bihar Agricultural College Farm, Sabour during during three consecutive years

of 2016-17, 2017-18 and 2018-19. 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. The initial status of soil was clay loam with pH- 7.4, Electrical Conductivity- 0.29 dSm⁻¹, organic carbon- 0.46%, Available N – 228.5 Kg N ha⁻¹, Available P- 19.22 Kg P₂O₅ ha⁻¹, Available K- 210.4 Kg K₂O ha⁻¹.

Experimental details

The experiment was conducted in split plot design replicated thrice with three cropping system establishment methods *viz.* System of rice intensification + conventional wheat, Transplanted rice + conventional wheat with 30% rice residue incorporation and Direct seeded rice + zero tilled wheat with 30% rice residue incorporation as main plot and with three nutrient Management Practices *viz.* 100% of Recommended dose of fertilizer (RDF) through inorganic sources, 75% of RDF through inorganic sources + 25% of RDF through organic sources (vermicompost), 50% of RDF through inorganic sources + 50% of RDF through organic sources (vermicompost) and 100% of RDF through inorganic sources + mungbean as green manuring. The plots were given uniform recommended dose of phosphorus and potassium @ of 60 and 40 kg P₂O₅ and K₂O ha⁻¹ respectively, during the crop season.

Crop management

Rice variety Rajendra Sweta was sown in mid June with a seed rate was 50 kg ha⁻¹ at a row spacing of 20 cm. A recommended dose of fertilizers in rice was 100 kg N + 60 kg P₂O₅ + 40 kg K₂O 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 was applied as per the treatment. 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 120 kg N + 80 kg P₂O₅ + 60 kg K₂O ha⁻¹ were applied as in the case of wheat.

Crop harvest and yield

At crop maturity, both rice and wheat crop was harvested manually. Rice was harvested by cutting and threshed manually. Wheat grains were threshed using a plot thresher. Yields of rice and wheat were estimated by harvesting the entire plot and converted it to q ha⁻¹. The grain yield of rice and wheat is reported at 14% and 12%, grain moisture, respectively. For comparing the productivity of rice and wheat crops and total system productivity of the different treatments, was converted into rice equivalent yield (q ha⁻¹) using the following equation:

$$\text{Rice equivalent yield } q \text{ ha}^{-1} = \frac{\text{Wheat yield } q \text{ ha}^{-1} \times \text{Minimum support price of wheat (INR } q^{-1})}{\text{Minimum support price of Rice (INR } q^{-1})}$$

Greenhouse gas (GHG) collection and analysis

The greenhouse gases *i.e.* CH₄, CO₂, N₂O were collected from both rice and wheat field through Pyrex glass gas chamber 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 120 minutes interval from each plot.

The Gas samples were analyzed for CH₄, CO₂, and N₂O concentrations by a gas chromatograph (Trace GC 1100, Thermo Fischer) equipped with two detectors. N₂O was detected by an electron capture detector (ECD), and CH₄ was detected by flame ionization detector (FID). CO₂ was reduced with hydrogen to CH₄ in a nickel catalytic converter 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 *et al.* (1998) [20].

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

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 three time intervals of each time (h) and T is the mean air temperature inside the chamber during four sampling.

Table 1: Effect of tillage and nutrient management on grain yield and economics in rice-wheat cropping system

Treatments	Yield (t ha ⁻¹)	Yield (t ha ⁻¹)	REY (t ha ⁻¹)	B:C ratio
Main Plots	Rice	Wheat		
M ₁ (SRI-Conventional Wheat)	4.87	3.49	8.60	1.53
M ₂ (Transplanted Rice-Conventional Wheat + 30% rice residue incorporation)	4.64	4.12	9.04	1.41
M ₃ (DSR- ZT Wheat + 30% residue retention)	4.11	4.70	9.13	1.92
SEm (±)	0.048	0.091	0.139	0.038
CD (p = 0.05)	0.133	0.254	0.386	0.105
Subplots	Rice	Wheat		
S ₁ (100% inorganic Fertilizer)	4.63	4.21	9.13	1.68
S ₂ (75% inorganic fertilizer + 25% organic Fertilizer)	4.44	3.95	8.66	1.56
S ₃ (50% inorganic fertilizer + 50% organic Fertilizer)	4.26	3.83	8.35	1.48
S ₄ (100% inorganic fertilizer + green manuring)	4.83	4.39	9.52	1.84
SEm (±)	0.059	0.111	0.167	0.040
CD (p = 0.05)	0.124	0.233	0.351	0.085

(SRI- System of Rice Intensification, DST- Direct seeded Rice, ZT- Zero Tillage, REY-Rice equivalent Yield, B:C Ratio- Benefit: Cost Ratio)

Basically, zero till soil or minimum disturb soil help in more root length density of the crop, produce greater xylem exudates and transport these towards shoot at faster rates. These features contribute to the maintenance of higher chlorophyll levels, enhance fluorescence and photosynthesis rates of the leaves and support more favorable yield attributes *i.e.* number of effective tillers per meter square of the crop and grains per spike than in more disturb soil. Moreover there was 30% residue retention under zero tillage system that creates a permanent or semi-permanent organic soil cover and reduces the evaporation losses from the soil and allows soil borne microorganism to accelerate the microbial degradation of soil organic matters and balancing the soil nutrient content which enhance the vegetative growth of plant. Basically under zero tilled condition seed sowing was done under adequate soil moisture and at proper depth therefore, higher energy stored within the seed which promotes good vigor of the crop. Moreover, there is an increase in infiltration of water into the soil and also increase organic matter retention under zero tilled condition that eliminate soil erosion, improving soil biological fertility and building up the more resilient soil for crop growth (Sharma 2007) [15]. Zero tillage improves soil physical, chemical and biological parameters and providing good amount of nutrient to crops that attribute to better yield determining parameter and good yield. Significantly higher grain yields (48.3 q ha⁻¹, 43.9 q ha⁻¹) were recorded respectively for Rice and wheat under S₄ (100% inorganic fertilizer + green manuring) as compared to other sub plot treatments. Similarly system productivity was higher in S₄.

Statistical analysis

Analysis of variance (ANOVA) was done to determine treatment effects using Microsoft excel 2007.

Result and discussion

Grain yield and system productivity

Tillage and nutrient management had a contrast impact on the grain yield of both crops. Maximum rice grain yield (48.7 q ha⁻¹) and system productivity (86.0 q ha⁻¹) was recorded from SRI method of crop establishment while highest wheat grain yields (47.0 q ha⁻¹) and system productivity (91.3 qha⁻¹) was obtained from zero tilled wheat with 30% rice residue incorporation (Table-1).

100% recommended dose of fertilizer through inorganic sources give adequate nutrients quickly as compare to organic substitution of chemical fertilization to the crop. Moreover, extra advantage is derived from green manuring being organic sources in S₄ plots. Nitrogen is an energy store in plant body. Being a constituent of amino acid, nucleotides, nucleic acid, a number of coenzymes, auxin, cytokinins and alkaloids, it includes cell elongation, cell enlargement and cell division (Salisbury and Ross1969) [13]. These activities in turn activate meristematic tissues which remain functional for longer periods resulting in better expression of yield and yield attributes and converting more solar energy to productive energy (Kumawat and Bansal 1996) [7].

Economics and profitability

Among different crop establishment method highest B: C ratio (1.92) was obtained from M₃ plots DSR-Zero tilled wheat. Similarly among different nutrient management practices maximum (1.84) B:C ratio was obtained from S₄ (Table-1) Exclusion of tillage practices and beneficial aspect of zero tillage could help not only reduce the cost of cultivation but also harness higher yield, hence higher net income and B:C ratio (Jat *et al.* 2014) [6].

Seasonal greenhouse gas emission

Tillage and nutrient management had a significant influence on greenhouse gases (GHGs) emission. Lowest GHGs emission was found under zero till condition irrespective of nutrient management (Table 2).

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

Treatments	CH ₄ (mg m ⁻² hr ⁻¹)			CO ₂ (mg m ⁻² hr ⁻¹)			N ₂ O (μg m ⁻² hr ⁻¹)		
	MT	PI	Mat.	MT	PI	Mat.	MT	PI	Mat.
Main Plots									
M ₁ (SRI-Conventional Wheat)	21.6	21	19.7	15.8	15.1	13	59.8	51.5	43.8
M ₂ (Transplanted Rice-Conventional Wheat + 30% rice residue incorporation)	27	26.2	25.7	14.3	13.1	11.7	36.5	27.9	18.5
M ₃ (DSR- ZT Wheat + 30% residue retention)	13.9	10.2	5.4	24	22.9	20.1	82.7	79.5	77.3
SEm (±)	0.392	0.452	0.324	0.157	0.236	0.325	0.607	0.531	0.312
CD (p = 0.05)	1.089	1.255	0.9	0.437	0.656	0.903	1.686	1.475	0.866
Subplots									
S ₁ (100% inorganic Fertilizer)	18.8	17.3	15.1	12.5	11.2	10.1	69.6	60.9	53.7
S ₂ (75% inorganic fertilizer + 25% organic Fertilizer)	21.3	20	17.3	14.8	14.2	12	55.1	48.4	43.5
S ₃ (50% inorganic fertilizer + 50% organic Fertilizer)	22.7	20.9	18.8	18.8	16.6	13.4	51.6	44.1	40.7
S ₄ (100% inorganic fertilizer + green manuring)	20.7	18.3	16.4	12.6	12.8	11	62.2	58.4	48.2
SEm (±)	0.439	0.249	0.177	0.192	0.409	0.550	0.576	0.923	0.912
CD (p = 0.05)	0.922	0.523	0.371	0.404	0.860	1.155	1.210	1.939	1.916

MT-Maximum tillering

PI-Panicle Initiation

Mat-maturity

Significant variation was found in methane (CH₄) and carbon dioxide (CO₂) emission in different phenological stages, but no significant variation was found in nitrous oxide (N₂O) emission in different growth stages. Least amount of total seasonal methane (13.9, 10.2, 5.4 mg m⁻²hr⁻¹) in kharif and (0.10, 0.07, 0.04 mg m⁻²hr⁻¹) rabi season respectively during maximum tillering, panicle initiation and maturity was

recorded from DSR-Zero tilled wheat with 30% residue incorporation. Lowest CO₂ and N₂O during kharif was obtained from M₂ while during rabi (Table-3) lowest CO₂ and N₂O was recorded under (M₂) DSR-Zero tilled wheat with 30% residue incorporation following decreasing trend from maximum tillering to harvesting stage. Interaction of tillage and nitrogen management was found non-significant.

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

Treatments	CH ₄ (mg m ⁻² hr ⁻¹)			CO ₂ (mg m ⁻² hr ⁻¹)			N ₂ O (μg m ⁻² hr ⁻¹)		
	MT	PI	Mat.	MT	PI	Mat.	MT	PI	Mat.
Main Plots									
M ₁ (SRI-Conventional Wheat)	0.19	0.16	0.14	44.8	40	33.6	1.16	0.91	0.64
M ₂ (Transplanted Rice-Conventional Wheat + 30% rice residue incorporation)	0.28	0.24	0.23	65.3	62.6	60.6	0.91	0.64	0.33
M ₃ (DSR- ZT Wheat + 30% residue retention)	0.10	0.07	0.04	12.9	11.3	9.8	0.58	0.48	0.19
SEm (±)	0.006	0.001	0.002	0.823	0.999	0.511	0.018	0.016	0.010
CD (p = 0.05)	0.016	0.004	0.006	2.284	2.774	1.419	0.051	0.045	0.028
Subplots									
S ₁ (100% inorganic Fertilizer)	0.16	0.12	0.11	32.4	30.7	26.4	1.10	0.84	0.52
S ₂ (75% inorganic fertilizer + 25% organic Fertilizer)	0.20	0.17	0.14	43.5	39.6	36.5	0.78	0.58	0.35
S ₃ (50% inorganic fertilizer + 50% organic Fertilizer)	0.22	0.19	0.17	53.0	48.8	45.6	0.75	0.55	0.29
S ₄ (100% inorganic fertilizer + green manuring)	0.18	0.14	0.12	35.2	32.8	30.1	0.91	0.74	0.40
SEm (±)	0.005	0.004	0.004	1.061	1.086	0.439	0.030	0.012	0.010
CD (p = 0.05)	0.010	0.009	0.009	2.230	2.282	0.922	0.063	0.026	0.021

MT-Maximum tillering

PI-Panicle Initiation

Mat-maturity

Mostly, anaerobic conditions are prerequisite for activities of methanogenic bacteria that enhance methane production. Since methane oxidation potential gets disturbed by tillage operation, so under zero tillage, no disturbance of the soil causes less exposure soil organic matter resulted in lower chance of methane emission. Moreover there is more retention of Methane in soil under zero tillage system because soil has high bulk density and reduced porosity. 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. Besides this, higher carbon dioxide release was found in response to tillage that means the ploughing operation break down the soil aggregate and exposed the 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 (Sapkota *et al.* 2015) [14]. Conventional tillage increases the porosity of the soil which favors the respiration of aerobic microorganism by recovering movement of water

and air within the soil that augment carbon dioxide emission (Wassmann *et al.* 2000) [18]. 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 (Ahmed *et al.* 2009) [1]. The nitrification and denitrification process both are responsible for nitrous oxide emission (Liu *et al.* 2015) [10]. Actually nitrous oxide is produced under reducing condition or poorly aerated soil. In few case, under zero tillage condition the soil is wetter and denser and having more soil microbial biomass. 30 per cent residue retention is a common practice in zero tillage system that supplies adequate labile substrate to denitrifying bacteria for nitrous oxide emission. Similar result was obtained by the study carried out by Raj *et al.* (2014) [11] Liu *et al.* (2006) [9] and Zhang *et al.* (2009) [20]. In addition to this highest methane and carbon dioxide was emitted from S₃ plots (Table 2 and 3) supplemented from organic sources both during kharif and rabi season. This might be due to the fact that organic manures enhance substrate availability for microbial decomposition. Nitrous oxide emission from soil is mainly by microbial process of nitrification and denitrification also (Liu *et al.* 2015) [10]. Tillage may affect the biological, chemical and physical property of soil as well as influence the greenhouse gas emission like nitrous oxide (Smith and Conen

2004) ^[16]. Under nutrient management practices it was found that maximum nitrous oxide emission was from 100% nitrogen through neem coated urea as under such conditions there are chances of rapid mineralization and prone to loss through different pathways before it is utilized by crop. Basically application of nitrogenous fertilizers as basal to the soil would have further increased the substrate availability for soil nitrous oxide emission. Moreover, stated that fertilizer N use is directly linked quantum of with nitrous oxide (Smith and Conen 2004) ^[16]. 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.

Conclusion

It can be concluded that Direct seeded rice + Zero tilled wheat along with 30% residue retention had positive impact on yield, yield attributes and economics of both crops and system along with decrease in level of greenhouse gas emission from field. Thus the extensive practice of resource conservation methods along with the use of green manuring can bring not only sustainability in production but also lead to saving energy and cost effectiveness in perspective of climate change.

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