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Research Article

Performance of rice-wheat cropping system under conservation agriculture based establishment techniques in eastern Indian plains

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Abstract

Field experiments were conducted for two consecutive rice-wheat rotations to assess performance on system productivity, nutrient uptake and chemical properties of the soil. Four different crop establishment techniques [Direct Seeded Rice (DSR) followed by Surface Seeding (SS) in wheat, Bed Planting (BP) in rice followed by BP in wheat, Unpuddled Transplanted Rice (UPTR) followed by Zero Tillage (ZT) in wheat and Conventional Puddled Transplanted Rice (PTR) followed by wheat under Conventional Tillage (CT)] were tested. The highest Rice Equivalent Yield (REY) (8549 Kg ha^{-1}) was recorded in conventional system where rice was grown under PTR and wheat under CT. It was statistically at par with rice (UPTR)-wheat (ZT) where the mean REY was 8545 Kg ha^{-1}. The N, P and K uptake increased with higher biomass production under alternate establishment techniques like zero tillage or bed planting in wheat and unpuddled or puddled transplanting in rice. Though available K in soil decreased slightly (116.7-121.0 Kg ha^{-1} against 122.1 Kg ha^{-1}), the status of organic C (0.87%) improved to 0.89-0.9% along with higher mineralizable N (131.2-137.9 Kg ha^{-1} against initial 128.4 Kg ha^{-1}) and P (17.7-19.0 Kg ha^{-1} against initial 17.5 Kg ha^{-1}) after two years of rotation suggesting the sustainability of this system under conservation tillage based establishment techniques.

Keywords: Crop establishment techniques, nutrient uptake, productivity, rice-wheat system, soil chemical properties

1. Introduction

The rice-wheat system is the world's largest agricultural production system which covers an area of 12.3 million hectare (Mha) in India being the most popular and prevalent crop sequence. Conservation agriculture (CA) and crop diversification or intensification in rice-wheat cropping system is an emerging need for ensuring food security in South Asia (Jat *et al.*, 2014; Islam *et al.*, 2019). It is also a common cropping sequence in *sub-Himalayan* plains of West Bengal where rice is grown mostly under rainfed puddle condition and wheat is grown after harvesting rice in tilled land. The sowing of wheat mostly gets delayed due to presence of high soil residual moisture even after harvesting of medium-long duration rice varieties (Mitra and Das, 2015). Traditional puddle transplanted rice is the common practice of the farmers which helps in ponding of water, reducing percolation losses and controlling weeds. However, the destruction of soil structure and formation of hard pan during puddling may have adverse effects on the growth and yield of subsequent crops in the rotation and these crops may require more energy for field preparation (Kumar and Ladha, 2011).

The productivity and sustainability of rice based cropping systems is challenging because of deterioration of soil health due to intensive wet and dry tillage in sequence along with scarcity of labour, water and energy, changing climate scenarios and emerging socio-economic changes. Technologies tested in West Bengal reflected the superiority of unpuddled transplanted rice (UPTR) in terms of production economics, resource-use efficiency and productivity over puddle transplanted rice (Mitra *et al.*, 2018). Islam *et al.* (2019) have reported that although the conservation agriculture based sustainable intensification practices did not significantly affect rice yields, but both subsequent wheat and maize yields increased by ~5% using these alternate establishment practices compared to conventional farming practice. The zero tillage and bed planting technologies have also shown several advantages in rice based systems (Gathala *et al.*, 2013; Mitra *et al.*, 2014; Jat *et al.*, 2014; Singh *et al,* 2018; Singha *et al.*, 2018) in different parts of Indo-Gangetic plains. However, Islam *et al.* (2019) have reported large variability in crop yields in different parts of eastern Gangetic plains due to varied soil types, management levels and soil quality parameters such as pH, organic matter and nutrient status which may also change following conservation tillage practices (Karlen *et al.*, 2003; Dalal *et al.*, 2011; Choudhary *et al.*, 2018; Sinha *et al.*, 2019); The soil physicochemical properties are affected differently by conservation tillage practices in eastern Ganga Alluvial plains (Sinha *et al.*, 2019). With this idea, the experiment was conducted with various crop establishment techniques in rice-wheat system to judge the system productivity and to assess the changes in nutrient uptake *vis-a-vis* chemical properties of soil.

2. Materials and methods

The experiment was conducted at the Instructional Farm of Uttar Banga Krishi Viswavidyalaya, Pundibari, Coochbehar located at 26°24' N latitude, 89°23' E longitude and at an elevation of 43 meters above mean sea level. It was carried out for two consecutive rice-wheat rotations, i.e., *Kharif* 2015 to *Rabi* 2016-17. The soil was sandy loam in texture having mineralizable N (128.4 Kg ha^{-1}), available P (17.5 Kg ha^{-1}) and available K (122.1 Kg ha^{-1}) with pH 5.5.

Four different crop establishment techniques were put in long narrow strips with a plot size of 100 m x 5 m. The experiment was conducted in Randomized Block Design (RBD) with five replications for each treatment. The treatments were:

T1 –Direct Seeded Rice (DSR) followed by Surface Seeded (SS) wheat

T2- Bed Planting (BP) in rice followed by Bed Planting (BP) in wheat

T3-Unpuddled Transplanted Rice (UPTR) followed by Zero Tillage (ZT) wheat

T4-Conventional Puddled transplanted rice (PTR) followed by Conventional Tillage (CT) wheat

The layout of the experiment was kept undisturbed for the entire experimental period. For ZT, BP and SS wheat, straw of preceding rice crop was retained at 15-20 cm height during harvest, while for DSR and BP rice, wheat straw was retained to a height of 15-20 cm in field. For conventional rice (PTR) and wheat (CT) as well as for UPTR, the previous crop stubbles were incorporated in the field during land preparations. The variety used was MTU 7029 (duration: 145-150 days; medium slender grain; suitable for rainfed ecosystem; average yield: 4.0 – 4.5 t ha^{-1}) for rice and HD 2967 (timely sown irrigated; duration: 135-140 days; resistant to leaf blight; average yield: 3.5 – 4.0 t ha^{-1} in north eastern plains) for wheat.

The entire produce from the net plot area of 12.8 m^2 (8 inner lines, each of 8 m length with 20 cm spacing) was harvested and weighed after thorough drying under sun. Grain yield from that area was converted to Kg ha^{-1}. The Rice Equivalent Yield (REY) of the system was worked out with the output price of rice and wheat as ₹ 11.00 and ₹ 13.00, respectively in first year and ₹ 11.50 and ₹ 14.00, respectively in second year.

Initial soil samples (up to 30 cm depth) from the experimental field were collected from various places and a composite soil sample was prepared. At harvest, soil samples (up to 30 cm depth) were also collected from each plot to determine the soil status after harvesting of the crop. Soils were air-dried, thoroughly mixed and then ground to pass through a 2 mm sieve for estimation of various properties following standard methods. The available nitrogen of the soils was estimated through the hot alkaline potassium permanganate method (Subbiah and Asija, 1956). The available phosphorus of the soils was extracted with 0.5 M $NaHCO_3$ and estimated by the method of Olsen *et al.* (1954). Available potassium of the soil samples was extracted with neutral ammonium acetate solution and estimated by the method of Brown and Warncke (1988).

Chemical analysis of plant parts was done by taking random samples of plant parts at harvest. Grain and straw portions were crushed and kept separately. Estimation of total nitrogen, phosphorus and potassium contents in plant materials was done on dry weight basis. The total nitrogen content in plants was determined by modified micro-kjeldahl method (Jackson, 1973). Phosphorus content of the plant materials was determined by tri-acid digestion through vanado-molybdate-orthophosphate complex of yellow colour in HNO_3 medium using a spectrophotometer at 420 nm wavelength and by using standard curve (Jackson, 1973). Potassium content of the plant materials was determined by tri-acid digestion method with the help of Flame Photometer and by using standard curve as described by Muhr *et al.* (1963). The total uptake of nitrogen, phosphorus and potassium by rice and wheat at harvest was determined on dry weight basis by multiplying the total dry matter of the crop with its corresponding nutrient content.

Data were subjected to analysis of variance (ANOVA) and analyzed using the SPSS window version 17.0

(SPSS Inc., Chicago, USA). Treatment means were separated by Duncan Multiple Range Test at 5% level of significance.

3. Results and discussion

3.1 System productivity

Mean REY was highest (8549 Kg ha^{-1}) in conventional system where rice was grown under PTR and wheat under CT (Table 1). This treatment was statistically *at par* with rice (UPTR)-wheat (ZT) where the mean REY was 8545 Kg ha^{-1}. It was interesting to note that rice under UPTR followed by wheat under ZT recorded lower REY (8223 Kg ha^{-1}) compared to conventional system (8560 Kg ha^{-1}) in the first year, but in the subsequent year REY obtained rice (UPTR)-wheat (ZT) was much higher (8867 Kg ha^{-1}) than the conventional system (8538 Kg ha^{-1}). The yield obtained under UPTR in second year was much higher than the first year due to better weed control, which was lacking in the first year. Actually rice crop grown under unpuddled condition faced severe weed infestation which was controlled from very beginning with appropriate herbicidal interventions in the second year. With improved weed management practices, the yield obtained under UPTR was similar to PTR during second year. Again, the yield of subsequent ZT-wheat was also higher compared to first year with higher farm gate price leading to higher system productivity under rice (UPTR)-wheat (ZT) system. Despite better performance of wheat under bed planting, rice (BP)-wheat (BP) recorded much lower mean REY (7472 Kg ha^{-1}) due to poor performance of rice under BP. Rice was grown under temporary beds having an elevation of only 8-10 cm, having stagnated water with peak monsoon resulting in poor crop stand. The lowest REY (5017 Kg ha^{-1}) was noted in the system where DSR was followed by SS of wheat. Poor performance of both the crops under this system is attributed to lower yield performance. In the experimental site, zero tillage was in vogue for last couple of years (even before start of experimentation, two crop rotations were under ZT for both rice and wheat). Better physico-chemical properties with the successive crop seasons resulted in higher yield performances under rice (UPTR)-wheat (ZT) reflecting almost similar REY as achieved under conventional system. Long term studies have indicated varying yield benefits under CA systems compared to CT; while working with a seven year study of RW systems in eastern India, Jat *et al.* (2014) have reported higher rice yields under CT compared to CA for the first three years, comparable yields for the fourth and fifth years, and higher yields in the CA system for the sixth year. CA systems had similar or higher yields than those of CT in long term trials (Gathala *et al.*, 2013; Kumar *et al.*, 2018). Higher system productivity of rice (UPTR)-wheat (ZT) in eastern Gangetic plains was previously reported by Islam *et al.* (2019). REY reflected the superiority of conservation agriculture (CA)-based system when it practiced over couple of years. Similar results under puddled and unpuddled transplanted rice were previously reported by Patra *et al.* (2018) in rice-wheat sequence under *terai* region of West Bengal.

Table 1: Rice equivalent yield of the system under various crop establishment techniques.

RW system under various CET	2015-16			2016-17			Mean REY (Kg ha^{-1})*
	Rice (Kg ha^{-1})	Wheat (Kg ha^{-1})	Rice equivalent yield (Kg ha^{-1})*	Rice (Kg ha^{-1})	Wheat (Kg ha^{-1})	Rice equivalent yield (Kg ha^{-1})*	
Rice(DSR)-Wheat(SS)	2254^{c}	2127^{c}	4768^{c}	2751^{c}	2066^{c}	5266^{c}	5017^{c}
Rice(BP)-Wheat(BP)	3027^{b}	3713^{a}	7415^{b}	3026^{b}	3699^{a}	7529^{b}	7472^{b}
Rice(UPTR)-Wheat(ZT)	4141^{a}	3454^{b}	8223^{a}	4616^{a}	3492^{a}	8867^{a}	8545^{a}
Rice(PTR)-Wheat(CT)	4502^{a}	3434^{b}	8560^{a}	4606^{a}	3230^{b}	8538^{a}	8549^{a}

******Within a column, means followed by the same letter are not significantly different at 0.05 level of probability accordingly to Duncan Multiple Range Test*

3.2 System nutrient uptake

Data on total uptake of nitrogen by rice-wheat cropping system indicated that there was significant variation in total uptake of nitrogen as it varied between 242.4 to 357.7 Kg ha^{-1} after two years of rotation (Table 2). Conventional system of cropping, i.e., rice (PTR)-wheat (CT) recorded the highest uptake of nitrogen (176.8 Kg ha^{-1}) in the first year, while rice (UPTR) - wheat (ZT) recorded the highest uptake (183.3 Kg ha^{-1}) in the second year, being *at par* with each other. The higher uptake of N is those systems was due to dry matter production by crop and less depletion of nutrients from the soil due to better management. It was noted that there was no significant difference in N uptake in PTR and UPTR for rice and ZT and BP for wheat. As the grain yields obtained under those systems for both the crops were similar, there was not much difference in uptake of N between the systems. The uptake of N in wheat grown under BP was much higher due to attainment of higher yields but unsatisfactory crop stand resulted in poor uptake in BP rice. Very poor crop stand *vis-à-vis* lesser yield attained under rice (DSR)-wheat (SS) system

Table 2: Nitrogen uptake of the system under various crop establishment techniques.

RW system under CET	Nitrogen uptake (Kg ha^{-1})						
	2015-16			2016-17			Grand Total
	Rice	Wheat	Total	Rice	Wheat	Total	
Rice(DSR)-Wheat(SS)	47.7^{d}	85.8^{ab}	133.5^{c}	53.0^{c}	56.0^{b}	109.0^{c}	242.4^{c}
Rice(BP)-Wheat(BP)	58.6^{c}	91.2^{a}	149.8^{b}	60.6^{b}	93.0^{a}	153.6^{b}	303.4^{b}
Rice(UPTR)-Wheat(ZT)	83.2^{b}	86.0^{ab}	169.2^{a}	94.0^{a}	89.3^{a}	183.3^{a}	352.4^{a}
Rice(PTR)-Wheat(CT)	92.2^{a}	84.5^{b}	176.8^{a}	96.5^{a}	84.5^{a}	181.0^{a}	357.7^{a}

Within a column, means followed by the same letter are not significantly different at 0.05 level of probability accordingly to Duncan Multiple Range Test

resulted in much lower uptake of N (32.23% lower than the conventional system) for the system as a whole. Malhi *et al.* (2007) have reported significantly higher grain and straw N uptake in ZT plots where straw was retained than CT plots. These findings are also corroborated with the study of Mukherjee (2008) and Gupta *et al.* (2007).

Data on phosphorus uptake by rice-wheat system under different crop establishment techniques also showed significant variations in total uptake of phosphorus. Phosphorus uptake over the system over the years were quite similar and it ranged between 24.7 to 46.0 Kg ha^{-1} and 24.3 to 45.0 Kg ha^{-1} during the first and second year of experimentation, respectively (Table 3). Alike N uptake, there was no significant variation in P-uptake between UPTR and PTR in both the years. Tillage and straw management hardly contributed to grain and straw P content, it was actually the total biomass for which the variation in P uptake was noticed. The uptake was very poor in DSR and BP rice due to its lesser biomass production; again it was SS which failed to produce higher biomass due to its poor crop stand. Due to attainment of higher yields under PTR and UPTR in rice and under ZT, BP and CT in wheat, being similar yields, there was no significant variation in P uptake between those establishment techniques. As far as the entire cropping system is concerned, rice (UPTR)- wheat (ZT) brought about an increased total uptake (89.54 Kg ha^{-1}) after two complete rotation closely followed by rice (PTR)- wheat (CT) (88.09 Kg ha^{-1}) and rice (BP)- wheat (BP)(82.88 Kg ha^{-1}). In agreement to our findings, significantly higher uptakes of macronutrients (N, P and K) under conservation tillage with residue retention have also been recorded by Kharia *et al.* (2017).

Total uptake of potassium followed similar trends like N and P. Likewise after two years of rotation, rice (UPTR)- wheat (ZT) and rice (PTR)- wheat (CT) recoded higher uptakes over the other two systems, being *at par* with each other (Table 4) and in each year these two systems resulted in almost similar uptake of potassium[183.06 and 196.26 Kg ha^{-1} in rice (UPTR)- wheat (ZT) and 196.28 and 195.22 Kg ha^{-1} in rice (PTR)- wheat (CT) during 2015-16 and 2016-17, respectively]. Better environment around the rhizosphere under CA practices enabled the crop to grow better and absorb more nutrients under the favourable environments with increased nutrient availability. Higher dry matter production with increased nutrient content in rice grain and straw resulted in higher uptake under PTR and UPTR. For the same reason, the uptake was higher under BP and ZT in wheat. Application of fertilizers in the seeding zone helps the plant to use it more efficiently for which the depletion was lesser. With better use of applied nutrients under ZT and BP system, plants could achieve higher yields with higher proportion of nutrients in grain and straw leading to higher nutrient uptake. Higher nutrient uptake in wheat under ZT over CT has been reported by Mitra

Table 3: Phosphorus uptake of the system under various crop establishment techniques.

RW system under CET	Phosphorus uptake (Kg ha^{-1})						
	2015-16			2016-17			Grand Total
	Rice	Wheat	Total	Rice	Wheat	Total	
Rice(DSR)-Wheat(SS)	13.1^{c}	11.6^{c}	24.7^{b}	13.4^{c}	10.8^{c}	24.3^{c}	49.0^{c}
Rice(BP)-Wheat(BP)	17.1^{b}	25.9^{a}	43.0^{a}	16.1^{b}	23.8^{a}	40.0^{b}	82.9^{b}
Rice(UPTR)-Wheat(ZT)	22.1^{a}	22.5^{b}	44.6^{a}	23.5^{a}	21.5^{b}	45.0^{a}	89.5^{a}
Rice(PTR)-Wheat(CT)	23.2^{a}	22.8^{b}	46.0^{a}	21.1^{a}	21.0^{b}	42.1^{ab}	88.1^{ab}

Within a column, means followed by the same letter are not significantly different at 0.05 level of probability accordingly to Duncan Multiple Range Test

Table 4: Potassium uptake of the system under various crop establishment techniques.

RW system under CET	Potassium uptake (Kg ha^{-1})						
	2015-16			2016-17			Grand Total
	Rice	Wheat	Total	Rice	Wheat	Total	
Rice(DSR)-Wheat(SS)	62.2^{d}	57.6^{c}	119.8^{c}	74.8^{b}	58.4^{b}	133.2^{c}	253.0^{c}
Rice(BP)-Wheat(BP)	78.7^{c}	93.5^{a}	172.2^{b}	81.9^{b}	90.2^{a}	172.1^{b}	344.4^{b}
Rice(UPTR)-Wheat(ZT)	98.0^{b}	85.1^{b}	183.1^{ab}	109.4^{a}	86.9^{a}	196.3^{a}	379.3^{a}
Rice(PTR)-Wheat(CT)	109.6^{a}	85.1^{b}	194.7^{a}	112.6^{a}	82.6^{a}	195.2^{a}	389.9^{a}

Within a column, means followed by the same letter are not significantly different at 0.05 level of probability accordingly to Duncan Multiple Range Test

et al. (2014) in *sub-Himalayan* plains. Varying levels of nutrient absorption in rice in relation to establishment techniques was also reported by Sing *et al.* (2007) and Singh *et al.* (2008).

The nutrient content in the grain and straw components varied across different tillage and management practices. The N, P and K uptake increased with increased biomass yield. The density of crop roots is usually greater near the soil surface under zero tillage or bed planting in wheat compared to conventional tillage that facilitate the higher uptake of these nutrients in plots having alternate crop establishment techniques with a good crop stand (Kumar *et al.*, 2015).

3.3 Soil chemical properties

The RW system under various resource conservation-based establishment techniques resulted in slight improvement of organic C over two years of experimentation. The initial status of the experimental soil was 0.9%; the value increased to 0.9, 0.9 and 0.9 % after two complete crop rotations under rice (DSR)-wheat (SS), rice (BP)-wheat (BP) and rice (UPTR) - wheat (ZT) systems, respectively (Table 5). The organic C under conventional rice (PTR) - wheat (CT) system dropped down to 0.8%. Retention of more crop residues under alternate establishment systems probably helped the soil to improve the status of organic C. Frequent and excessive tillage under conventional method along with residue removal resulted in decreased organic C. Higher organic C under CA-based practices than conventional tillage practices has been previously reported by Sinha *et al.* (2019) in eastern Ganga alluvial plains. Higher mineralized nitrogen (N) after each year of experimentation (131.5 and 137.9 Kg ha^{-1} after year I & II, respectively) was recorded under rice (DSR)-wheat. (SS) system. Rice (BP)-wheat (BP) and rice (UPTR)-wheat (ZT) systems also resulted in improved N status over the initial soil status in terms of mineralized N. However, under conventional system, i.e., rice (PTR)-wheat (CT), there was slight decrement in N status of the soil (125.5 and 124.3 Kg ha^{-1} after first and second rotation, respectively). The N status in rice (BP) - wheat (BP) increased to 132.8 Kg ha^{-1} at the end of second year from the initial status of 128.4 Kg ha^{-1}. Tillage-induced changes in soil N are often directly related to changes in soil organic C.

There was improvement in soil available P under alternate crop establishment techniques particularly where no tillage was performed along with retention of more crop residues. The accumulation of P at the top soil under zero tillage or tillage with minimum soil disturbance could be explained by the limited downward movement of particle-bound P and the upward movement of nutrients from deeper layers through uptake by roots (Roldan *et al.*, 2005). The soil available P decreased to 15.0 Kg ha^{-1} after two complete rotations under systems where rice was transplanted under puddled land followed by wheat under repeated tillage operations. These improvements

Table 5: Soil chemical properties as influenced by various crop establishment techniques

RW system under various CET	Organic C (%)		Mineralizable N (Kg ha^{-1})		Available P (Kg ha^{-1})		Available K (Kg ha^{-1})	
	After 1st rotation	**After 2nd rotation**	**After 1st rotation**	**After 2nd rotation**	**After 1st rotation**	**After 2nd rotation**	**After 1st rotation**	**After 2nd rotation**
Rice(DSR)-Wheat(SS)	0.9	0.9	131.5	137.9	18.6	19.0	122.0	121.3
Rice(BP)-Wheat(BP)	0.9	0.9	131.3	132.8	17.9	18.4	116.1	118.2
Rice(UPTR)-Wheat(ZT)	0.9	0.9	131.2	131.7	17.8	17.7	116.9	116.7
Rice(PTR)-Wheat(CT)	0.8	0.8	125.5	124.3	15.1	15.0	116.1	114.3
Initial	0.9		128.4		17.5		122.1	

under ZT/BP/UPTR/DSR systems were prominent in surface (0-15 cm) layer. The residue mulch provided an optimum soil thermal regime, allowing better seedling emergence and subsequent rooting. The improvements in soil properties and water infiltration under ZT with residue retention have profound implications for crop production in rice-wheat system (Gathala *et al.*, 2017).

Available potassium (K) content of the experimental soil after two years of experimentation suggested that it was maintained little bit only under rice (DSR)-wheat (SS) system. There was decrement in available K status even under rice (BP)-wheat (BP) and rice (UPTR)-wheat (ZT) systems though the extent of decrement was very less. The changes in soil potassium status was marginal and retained straw under alternate crop establishment techniques helped to maintain the soil K status due to higher K contents in straw. However, the available K after two years crop rotation decreased to 114.30 Kg ha^{-1} from the initial status of 122.09 Kg ha^{-1} under conventional system.

4. Conclusions

The study indicated that sustainable conservation of resources with crop residue retention under alternate crop establishment techniques in rice-wheat system would improve soil physico-chemical parameters with increased system yield. The status of soil organic C, N and P improved after two complete rotations suggesting the sustainability of this system under conservation tillage-based establishment techniques. The study further suggests the need of K inputs towards maintenance of soil fertility under CA-based rice-wheat system.

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