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Research Paper

Comparative assessment of different tillage-cum-crop establishment practices and crop-residue management on crop and water productivity and profitability of rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system

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ABSTRACT

A field experiment was conducted during the winter 2009 at Patna, Bihar, to assess the impact of the continuous practice of 4 different tillage-cum-crop establishment and 2 residue-management treatments on crop growth, productivity and profitability of rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L.) cropping system (RWCS) in eastern Gangetic plains. After 5-year continuous rice–wheat rotation, crop-residue retention (~33%) in both the crops significantly improved the rice (9.4–9.7%) and wheat (4.6–9.3%) productivity over the residue removal. Conservation tillage-based crop-establishment practices, viz. unpuddled transplanted rice followed by (*fb)* zero-till wheat (UPTR-ZTW), zero-till transplanted rice *fb* zero-till wheat (ZTTR–ZTW), zero-till direct-seeded rice, *fb* zero-till wheat (ZTDSR–ZTW) increased the system productivity of RWCS by 10.3, 16.1, and 23.2% respectively, over conventional puddled transplanted rice *fb* conventional-till wheat (PTR–CTW). Conservation tillage-based crop-establishment practices and residue retention enhanced the biomass accumulation rate in both crops, being higher in ZTDSR-ZTW *fb* ZTTR-ZTW. Significant up-scaling of water productivity in rice crop was evident in conservation tillage-cum-crop-establishment practices over PTR-CTW. The additional income of ₹24,248, ₹36,689, and ₹48,553 was realized for the treatments UPTR-ZTW, ZTTR–ZTW and ZTDSR–ZTW respectively, over PTR-CTW.

Key words : Direct-seeded rice, Economics, Productivity, Residue retention, Unpuddled transplanting, Tillage, Zero tillage transplanting

Rice–wheat cropping system (RWCS) is the dominating cropping system in Indo-Gangetic Plain (IGP). Presently, the RWCS covers an area of 10.5 million ha in India (Singh *et al*., 2016). The productivity and sustainability of the RWCS is very crucial for the country's food security and livelihood of farmer's community in the IGP (Jat *et al*., 2014). However, several major challenges are now progressively being evident in RWCS like degradation of soil native fertility and multi-nutrient deficiency, the decline in watertable, and increased pest pressure including weeds (Venkatesh *et al*., 2013; Hazra *et al*., 2014; Das *et al*., 2014; Nath *et al*., 2017a;). In the post-green revolution era, resource conservation issues have assumed greater importance in view of the widespread land and water degradation problems due to mechanized intensive tillage in RWCS (Humphreys *et al*., 2010). In addition, the conventional production practices resulted in high cultivation cost and inefficient input use. This call for identification of suitable production practices other than puddled transplanted rice followed by conventional till-wheat (PTR-CTW) in the IGP. Also, there is need for shifting production practices in accordance to the resource availability, particularly with soil characterization and water availability.

Several alternative rice-establishment practices and conservation tillage practices are now being advocated for RWCS (Jat *et al*., 2009; Nath *et al*., 2017b) in place of PTR-CTW. The unpuddled transplanting of rice, direct-seeded rice, zero-tillage direct-seeded rice and successive

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wheat-crop establishment under zero-tillage often recommended for conserving the natural resources and improving the sustainability of RWCS (Das *et al*., 2013). Potential productivity and assured high returns could be realized from these alternative tillage practices in RWCS, which also improves the livelihood of the farmers of the region. In cereal-based cropping systems, huge volume of crop residues are produced and are used as animal feed, thatching homes and domestic fuels. Large portion of unused crop residues is burned which leads to environmental pollution. Residue application was found beneficial to soil health, crop productivity, and nutrient-use efficiency. Zero tillage and surface maintained crop residues result in resource improvement gradually and benefits come about only with time (Prasad *et al*., 1999).

Therefore, as major components of conservation agriculture in RWCS suitable tillage-cum-crop-establishment techniques has to be identified based on system productivity, resource-conservation efficiency and profitability. Fewer studies have been conducted on the new generation crop-establishment practices in rice and in succeeding wheat in the IGP, particularly in a system mode for long-term. Moreover, information regarding the combined effect of residue management and alternate tillage-cum-crop establishment on water productivity is not available. In the present investigation, the mid-term effect of the different system-based tillage-cum-crop establishment practices and residue management were evaluated at fourth and fifth years on crop productivity and profitability of RWCS.

MATERIALS AND METHODS

The field experiment was initiated during 2009 at research farm of Indian Council of Agricultural Research, Research Complex for Eastern Region, Patna, Bihar. The climate of experimental site is subtropical humid, with an average annual rainfall of 1,130 mm. The experimental soil comes under the taxonomical class Typic Ustochrept with silty-clay soil texture with medium soil organic carbon (SOC) content (6.5 g/kg soil). In the present investigation, we presented the data of 2013–14 (4th year) and 2014–15 (5th year) for the comparative assessment of different treatments. Treatment comprised 2 levels of residue management [residue removal and residue retention (~33%)], and 4 levels of tillage-cum-crop establishment practices as follows: (*i*) conventional puddled transplanted rice *fb* conventional-till wheat (PTR-CTW): 2 dry-harrowing followed by 2 wet-tillage (puddling) and 1 planking was done before the manual transplanting of 21 days old seedling at 20 cm spacing. After rice harvesting, wheat was sown by broadcasting in conventionally tilled plots (2 harrowing + 2 tillage + 1 planking); (*ii*) unpuddled transplanted rice *fb* zero-till wheat (UPTR-ZTW): dry tillage was followed by planking and wet tillage was avoided. Rice seedlings of 21 days old were transplanted at 20 cm spacing. Wheat crop was sown under ZT using zero till happy-seeder machine; (*iii*) zero-till transplanted rice *fb* zero-till wheat (ZTTR-ZTW): The plots were flooded 1 day before transplanting of the seedling to make the soil soft. Line transplanting was done in flooded plots with 20 cm spacing. Wheat crop was sown under ZT using Zero till happy-seeder machine; (*iv*) zero-till direct-seeded rice *fb* zero-till wheat (ZTDSR-ZTW): direct-seeding of rice was done using zero-till seed-cum-fertilizer drill in ZT-flat plots at 20 cm row spacing. Wheat crop was sown in zero tillage using zero till happy-seeder machine. Rice variety (Hybrid 'Arize Tez') was sown directly by zero till happy-seeder in ZTDSR-ZT plots in the first fortnight of June. On the same date, rice seedlings for transplanting were raised in nursery by 'Wet bed method'. Twentyone days old seedling was transplanted in the plots with different tillage practices (PTR-CTW, UPTR-ZTW and ZTTR-ZTW). Recommended dose of fertilizer N : P_2O_5 : K_2O was 120 : 40 : 40 kg/ha. Half dose of nitrogen and full dose of phosphorus and potassium along with 25 kg $ZnSO_4$ was applied manually. Remaining dose of nitrogen in 2 equal split was applied at 30 and 60 days after sowing (DAS). The wheat crop (variety 'HD 2967') was sown in the second fortnight of November with the help of with row spacing of 22.5 cm and manually brodcasted in conventional plot (PTR-CTW). Recommended dose of applied N : P_2O_5 : K_2O was 120 : 60 : 40 kg/ha. The half quantity of N and full doses of P and K were applied at the time of sowing. Remaining dose of N in form of urea was applied in 2 equal splits at 21 and 50 DAS.

For estimation of crop growth rate (CGR) the dry biomass of rice and wheat was recorded at 30, 60, 90, 120 DAS. The mean crop growth rate was worked out with the following formula:

$$\text{CGR} = \left(\frac{W_2 - W_1}{T_2 - T_1}\right)\left(\frac{1}{A}\right)$$

where, W_1 and W_2 are dry weight (g) of plants at time T_1 and T_2, respectively; T_2- T_1 is the interval of time in days; A is the land area (m^2) occupied by plants.

In the present investigation, the irrigation water was applied at measured quantity using water meter according to the tillage-cum-crop establishment treatments. The irrigation water productivity (IWP) (kg/ha-cm) was calculated as:

$$\text{IWP} = \frac{\text{Grain yield (kg/ha)}}{\text{Total irrigation water applied (ha–cm)}}$$

Rice and wheat were harvested using combine harvester and were threshed by a power-operated thresher. Data on grain yield were recorded from the net plot, whereas tillers density was measured by using quadrat of 0.5 m × 0.5 m by selecting 2 spots randomly and density was expressed in number of tillers/m^2. The economics of treatments was computed on the basis of prevailing market prices of inputs and outputs under each treatment. For calculating economics of the systems, the input costs of all the items like tillage operation, costs of seed, herbicide treatment application, chemical fertilizers, and the hiring charges of human labour and machines for land preparation, irrigation, fertilization, harvesting, and threshing were used in cost of cultivation. While, gross output was calculated based on the grain and straw price produced from the field. The benefit: cost ratios were calculated for each treatments applied in the system as the ratios of net returns to cost of cultivation. The data collected for all parameters at different crop stages were compiled and subjected to statistical analysis using the analysis of variance technique (Gomez and Gomez, 1984). The critical difference (at 5% level of probability) was computed for comparing treatment mean in cases where effect came out to be significant by F-test as follows.

RESULTS AND DISCUSSION

Crop-growth rate

The crop-residue management and tillage-cum-crop establishment practices (T and CE) significantly influenced the crop-growth rate (CGR) of both rice and wheat crop at 4th (2013–14) and 5th (2014–15) year of crop rotation (Fig. 1). During both the study year, rice crop under residue retention plots had higher rate of biomass accumulation over residue removal plots. The increased CGR in residues-retention treatment might be associated with additional input of plant nutrients added through the crop residues and improved soil properties, particularly the soil organic carbon (Venkatesh *et al*., 2013). Likewise, among the different T and CE practices, the conservation tillage practices (UPTR-ZTW, ZTTR-ZTW, and ZTDSR-ZTW) had the higher rate of crop growth during 30–60, 60–90, and 90–120 DAS. The ZTDSR-ZTW treatment resulted in higher CGR values over other T and CE practices (Fig. 1). However, results indicated that ZT-based crop-establishment practices resulted in slow crop-growth rate compared with conventional PTR-CTW at initial stage (0–30 DAS). According the Jat *et al*. (2014), the higher biomass accumulation under continuous ZT-based crop-establishment practices is attributed to higher production of tillers and their individual growth. This way, the results indicated that conventional puddle-based system is not necessarily the optimum for rice growth and there is a long-term negative impact on crop growth.

Likewise for wheat crop, the significant difference in CGR was apparent at different growth stages with different residues management and T and CE practices. The trend was almost similar to the rice crop and crop-residues retention improved the crop-biomass accumulation, particularly at 30–60 and 90–120 DAS. On the other side, conservation T and CE improved the CGR than conventional PTR-CTW treatment. In fact, the line sowing of wheat by machine in conservation-tillage treatments is one of the reasons of improved crop growth than broadcast sown conventional wheat in PTR-CTW. Moreover, resi-

Table 1. Grain yield (t/ha) of rice and wheat as influenced by residue management and tillage-cum-crop-establishment practices during 4th and 5th year of crop rotation

Treatment	Grain yield (t/ha)				System productivity (REY*, t/ha)	
	2013–2014		2014–2015		2013–2014	2014–2015
	Rice	Wheat	Rice	Wheat		
Residue management						
Residue removal	4.61	5.02	4.43	5.12	9.63	9.74
Residue retention	5.08	5.29	4.81	5.66	10.37	10.68
SEm±	0.02	0.03	0.05	0.02	0.02	0.06
CD (P=0.05)	0.13	0.16	0.21	0.16	0.12	0.36
Tillage-cum-crop-establishment						
PTR-CTW	4.47	4.59	4.06	4.68	9.06	8.92
UPTR-ZTW	4.59	5.07	4.46	5.51	9.66	10.18
ZTTR-ZTW	4.94	5.34	4.75	5.63	10.28	10.59
ZTDSR-ZTW	5.39	5.62	5.21	5.73	11.01	11.15
SEm±	0.09	0.13	0.11	0.13	0.21	0.18
CD (P=0.05)	0.29	0.41	0.34	0.40	0.66	0.57

REY, Rice-equivalent yield (t/ha); PTR-CTW, puddled transplanted rice *fb* conventional-till wheat; UPTR-ZTW, unpuddled transplanted rice *fb* zero-till wheat; ZTTR-ZTW, zero-till transplanted rice *fb* zero-till wheat; ZTDSR-ZTW, zero-till direct-seeded rice *fb* zero-till wheat

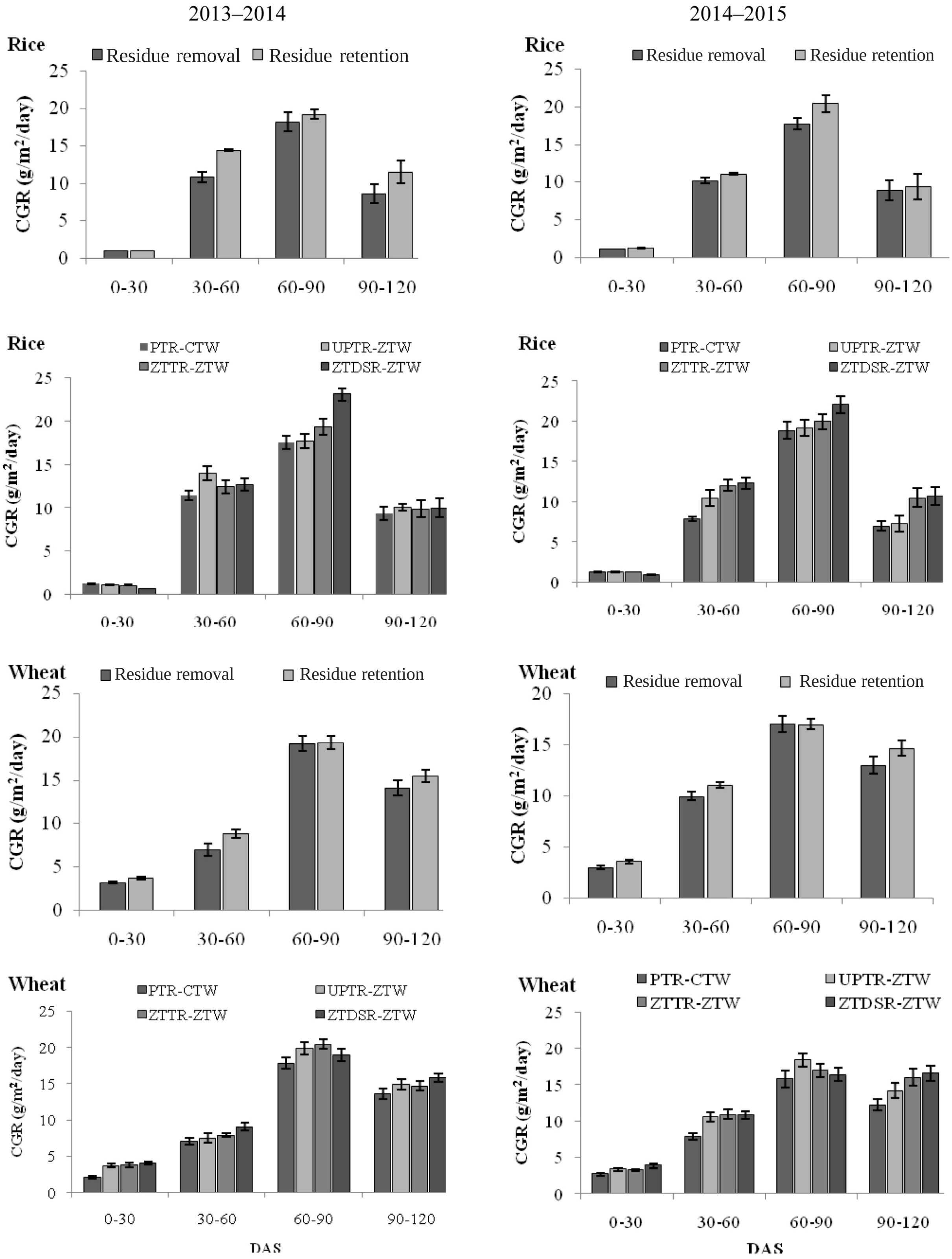

Fig. 1. Crop growth rate of rice and wheat crop as influenced by residues retention and tillage-cum-crop-establishment practices

dues application under ZT-wheat treatments (UPTR-ZTW, ZTTR-ZTW, and ZTDSR-ZTW) moderated abiotic stress, particularly soil temperature and conserved soil moisture, resulting in better crop growth. This effect of ZT was also compounded by the residue retention, which suppressed the weed growth due to shedding of residue. The ZT with residues retention suppressed weed-seedling emergence, delayed the time of emergence, and allowed the crop to gain an advantage over weeds that ultimately enhanced the crop growth (Nath *et al*., 2015).

Grain yield and system productivity

In the present study, continuous residues retention (~33%) significantly improved the grain yield of both the component crops. For rice crop, 9.4–9.7% higher grain yield was realized with retention of crop residues. Likewise, residues retention increased the wheat grain yield by 4.6–9.3% (Table 1). In consistent with our results, Choudhury *et al*. (2014) and Laik *et al*. (2014) also reported the improved crop productivity with residues retention in RWCS. The effect of T and CE practices was much stronger and conservation tillage practices had improved the grain yield of both rice and wheat crop over conventional puddled transplanted rice. Among the T and CE practices, higher grain yield were registered in ZTDSR-ZTW (5.21–5.39 t/ha) closely followed by ZTTR-ZTW (4.75–4.94 t/ha) and recorded the least in PTR-CTW (4.06–4.47 t/ha). Like rice crop, wheat grain yield was also higher in ZT-based crop establishment and higher yield was realized in ZTDSR-ZTW (5.62–5.73 t/ha) indicating that the tillage practices adopted in preceding rice crop may impact largely to the successive wheat crop (Table 1). Indeed, wheat crop was particularly suffered after puddling for rice which can be attributed to poor rooting due to soil compaction and poor aggregation, as reported by other researchers in the region (Jat *et al*. 2009; Kumar and Ladha, 2011; Gathala *et al*. 2011). The increased grain yield of rice and wheat was mainly associated with the increased tiller formation under conservation tillage-based crop-establishment practices. Therefore, a higher correlation (r) of grain yield and tiller density was evident in the study (Fig. 2). The system productivity as expressed by rice-equivalent yield (t/ha) was increased by 10.3, 16.1, and 23.2%, respectively, in UPTR-ZTR, ZTTR-ZTW and ZTDSR-ZTW treatments over conventional PTR-CTW. The grain yield in ZT was significantly higher owing to greater number of ear-bearing tillers/m^2 and 1,000-grain weight (data not presented). This might have resulted from greater sink and good growth in the reproductive phase (as reflected in higher CGR and tillers in rice and wheat). Also there may be a positive impact of ZT and residues on soil water balance, because of reduction in soil evaporation

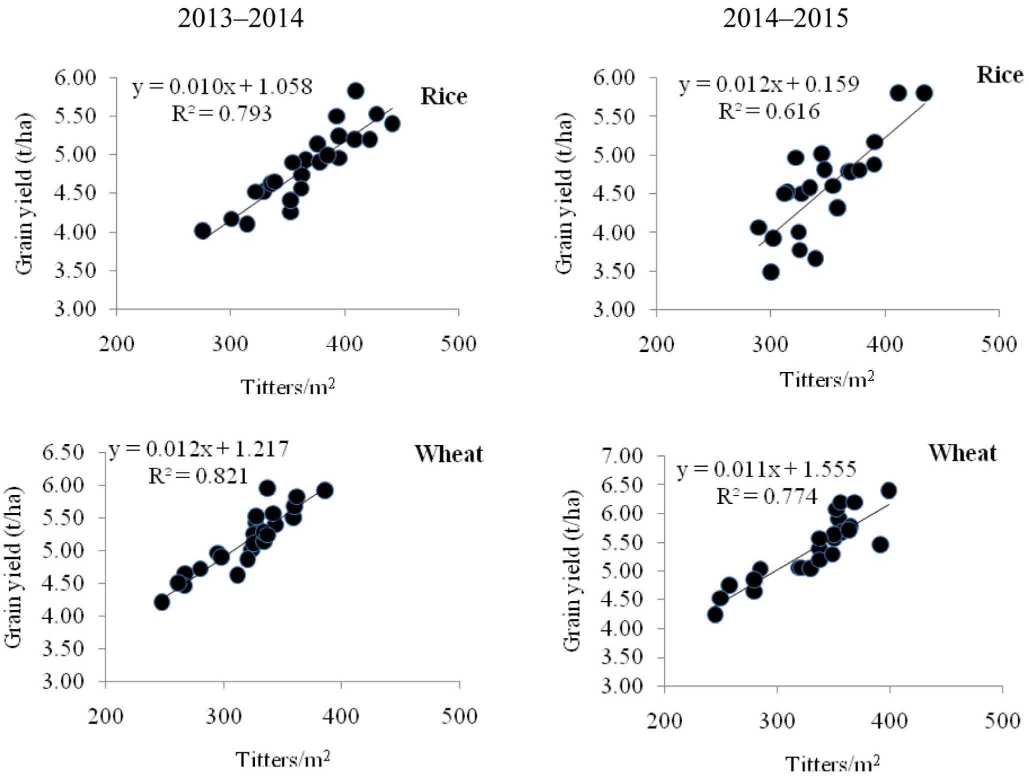

Fig. 2. Relationship between tiller density (numbers/m^2) and grain yield of rice and wheat during 2013–2014 and 2014–2015

Table 2. Irrigation water productivity and economics under different residue management and tillage-cum-crop-establishment practices in rice–wheat system (mean data of 2 years, 2013–2014 and 2014–2015)

Treatment	Irrigation water applied (ha-cm)			Irrigation water productivity (kg/ha-cm)			Economics		
	Rice	Wheat	System	Rice	Wheat	System	GR* ($\times 10^3$ ₹/ha)	NR** ($\times 10^3$ ₹/ha)	Benefit: cost ratio
Residue management									
Residue removal	129	36	165	35.0	140.8	58.7	184.0	127.4	2.30
Residue retention	129	36	165	38.3	152.1	63.8	178.7	123.5	2.25
SEm±	–	–	–	0.1	0.6	0.2	–	–	–
CD (P=0.05)	–	–	–	0.7	4.0	1.3	1.4	1.4	–
Tillage-cum-crop-establishment									
PTR-CTW	156	36	192	27.3	128.8	46.8	162.4	98.1	1.61
UPTR-ZTW	117	36	153	38.7	146.9	64.8	177.4	122..3	2.24
ZTTR-ZTW	117	36	153	41.4	152.4	68.2	187.3	134.8	2.50
ZTDSR-ZTW	126	36	162	42.1	157.6	68.4	198.2	146.6	2.76
SEm±	–	–	–	0.7	3.6	1.2	–	–	–
CD (P=0.05)	–	–	–	2.1	11.1	3.6	10.5	10.5	0.25

GR, Gross return; NR, net return; PTR-CTW, puddled transplanted rice *fb* conventional-till wheat; UPTR-ZTW, unpuddled transplanted rice *fb* zero-till wheat; ZTTR-ZTW, zero-till transplanted rice *fb* zero-till wheat; ZTDSR-ZTW, zero-till direct seeded rice *fb* zero-till wheat

and better soil water retention that ultimately increased wheat yields (Das *et al*., 2014; Nath *et al*., 2017b; Kumar *et al*., 2017). Similarly, higher system productivity is due to fact that ZT and residues retention increased the crop yield component by improving soil condition, with higher soil water content and other soil physical, chemical and biological properties.

Water productivity

In the present investigation, variable rate of irrigation water was applied according to the principles of different T and CE practices and crop-water requirement. The higher amount of irrigation water to rice crop was applied in PTR-CTW (156 ha-cm) > ZTDSR-ZTW (126 ha-cm) > UPTR-ZTW = ZTTR-ZTW (117 ha-cm) (Table 2). While a similar quantity of water was applied to wheat crop irrespective of the treatments. The data on irrigation water productivity indicate that residue retention had marginally improved the irrigation water productivity of rice, wheat as well as in system. On the other side, the higher productivity and minimum use of irrigation water increased the water productivity of both the crops in ZTDSR-ZTW system. The higher water requirement under PTR-CTW drastically reduced the WP of rice crop. In this IGP region, crop residues are either removed or burned and resources are indiscriminately used. As a result, productivity and resource use efficiency in the region has become static or started declining. To address these issues, this experiment was conducted under different T and CE and residues-management practices in a rice–wheat sequence and intensive studies were undertaken. The higher water productivity of ZTDSR-ZTW, UPTR-ZTW and ZTTR-ZTW systems over PTR-CTW was due to higher system yield, which was in turn owing to consistent trends for higher rice and wheat (Laik *et al*., 2014; Das *et al*., 2014). These treatments received lower water input and also had higher system yield, resulting in higher system water productivity to that of PTR-CTW (farmers practice).

Economics

The data on economics revealed that at 4th and 5th year of crop rotation residues retention treatment was economically inferior to that of residue removal (Table 2). However, no significant difference was apparent in benefit: cost for both the residue treatments. The economic return form conservation T and CE was largely higher than conventional PTR-CTW. In the study, the average of 2 years data show that the UPTR-ZTW, ZTTR-ZTW and ZTDSR-ZTW fetched an addition income of 24,248, 36,689 and 48,553 respectively. The positive effects of zero tillage and residues management on yield were well reflected into more favourable economics both for rice and wheat production and thus for the system as well. Higher net returns in zero-till direct seeding systems (with and without residue retention, flat and bed planting) can be attributed mainly to reduced cost of production. Zero tillage resulted in lower cost of cultivation because of less use of machinery, labour and less fuel cost.

Thus, it can be concluded that crop residue retention (~33%) and conservation tillage particularly the zero tillage-based crop establishment (ZTTR-ZTW and ZTDSR-ZT) of rice and wheat crop could improve the crop productivity, reduced water requirement and enhance farm income in the IGP.

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