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Performance of crop residue management with different tillage and crop establishment practices on weed flora and crop productivity in rice-wheat cropping system of eastern *Indo-Gangetic* plains

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ABSTRACT

Weeds growth and crop productivity were studied in rice-wheat cropping system under different tillage cum crop establishment practices (T&CE) and residue management treatment practices. The experiment was comprised of two residue management practices and four T&CE practices in a split plot design. Results revealed that zero-till dry seeded rice followed by zero tillage wheat (ZTDSR-ZT) recorded significantly higher density of total broad-leaved and total weeds in 2013 and 2014 in rice. However in wheat crop, the ZTDSR–ZT system suppressed the winter season broad-leaved and total weeds effectively over other tillage practices. Crop residue retention in soil surface significantly reduced the weed density both in rice and wheat crops. The higher grain yield of rice and wheat crop was recorded in conservation tillage practices (ZTDSR–ZT) in both years over conventional tillage practices in rice and wheat crop.

***Keywords*:** Conservation tillage, direct seeded rice, unpuddled transplanting, yield

In Asia, the conventional rice cultivation technique is manual transplanting of seedlings into puddled soil. This puddling operation requires a huge amount of water. The puddling operation besides consuming a large quantity of water, also emits the greenhouse gas (GHG) like methane. Extensive tillage operation in rice with standing water disintegrates the soil aggregates and called the second generation problems of soil physico-chemical and biological health deterioration (Nath *et al*., 2017a). Also, conventional-till wheat (CTW) following the puddled transplanted rice (PTR) aggravates these problems. In all, the PTR and CTW system is confronting several crop productivity and soil sustainability issues in Asia particularly in the Indo-Gangetic plains (IGPs). The puddling operation was being promoted since long time in the IGP region with the objective of surface water retention and controlling weeds. The puddling with wet tillage in rice followed by conventional dry tillage in wheat creates an edaphic conflict rice-wheat cropping system (RWCS).

Some alternatives to rice establishment techniques were recently identified *viz.* unpuddled transplanted rice (UPTPR), zero tillage transplanted rice (ZTTPR), and zero tillage direct seeded rice (ZTDSR). These establishment techniques can bring down the water requirement and reduce the GHGs emissions (Farooq *et al*., 2011). However, due to the withdrawal of pudding operation, these practices can suffer from heavy weeds infestation. In fact, a few studies reported a reduction in yield when moving from PTR to UPTPR, ZTTPR, and ZTDSR (Bhushan *et al*., 2007). Weed control is particularly challenging in these systems because of the diversity and severity of weed infestation, the absence of standing water layer to suppress the weed at the time of rice emergence. Weed flora may also shift with the adoption of ZT and dry seeding, with annual grassy weeds particularly increasing in density (Chauhan and Opeˇna, 2012). However, perceptions are difficult to generalize as the tillage mediated effects are manifested in the form of species and location specificity.

The residue management practices can alter the weed periodicity of germination and emergence pattern (Nath *et al*., 2017b). Surface crop residue act as a physical barrier for weed germination due to hindrance in light penetration. The new generation tillage and crop establishment (T&CE) practices in RWCS with residue management can decimate the weeds infestation over time. However, these rice establishment technologies (UPTPR, ZTTPR, and ZTDSR) are not systematically studied in the Eastern IGP region (Bihar), particularly in connection with studies tending to a precise examination of weed infestation and diversity over time. Hence, for achieving more sustainable weed management approaches, there is an obvious need to correlate the knowledge of weed diversity and agricultural management practices. Therefore, a study was conducted to evaluate the effect of tillage and crop establishment method on weed diversity, growth, and crop productivity in RWCS.

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MATERIALS AND METHODS

The field experiment was initiated during 2013-14 at the 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 1130 mm. The minimum and maximum temperature in the study site ranged between 7-9^{o}C and 36-41^{o}C, respectively. The experimental soil comes under the taxonomical class *Typic Ustochrept* with silty-clay soil texture with low SOC content (Table 1).

Table 1: Initial physico-chemical properties of soil at study site

Soil physico-chemical properties	Values
Sand (%)	15.0
Silt (%)	41.0
Clay (%)	44.0
pH (1:2) soil : water	7.11
EC (dS m^{-1})	0.38
Organic carbon (%)	0.49
Bulk Density (g cm^{-3})	1.44
Penetration Resistance (MPa)	1.75
Available nitrogen (kg N ha^{-1})	135.2
Available phosphorus (kg P ha^{-1})	35.2
Available potassium (kg K ha^{-1})	239.2
DTPA extractable Zn (ppm)	0.83
DTPA extractable Fe (ppm)	19.9
DTPA extractable Mn (ppm)	25.5
DTPA extractable Cu (ppm)	2.59

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 of two levels of residue management [residue removal and residue retention (~33%)], and four levels of tillage cum crop establishment practices (T&CE) as follows: (i) conventional puddled transplanted rice followed by (*fb)* conventional-till wheat (CTTPR-CT): two dry-harrowing *fb* two wet-tillage (puddling) and one planking was done before the manual transplanting of 21 days old seedling at 20 cm spacing. After rice harvest, wheat was sown by broadcasting in conventionally tilled plots (2 harrowing + 2 tillage + 1 planking). (ii) Unpuddled transplanted rice *fb* zero-till wheat (UPTPR-ZT): dry tillage was *fb* 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 (ZTTPR-ZT): The plots were flooded one 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-ZT): 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 shown 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'. Twenty one days old seedling was transplanted in the plots with different tillage practices (CTTPR-CT, UPTPR-ZT and ZTTPR-ZT). Recommended dose of fertilizer N: P_2O_5: K_2O was 120:40:40 kg ha^{-1}. Half dose of nitrogen and full dose of phosphorous and potassium along with 25 kg $ZnSO_4$ was applied manually. Remaining dose of nitrogen in two equal split was applied at 30 and 60 days after sowing (DAS). The wheat crop (variety 'HD 2967') was shown on second fortnight of November with the help of with row spacing of 22.5 cm and manually broadcasted in conventional plot (CTTPR-CT). Recommended dose of N: P_2O_5: K_2O applied was in the ratio120:60:40 kg ha^{-1}. The half quantity of N and full doses of phosphorus and potassium were applied at the time of sowing. Remaining dose of N in form of urea was applied in two equal split at 21 and 50 DAS.

The recommended weed management practice was followed in PTR and DSR systems. For rice crop in CTTPR and UPTPR treatments, pretilachlor 0.4 kg *a.i.* $ha^{–1}$ as pre–emergence was applied within 24 h after transplanting of rice. No post–emergence herbicides were applied in CTTPR and UPTPR plots. In ZTTPR and ZTDSR treatments, pendimethalin (30 EC) at 0.75 kg *a.i.* $ha^{–1}$ as pre–emergence was applied within 24 h after sowing of rice. In ZT–based systems of rice (ZTTPR and ZTDSR), a post–emergence application of bispyribac sodium 10% SC at 20 g *a.i.* $ha^{–1}$ at 25-30 DAS was performed. One hand weeding at 65 DAS was done in all the plots irrespective of treatments. In wheat crop under ZT plots, glyphosate (41% SL) at 1.5 L *a.i.* $ha^{–1}$ was sprayed as pre–sowing application to control the left–over weed of the rainy season. But, no pre–sowing glyphosate was applied in CT plots of wheat crop and weeds were controlled by tillage operation. In wheat crop, ready-mix application of sulfosulfuron (75% WG) + metsulfuron methyl (5% WG) at 40 g $ha^{–1}$ as post–emergence at 25–30 DAS was performed in all the CT and ZT plots. The application of herbicides was performed by using knapsack sprayer with flat fan nozzle with the required quantities of water. The data on weed density and dry weight were recorded at 35 DAS in rice and wheat crop. Two quadrats each of 1 m ×1 m were randomly selected in each plot leaving the border area. The weed species present in the quadrats were collected, identified and counted. After identification, the weed species were categorized in terms of morphological characteristics i.e grasses, sedges and broad-leaved. Then by summing up the grasses, sedges, and broad-leaved total number of weed species was obtained and expressed in number m^{-2}. Weed after counting, were first sun-dried for two days and then kept in an oven at 65^0C till constant weight according to grasses, sedges, and broad-leaved. Dry weight was expressed in g m^{-2}.

Rice and wheat was harvested using combine harvester and were threshed by a power-operated thresher. Data on grain yield were recorded from the net plot. The data collected for all parameters during the course of investigation was compiled and subjected to statistical analysis using the analysis of variance technique using windows based SPSS programme (Gomez and Gomez, 1984). The least significant difference (at 5% level of probability) was computed for comparing treatment means in cases where effect came out to be significant by F- test.

RESULTS AND DISCUSSION

Dominant weed flora present in rice and wheat crop is presented in the table 2. Total fifteen weeds were present in rice comprising of five grasses, two sedges, and eight broad-leaves. While, twenty one weed species comprising four grasses, one sedge, and sixteen broad-leaves were present in wheat. In rice crop, grasses and sedges were more dominating weeds (Table 3), while broad-leaved dominated in wheat crop at 35 DAS (Table 4). Differences in density of weeds at 35 DAS due to crop residue management practices across the years were non-significant. Among the T&CE practices, ZTDSR-ZT system recorded significantly higher density total grasses and total sedges in 2013 and total broad-leaves and total weeds in both the years in rice. The sequence of total weeds density followed the order of ZTDSR–ZT> CTTPR–CT> ZTTPR-ZT> UPTPR-ZT in 2013 and 2014. However in wheat crop, CTTPR–CT system led to significantly higher broad-leaved and total weeds density in 2013-14. The ZTDSR–ZT system suppressed the winter season broad-leaves and total weeds effectively over other tillage practices. Crop residue retention on soil surface significantly reduced the weeds biomass of total grasses in both the years and total weeds in 2014 in rice over residue removal (Table 5). While in wheat crop, residue retention significantly enhanced total grasses and total weeds in both the years (Table 6). The dry weight of sedges and broad-leaves did not differ for residue management practices in both years. Among the T&CE practices, ZTDSR–ZT practices recorded significantly higher dry weight of all categories of weeds in rice and wheat crop at 35 DAS. The ZTTPR-ZT and UPTPR-ZT systems recorded lower weeds dry weight over ZTDSR–ZT in rice and wheat crop at 35 DAS.

Table 2: Weeds flora present in rice and wheat crop during the study period

Dominant weeds flora	
Rice	**Wheat**
Grasses	***Grasses***
Cynodon dactylon	*Avena ludoviciana*
Echinocloa sp.	*Cynodon dactylon*
Elucine indica	*Phalaris minor*
Leptochloa chinensis	*Polypogon monsipeliensis*
Paspalum disticum	
Sedges	***Sedges***
Cyperus iria	*Cyperus rotundus*
Frimbristylis miliacea	
Broad-leaved	***Broad-leaved***
Alternanthera philoxeroides	*Anagallis arvensis*
Amaranthus viridis	*Chenopodium murale*
Ammania baccifera	*Circium arvense*
Caesulia axillaris	*Coronopus didymus*
Eclipta prostrata	*Fumaria parviflora*
Phyllanthus nururi	*Lathyrus aphaca*
Physalis minima	*Medicago denticulata*
Trianthema portulacastrum	*Melilotus indica*
	Oenothera laciniata
	Oxalis corniculata
	Physalis minima
	Polygonum plebejum
	Rumex dentatus
	Sonchus oleraceous
	Synapsis arvensis
	Vicia sativa

Weed growth (density and biomass) exhibited a variable response to the different tillage and residue management practices in the present study. The local climate and soil moisture regimes of experimental sites favour weed diversity as well as their luxurious growth (Dwibedi *et al*., 2016). In our study, the higher weed diversity was noticed in 2013-14, than 2014-15. The meteorological data showed that higher amount of rainfall was received during 2013-14, both in rainy and winter season, led to the higher weed pressure in 2013-14 in all the treatments. Residue addition invariably reduced the weed density both in rainy and winter seasons because surface residue retention affects the seed germination via physical and chemical changes in the seed environment. The physical effect includes a reduction in light and soil surface insulation (Teasdale & Mohler, 1993). While, in wheat dry biomass of weeds was higher in residue added treatment because of higher vigour of weeds. The smaller density of weeds caused the more vigorous weeds dry weight over residue removal. The pudding operation in rice reduced the

Table 3: Category-wise weeds density in rice at 35 DAS

Treatments	Weeds density (no. m^{-2})							
	Total grasses		Total sedges		Total broad-leaves		Total weeds	
	2013	**2014**	**2013**	**2014**	**2013**	**2014**	**2013**	**2014**
Residue management								
Residue removal	4.57	2.87	4.36	2.85	4.43	2.79	7.84	4.98
	(20.50)	(8.33)	(24.50)	(9.88)	(20.50)	(8.21)	(65.50)	(26.42)
Residue retention	5.11	2.16	4.30	1.91	4.23	2.68	7.98	4.00
	(28.96)	(4.33)	(25.33)	(4.42)	(17.88)	(7.71)	(72.17)	(16.46)
LSD (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
T&CE practices								
CTTPR - CT	4.45	1.79	3.99	2.78	4.10	3.05	7.18	4.60
	(19.42)	(2.75)	(15.75)	(9.08)	(16.42)	(10.00)	(51.58)	(21.83)
UPTPR - ZT	3.95	2.30	2.34	2.10	3.88	2.28	5.94	3.77
	(15.25)	(5.00)	(5.00)	(4.00)	(14.75)	(4.75)	(35.00)	(13.75)
ZTTPR - ZT	4.72	3.12	2.42	2.42	3.71	2.08	6.42	4.57
	(21.83)	(9.33)	(5.42)	(8.92)	(13.83)	(4.33)	(41.08)	(22.58)
ZTDSR - ZT	6.25	2.84	8.58	2.22	5.62	3.52	12.11	5.04
	(42.42)	(8.25)	(73.50)	(6.58)	(31.75)	(12.75)	(147.67)	(27.58)
LSD (0.05)	**0.67**	**NS**	**0.31**	**NS**	**0.56**	**0.48**	**0.64**	**0.77**

Note: Data in the parentheses are original values. Data were $\sqrt{(x+0.5)}$ *transformed*

Table 4: Category-wise weeds density in wheat at 35 DAS

Treatments	Weeds density (no. m^{-2})							
	Total grasses		Total sedges		Total broad-leaves		Total weeds	
	2013-14	**2014-15**	**2013-14**	**2014-15**	**2013-14**	**2014-15**	**2013-14**	**2014-15**
Residue management								
Residue removal	2.36	0.82	0.75	0.97	3.88	2.99	4.51	3.12
	(5.13)	(0.21)	(0.08)	(0.67)	(14.79)	(8.80)	(20.00)	(9.67)
Residue retention	2.17	0.77	0.77	0.90	3.96	3.20	4.52	3.33
	(4.50)	(0.13)	(0.13)	(0.58)	(15.46)	(11.54)	(20.08)	(12.25)
LSD (0.05)	**0.09**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
T&CE practices								
CTTPR - CT	1.77	0.71	0.71	0.85	4.55	2.06	4.85	2.13
	(2.83)	(0.00)	(0.00)	(0.33)	(20.33)	(3.86)	(23.17)	(4.19)
UPTPR - ZT	2.65	0.93	0.84	0.99	3.70	3.35	4.53	3.50
	(6.58)	(0.42)	(0.25)	(0.67)	(13.33)	(11.41)	(20.17)	(12.49)
ZTTPR - ZT	2.18	0.71	0.79	0.90	4.02	4.20	4.53	4.27
	(4.25)	(0.00)	(0.17)	(0.50)	(15.67)	(18.08)	(20.08)	(18.58)
ZTDSR - ZT	2.45	0.84	0.71	1.01	3.41	2.76	4.14	2.99
	(5.58)	(0.25)	(0.00)	(1.00)	(11.17)	(7.33)	(16.75)	(8.58)
LSD (0.05)	**0.15**	**NS**	**NS**	**NS**	**0.45**	**0.67**	**0.45**	**0.75**

Note: Data in the parentheses are original values. Data were $\sqrt{(x+0.5)}$ *transformed*

Table 5: Category-wise weeds biomass in rice at 35 DAS

Treatments	Weeds biomass (g m^{-2})							
	Total grasses		Total sedges		Total broad-leaves		Total weeds	
	2013	2014	2013	2014	2013	2014	2013	2014
Residue management								
Residue removal	7.70	7.59	7.89	3.41	7.63	4.09	14.15	9.67
	(61.58)	(62.00)	(130.5)	(16.56)	(68.94)	(24.77)	(261.1)	(103.3)
Residue retention	9.45	4.88	7.11	2.13	6.87	3.20	14.03	6.47
	(121.1)	(27.16)	(103.8)	(6.43)	(52.71)	(10.56)	(277.6)	(44.15)
LSD (0.05)	**0.53**	**0.46**	**NS**	**NS**	**NS**	**NS**	**NS**	**1.62**
T&CE practices								
CTTPR - CT	6.61	3.47	3.88	3.30	6.53	3.07	10.20	5.84
	(43.34)	(12.37)	(17.08)	(12.97)	(44.86)	(9.01)	(105.2)	(34.34)
UPTPR - ZT	5.80	5.65	2.58	2.76	5.44	1.65	8.37	6.52
	(33.72)	(33.97)	(7.43)	(8.16)	(29.21)	(2.26)	(70.36)	(44.38)
ZTTPR - ZT	7.10	9.12	2.91	2.98	5.16	5.06	9.30	11.40
	(50.18)	(84.26)	(9.08)	(18.37)	(27.31)	(34.84)	(86.56)	(137.4)
ZTDSR - ZT	14.79	6.68	20.64	2.05	11.86	4.79	28.50	8.52
	(238.1)	(47.74)	(435.3)	(6.48)	(141.9)	(24.56)	(815.3)	(78.78)
LSD (0.05)	**0.64**	**0.33**	**2.35**	**NS**	**1.10**	**2.51**	**1.51**	**1.48**

Note: Data in the parentheses are original values. Data were $\sqrt{(x+0.5)}$ *transformed*

Table 6: Category-wise weeds biomass (g m^{-2}) in wheat at 35 DAS

Treatments	Weeds biomass (g m^{-2})							
	Total grasses		Total sedges		Total broad-leaves		Total weeds	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Residue management								
Residue removal	3.87	7.81	0.72	0.73	4.19	1.22	5.70	7.89
	(14.8)	(63.0)	(0.01)	(0.04)	(18.0)	(1.08)	(32.9)	(64.17)
Residue retention	4.52	9.24	0.72	0.75	4.30	1.43	6.29	9.38
	(21.6)	(113.0)	(0.02)	(0.08)	(18.5)	(1.77)	(40.2)	(114.9)
LSD (0.05)	**0.14**	**0.77**	**NS**	**NS**	**0.08**	**NS**	**0.07**	**0.72**
T&CE practices								
CTTPR - CT	2.75	6.86	0.71	0.73	3.41	0.88	4.39	6.88
	(7.28)	(46.68)	(0.00)	(0.03)	(11.5)	(0.29)	(18.8)	(46.99)
UPTPR - ZT	4.89	5.80	0.73	0.73	4.48	1.68	6.61	6.01
	(23.4)	(33.72)	(0.04)	(0.04)	(19.9)	(2.36)	(43.4)	(36.12)
ZTTPR - ZT	4.79	7.10	0.72	0.73	5.07	1.64	6.96	7.27
	(22.8)	(50.18)	(0.03)	(0.03)	(25.3)	(2.31)	(48.3)	(52.52)
ZTDSR - ZT	4.36	14.34	0.71	0.79	4.02	1.11	6.01	14.38
	(19.4)	(221.6)	(0.00)	(0.15)	(16.3)	(0.74)	(35.7)	(222.5)
LSD (0.05)	**0.21**	**0.61**	**NS**	**NS**	**0.37**	**0.12**	**0.37**	**0.62**

Note: Data in the parentheses are original values. Data were $\sqrt{(x+0.5)}$ *transformed*

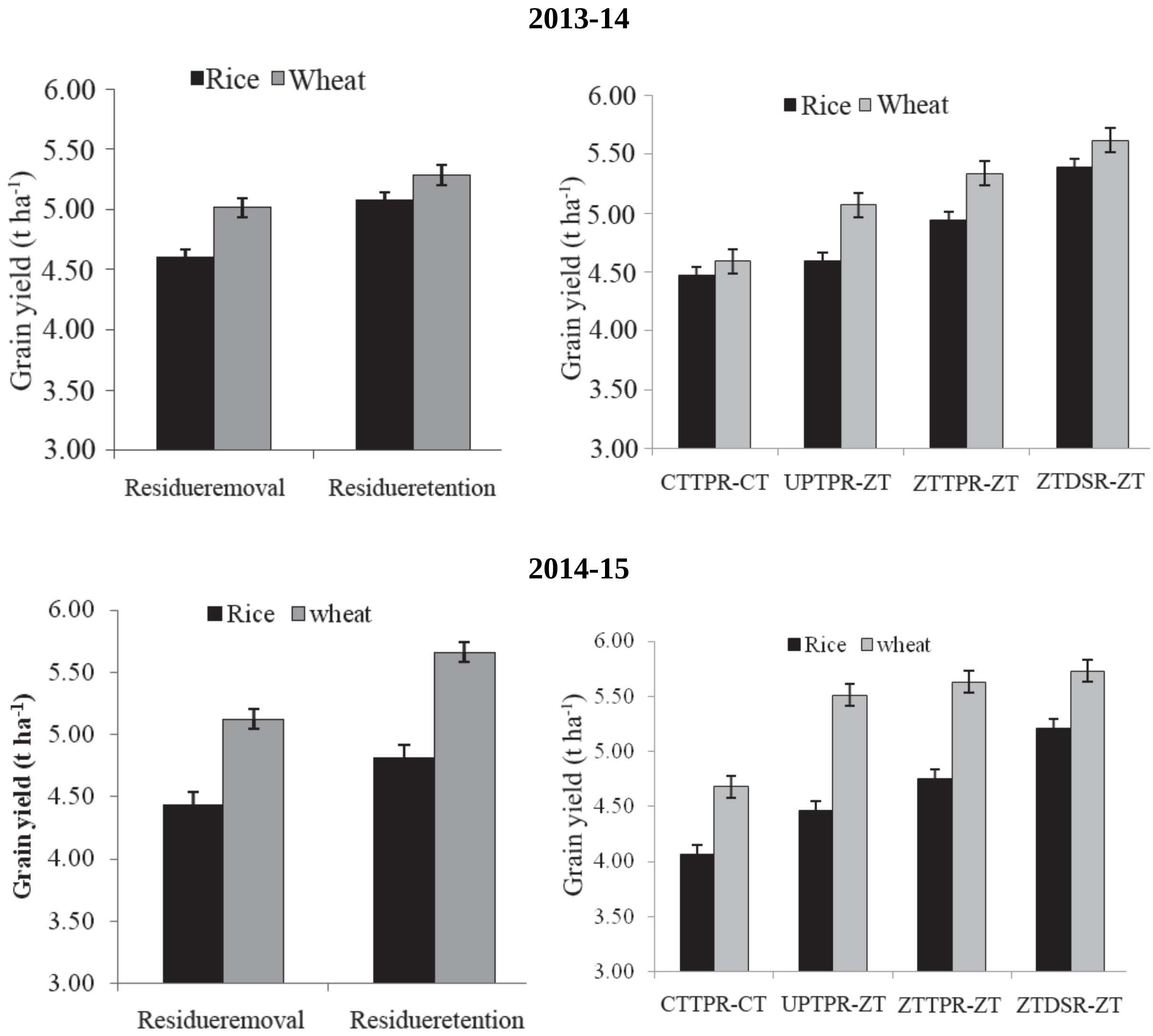

Fig. 1:Effect of crop residue management and tillage cum crop establishment practices on grain yield of rice and wheat (t ha^{-1}) in 2013-14 and 2014-15

weeds density over other tillage practices. However, in wheat crop due to intensive tillage operation caused higher weeds density because of soil disturbance. The less weeds density in ZTDSR–ZT, ZTTPR-ZT, and UPTPR-ZT systems in wheat crop led to more vigorous growth and higher weeds biomass over CTTPR–CT system.

In the present study, continuous residues retention significantly improved the grain yield of rice and wheat crops. For rice crop, 9.4-9.7per cent higher grain yield was realized with retention of crop residue. Likewise, residue retention increased the wheat grain yield by 4.6-9.3per cent (Fig. 1). The effect of T&CE practices was much stronger and conservation tillage practices improved the grain yield of both rice and wheat crop over conventional puddled transplanted rice. Among the T&CE practices, higher grain yield were registered in ZTDSR–ZT (5.21-5.39 t ha^{-1}) closely followed by ZTTPR-ZT (4.75-4.94 t ha^{-1}) and recorded least in CTTPR–CT (4.06-4.47 t ha^{-1}) in both the years. The sequence of grain yield followed the order of ZTDSR–ZT> ZTTPR-ZT> UPTPR-ZT> CTTPR–CT in 2013-14 and 2014-15. The higher grain yield was recorded in conservation tillage practices (ZTDSR–ZT, ZTTPR-ZT, and UPTPR-ZT) in both years over CTTPR–CT. The higher yield attributes in these systems led to higher grain yield. This might have resulted from greater photosynthesis, and, hence, better translocation of photosynthates, besides larger sink and stronger reproductive phase. Also there may be a positive impact on soil water balance resulting from crop residue on the soil surface under no-till management. The increased grain yield of rice and wheat was mainly associated with the increased tiller formation under conservation tillage based crop establishment practices. The use of surface residue coverage is an integral part of any successful conservation tillage practices. Also, higher soil organic matter and biological properties under conservation tillage practices (ZTDSR–ZT, ZTTPR-ZT, and UPTPR-ZT) enhanced the grain yield in rice and crops across the years.

The results of our study demonstrate that promising rice and wheat crop establishment techniques (UPTPR-ZT, ZTTPR-ZT, and ZTDSR-ZT) can produce yields comparable with that of CTTPR, provided that weed are properly controlled. Weed pressure was higher in these systems than in CTTPR in initial years which over time will reduce. Importantly, the conservation tillage practices (UPTPR-ZT, ZTTPR-ZT, and ZTDSR-ZT) produced higher grain yield over conventional tillage practices in RWCS. Thus, it can be concluded that crop residue retention (~33%) and conservation tillage particularly the ZT-based crop establishment of rice and wheat crop can improve the crop productivity in the IGP.

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