Original Research Article

Tillage and Rice Straw Management affect Soil Enzyme Activities and Chemical Properties after Three Years of Conservation Agriculture Based Rice-Wheat System in North-Western India

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ABSTRACT

Aims: To evaluate the effects of rice establishment, tillage and rice straw management on changes in soil enzyme activities and chemical properties in soil after three cycles of continuous rice-wheat system.
Study design: The experiment was laid in split plot design with three replications.
Place and Duration of Study: PAU, Ludhiana, 2010-2013
Methodology: The experiment was started during kharif season of 2010. The design of an experiment was having 12 treatments with 3 replications. The main plot treatments in rice (zero till direct seeded rice, ZT-DSR; conventional till direct seeded rice, CT-DSR; zero till direct transplanted rice, ZT-DTR and puddled transplanted rice, PTR) and three sub-plot treatments in wheat (conventional till wheat without rice straw, CTW-R; ZT wheat without rice straw, ZTW-R, and ZT wheat with rice straw retained as surface mulch using Happy Seeder, ZTW+R).
Results: Zero tillage with rice straw retention (ZTW) as surface mulch (+R) increased wheat yield by 9% and 15% compared with conventional tillage (CTW) and ZTW with no residue (-R). Significantly higher dehydrogenase, fluorescein diacetate, alkaline phosphatase, phytase and urease activities were recorded under ZTW+R compared with ZTW/CTW-R in 0-5 cm soil layer. Organic carbon, Olsen-P, available K and DTPA-extractable micronutrients (Zn, Fe, Mn and Cu) in the surface 0-5 cm soil layer were significantly higher in ZTW+R compared with ZTW/CTW-R. Soil enzyme activities were significantly and positively correlated with each other, soil organic carbon, Olsen-P and grain yield of wheat. **Conclusion:** We concluded that RCTs (ZTW and rice residue retention) improve soil enzyme activities and chemical properties in surface 0-5 cm soil layer and enhance productivity and sustainability of rice-wheat system.
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Keywords: conservation agriculture, rice straw surface mulch, tillage, enzyme activities, rice-wheat system

1. INTRODUCTION

The rice–wheat cropping system (RWS) occupies about 13.5 million hectares (M ha) in the Indo-Gangetic Plains (IGP) of South Asia (Gupta and Seth, 2007) and is fundamental to employment, income and livelihood for millions of people in the region. However, sustainability of intensive tillage-based

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conventional RWS is constrained or limited by water, energy and labour scarcity, increasing cost of production, increasing air pollution and deteriorating soil health. To reverse this situation various Resource Conservation Technologies (RCTs) such as zero tillage, direct seeded rice and crop residue retention are being developed and promoted for RWS (Sidhu *et al*., 2007; Gathala *et al*., 2013). Puddling in rice and intensive tillage in wheat are known to cause sub-soil compaction, deterioration of soil structure, and decrease in permeability in the subsurface layer and thereby adversely affecting productivity of RWS (Jat *et al*., 2009).

The increasing constraints of labour and time under intensive agriculture have led to the adoption of mechanized farming in RWS leaving large amounts of crop residues in the fields. As crop residues interfere with tillage and seeding operation for the next crop, farmers in northwestern (NW) India often prefer to burn surplus rice residues on-farm after grain harvest to establish the next wheat crop. Residue burning impacts human and animal health both medically, and by traumatic road accidents due to restricted visibility (Yadvinder-Singh *et al*., 2014). Establishment of wheat crop by ZTW with retention of crop residues on the soil surface potentially offers a labour-saving and cost-effective alternative to the burning of rice residues. A new machine, known as the 'Happy Seeder' (HS), has now been developed for this purpose which is capable of direct drilling wheat into heavy rice residue loads, without burning in a single operation (Sidhu *et al*., 2007, 2015).

There is currently much interest in dry direct seeded rice (DSR) as an alternative to conventional transplanted rice in North-West India due to labour scarcity for transplanting, and because puddling and transplanting require large quantities of water to establish the rice crop. Zero tillage with rice residue retained on soil surface significantly improve water content in soil, improve overall soil physical and chemical health through replenishing soil organic matter and to support sustainable RWS (Jat *et al*., 2009; Gathala *et al*., 2013). Tillage, crop establishment and residue management options may also have significant effect on soil biological health.

Soil enzyme activities respond much more quickly to the changes in tillage and soil management as compared with soil organic matter (Jiang *et al*., 2006) and therefore could be used as potential biological indicators of soil quality (Yang *et al*., 2011). Dehydrogenase activity is involved in oxidative phosphorylation and reflects the total oxidative potential of the soil microbial community (Dick, 1997). Fluorescein diacetate (FDA) hydrolyzed by a number of different enzymes, can provide adequate microbial activity (Bendick and Dick, 1999). The activity of alkaline phosphatase is linked to transformation of organic P in soil to inorganic P compounds (Yang *et al*., 2008). The soil phytase enzyme increases the availability of P from phytate in soils. Urease activity controls hydrolysis of urea in soils, which is an important source of N.

Significant increases in the activity of soil enzymes have been observed under ZT and residue retention in non-rice based cropping systems (Eivazi *et al*., 2003) and the magnitude of the change depends on soil type and climate. However, little information is available in the literature on the effects of RCTs (DSR, tillage and rice straw management) on changes in soil biochemical properties under RWS in South Asia. The present study was therefore, carried out to determine the effects of rice establishment methods, tillage and rice straw management on biochemical properties after three cycles of RWS in northwestern India.

2. MATERIALS AND METHODS

Description of the experimental site and climate

A three-year (2010-2013) field experiment on irrigated RWS was conducted on a Typic Ustochrept sandy loam soil at the experimental farm of the Punjab Agricultural University, Ludhiana (30°56′N and 75°52′E) in the IGP in the northwestern India. The top-soil (0–15 cm layer) at the start of experiment was non-saline (electrical conductivity 0.36 dS m^{-1}) with pH 7.88 and contained 4.5 g kg^{-1} Walkley-Black carbon, 8.2 mg kg^{-1} 0.5 M $NaHCO_3$-extractable P (Olsen *et al.,* 1954) and 50.4 mg kg^{-1} 1 N NH_4OAc-extractable K. The region has a sub-tropical climate, with hot, wet summers and cool dry winters. Annual mean rainfall is 760 mm, about 80% of which occurs from June to September. The long-term average (30 years) mean minimum and maximum temperatures in wheat (November to April) are 6.7 and 22.6^{0}C while in rice (June to October) are 18 and 35^{0}C, respectively.

Experimental layout and treatments

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Treatments applied to RWS were arranged in a split-plot design with a total of twelve treatments replicated three times. Main plot treatments applied to rice were four combinations of tillage and crop establishment methods in rice (zero till direct seeded rice, ZT-DSR; conventional till direct seeded rice, CT-DSR; zero till mechanically transplanted rice, ZT-DTR and puddled transplanted rice, PTR). The three sub-plot treatments in wheat were combinations of tillage and residue management options (conventional till wheat without residues, CTW-R; ZT wheat without residues, ZTW-R, and ZT wheat with residues retained as surface mulch using Happy Seeder, ZTW+R). The treatments were assigned to the same experimental plots in the 3 years of the study. The treatment details are summarized in Table 1.

Soil and crop management

Wheat straw was removed at harvest in April each year and the plots were fallowed until pre-irrigation for rice in early June. ZT-DSR was sown in a single operation using zero-till-fertilizer cum seed drill at 20 cm row spacing. In CT-DSR, plots were prepared by 2 harrowings + 1 cultivator + 1 planking followed by dry seeding of rice using a seed rate of 20 kg ha^{-1}. Light irrigation (50 mm) was applied at 1 day after seeding to ensure satisfactory germination, and then at 4–5 day intervals until physiological maturity depending on the rainfall events during the growing season. In ZT-DTR, rice seedlings were transplanted in ZT plots with standing water using mechanical transplanter. In PTR, tillage included disking twice in early June followed by two cultivator operations in standing water to puddle the soil and planking. Rice (variety PR 114) was transplanted manually using 30-day-old seedlings spaced at 15 cm x 20 cm in the second week of June. All treatments received a uniform dose of 150 kg N as urea, 26 kg P as diammonimum phosphate and 25 kg K as muriate of potash. Whole of P and K was applied at rice planting on all the plots. Fertilizer N in PTR and ZT-DTR was applied in three equal split doses at transplanting and at 3 and 6 weeks after transplanting. While in CT-DSR and ZT-DSR fertilizer N was applied in three equal spilt doses at 3, 5 and 9 weeks after sowing. Rice was harvested manually in the second week of October in –R to remove the rice straw from the field plots and the combine harvester was used in +R plots to retain the rice straw in the field.

All plots received flood irrigation (75-80 mm) prior to planting of wheat. In conventional plots, seed bed was prepared by 2 dry harrowings followed by 2 cultivators and one planking. Wheat (variety PBW 621) was sown in the second week of November using a seed rate of 100 kg ha^{-1}. Sowing of wheat was done on the same day in all the treatments at row spacing of 20 cm using Happy Seeder machine. Fertilizer N (120 kg ha^{-1}) as urea was applied in three equal split doses at sowing, and three weeks and 8 weeks after planting. A basal dose of 26 kg P ha^{-1} as single super phosphate and 25 kg K ha^{-1} as muriate of potash were applied on all plots at planting. Wheat was irrigated (each of 75 mm) at crown root initiation (CRI), maximum tillering (MT), panicle initiation and dough stages recommended for wheat crop in the region. Grain yield of wheat was recorded from 1.4 m x 9 m area in the center of each plot and was reported on dry weight basis.

Soil sampling and analysis

Soil samples were collected from 0-5 cm, 5-10 cm and 10-15 cm soil layers, after the harvest of wheat crop (after 3 cycles of rice-wheat rotation). The soil samples were collected with the help of tube auger (25 mm internal diameter) from randomly selected 4 places within each treatment plot. After removing visible root debris, the soil samples were mixed, sieved (2 mm) and stored at 4^0C for subsequent analysis for biochemical soil properties. The methods used for assaying biochemical soil properties are listed in Table 2.

Statistical analysis

All the dataset was analyzed using analysis of variance (ANOVA) and differences among treatments were compared at p=0.05 level of significance using the IRRISTAT data analysis package (IRRI, 2000). Statistical software used for this study was SPSS version 20.0. Correlations between the variables were determined using Pearson correlation coefficients (r) and probabilities. In all the analyses, significance was accepted at a level of probability (p) of <0.05.

3. RESULTS AND DISCUSSION

There was no significant interaction effects of rice establishment methods and tillage and rice residue management in wheat) on enzymes activities and chemical properties in all the three soil layers (0-5, 5-10

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and 10-15 cm). Rice establishment systems also showed no significant effects on the grain yield of subsequent wheat and any of the soil property measured in the study.

Enzyme activities in soil

Tillage and rice straw management in wheat significantly ($P \leq 0.05$) influenced all the enzyme activities in 0-5 cm soil layer but showed no effect at 5-10 cm and 10-15 cm soil layers (Tables 3-7). In general, enzyme activities decreased with depth. In 0-5 cm soil layer, DHA under ZTW+R were 6% and 14 % higher as compared to ZTW-R and CTW-R, respectively (Table 3). DHA was 9 % higher under ZTW-R than CTW-R. FDA and APA at 0-5 cm depth were 9 and 13 % higher in ZTW+R as compared to ZTW-R and CTW-R, respectively (Table 4 and 5). PA was increased by 9% and 24 % under ZTW+R in 0-5 cm layer compared to ZTW-R and CTW-R, respectively (Table 6). Three enzyme activities (FDA, APA and PA) were significantly higher under ZTW-R than CTW-R. The increase in UA under ZTW+R was 8 and 13 % higher as compared to ZTW-R and CTW-R in 0-5 cm soil layer, respectively (Table 7).

Chemical properties of soil

Tillage and rice straw management practices in wheat significantly affected the soil chemical properties, except soil pH and EC in the 0-5 cm layer only (data not shown) (Tables 8-11). Soil organic carbon content in 0-5 cm layer in ZTW+R treatment was increased by 10.3% and 23.1% compared to ZTW-R and CTW-R, respectively (Table 8). ZTW-R plots had significantly higher organic carbon content than CTW-R. Similarly, Olsen-P, NH_4OAc-extratable - K and DTPA-extractable micronutrients (Zn, Fe, Mn and Cu) were significantly higher in ZTW+R compared to ZTW-R and CTW-R treatments (Table 9-11). The increase in micronutrient availability was greater for Fe and Cu (12-14%) compared with the increase in the Zn and Mn (3-6%) (Table11).

Grain yield and yield attributes of wheat

Grain yield of subsequent wheat was not significantly affected by the rice establishment methods, irrespective of tillage and straw management in wheat (Table 12). However, tillage and rice straw management practices in wheat significantly affected grain yield of third wheat crop (Table 12). ZTW+R produced 9% and 15% higher grain yield than ZTW-R and CTW-R, respectively. CTW-R produced significantly higher (6 %) grain yield than ZTW-R. As the grain yield of subsequent wheat was not significantly affected by the rice establishment methods so the yield attributes did not differ significantly (Table 12). However, tillage and straw management practices in wheat significantly affected wheat grain yield attributes. All the yield attributes namely Spike length, grains per spike, grain weight per spike and 1000 grain weight were highest under ZTW+R followed by CTW-R and ZTW-R.

Correlation between soil enzyme activities, grain yield and soil chemical properties

Activities of all of the enzymes in the study were significantly and positively correlated with each other as well as with organic carbon and Olsen-P in surface 0-5 cm soil layer (Table 13). The values of correlation coefficient (r) for soil enzyme activities ranged from 0.62 to 0.96. While the lowest value of ‘r’ was between APA and PA, the highest value was recorded for FDA and PPA. Except for APA, all the other enzymes showed significant and positive relationship (r = 0.61 - 0.72) with organic carbon in the 0-5cm soil layer. A strong and positive relationship (r = 0.65 - 0.83) was observed between all the enzyme activities and Olsen P in 0-0.5 m layer. Grain yield of wheat showed significant positive relationship (r = 0.69 - 0.86) with FDA, PA, PPA and UA in the surface 0-5 cm soil layer (Table 13). The activities of all the enzymes were significantly and positively correlated (r = 0.63 - 0.86) with DTPA-extractable Fe and Zn in 0-5 cm layer (Table 14). The relationship with DTPA-Mn was significant only for FDA and PA.

DISCUSSION

In our study, ZTW+R improved all soil enzyme activities in the 0-5 cm soil layer of than ZTW-R and CTW-R. Tillage and crop residues management practices have been reported to increase enzyme activities in soils (Klose *et al*., 1999). The stimulating effect of organic materials on enzyme activities in soil is consistent with results earlier reported (Elfstrand *et al*., 2007; Garcia *et al*., 1998). The rice straw provided carbon for enhancing microbial activity and thereby increased activity of several enzymes (Caravaca and Roldan, 2003). The increases in microbiological activities under ZT compared to CT have been linked to

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the increases in organic matter content of surface soils (Roldan *et al*., 2007; Melero *et al*., 2009). The addition of organic matter on CT fields can rapidly increase the soil enzyme activities (Kandeler *et al*., 2006).

DHA activity occurs intracellular in all living microbial cells (Yuan and Yue, 2012; Zhao *et al*., 2010) and can be used as an indicator of overall soil microbial activity (Salazar *et al*., 2011). DHA responded to tillage and residue management treatments in a similar manner as SOC. DHA activity in soil decreased with depth possibly due to the decrease in SOC, soil aeration and root biomass. Consistent with our study, reduced tillage or ZT increased DHA compared to CT and the values decreased with soil depth (Madejon *et al*., 2007; Tao *et al*., 2009).

The FDA hydrolysis is a sensitive and nonspecific test to depict the hydrolytic activity of soil microorganisms and has been commonly accepted as a simple measure of total microbial activity (Adam and Duncan, 2001). The large increase in FDA hydrolysis due to combined effect of ZTW and rice residue could be attributed to organic matter enrichment in 0-5 cm soil layer. Earlier studies have showed a similar increase in FDA in ZT systems under different climatic conditions (Perez-Brandan *et al*., 2012; Gajda *et al*., 2013). The activity of APA is linked to the transformation of organic to inorganic P (Yang *et al*., 2008). Consistent with our results, several studies have reported higher APA activities under ZT than CT (Tao *et al*., 2009; Qin *et al*., 2010). Higher PA in ZT with retaining rice straw may be due to organic matter build up after 3 years of continuous ZT than under CT (Yadav and Tarafdar, 2004). The increase in PA under ZTW+R is likely to increase the release of P from phytate present in soil.

Urease (UA) was significantly increased under ZTW+R in 0-5 cm soil layer demonstrating an improvement of soil quality. Mikanova *et al*., (2009) observed that UA was significantly higher under reduced tillage compared to the CT at soil depth of 0–10 cm. Similarly, Qin *et al.,* (2010) also observed UA was significantly higher in ZT with maize residue as compared to CT without maize residue in 0-10 cm soil layer. An increase in UA is generally accompanied by increase in SOC (Kheyrodin *et al*., 2012). Activity of UA decreased with depth in all treatments which might be owing to a decrease in SOC.

Retention of rice residue in ZT caused significant increase in the contents of OC, Olsen-P, NH_4OAc-K and DTPA-micronutrients compared to CTW-R (Table 3). The increases in OC under ZT+R have been observed in a range of soil and climatic conditions (Melero *et al.,* 2009; Yadvinder-Singh *et al*., 2010b). The significant increases in the contents of Olsen-P, NH_4OAc-K and DTPA-micronutrients in 0-5 cm soil layers under ZTW+R compared to CTW-R were probably positive effects of rice residue retention and lower rate of soil organic decomposition under ZT conditions (Salinas-Garcia *et al*., 2002; Yadvinder-Singh *et al*., 2014). In addition, the increase in the availability of P in surface layer under ZTW+R compared to CTW-R could also be due to lower P adsorption by soil and the release of organic P during decomposition of rice residues (Qin *et al*., 2010; Wang *et al*., 2008). Being a rich source of K, rice straw increased the availability K under ZT+R than the other treatments (Yadvinder Singh *et al*., 2010a).

In our study, ZTW+R significantly increased the grain yield over ZTW-R and CTW-R. The increase in grain yield of wheat under ZTW+R may be ascribed to the positive effects of soil temperature modifications, soil moisture supply and improved soil fertility due to rice residue mulch (Yadvinder-Singh and Sidhu, 2014). Consistent with our results, earlier studies have also reported higher yields of wheat under ZT+R compared to CT-R (Sidhu *et al*., 2007). When the entire rice residue was removed (-R), yield of ZTW was significantly lower than CTW. In an earlier study, Arora *et al*., (2010) reported that poor root growth and lower N use efficiency was responsible for lower wheat yields in ZT-R compared to CT-R.

Significant correlations between different enzyme activities observed in our study (Table 4) suggest a general relationship between soil microbiological properties. Retention of crop residues improved the organic carbon status of soils, which in turn was reflected in the higher soil enzymatic activities (Omidi *et al*., 2008; Gajda *et al*., 2013). Qin *et al*., (2010) found that UA and APA activities were significantly correlated with available P content in soil. The relationship between all assayed soil enzyme activities and chemical properties indicate that these enzymes play an important role in the cycling of elements and initial phases of the decomposition of crop residues. This implies that continuous addition of diversified carbon sources through rice residues as organic manuring enhanced the microbial biomass carbon and abundance of different microbial communities of soil and perhaps the enzyme activities.

4. CONCLUSION

The study showed that zero tillage with rice residues as surface mulch (ZTW+R) markedly improved grain yield of wheat over zero tillage without residue (ZTW-R) after three years of RW cropping sequence. ZTW+R was more effective than ZTW/CTW for increasing the soil organic carbon, Olsen-P, NH_4OAc-K

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and DTPA-extractable micronutrients in soil surface 0-5 cm layer. A significant change in soil enzyme activities occurred after 3 years of ZTW+R. All soil enzymes were positively correlated with each other and with soil chemical properties and grain yield. The increase in enzyme activities in soil may contribute to a long-term sustainability of RWS under semi-arid climate conditions of South Asia. The beneficial effect of RCTs on soil quality was mainly confined to the soil surface layer.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration between all authors. Author HST, HSS, MLJ and YS designed the study, started the experiment in 2010. Author SKK collected the data, performed the statistical analysis and wrote the first draft of the manuscript. All co-authors were give technical support in data collection, determination of different parameters and statistical analyses of the study. All authors read and approved the final manuscript.

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Table 1. Description of experimental treatments (Kharia *et al* 2017)

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Rice (main plots)	Wheat (sub-plots)
T_1. Zero till direct seeded rice (ZT-DSR). Residues of previous wheat crop were removed. DSR was sown using same drill as in treatment. T_2. Conventional direct seeded rice (CT-DSR). Residues of previous wheat crop were removed. Tillage for DSR included two passes of harrows and two passes of Tyne plough[γ] followed by planking, The DSR was sown using seed cum fertilizer drill in 20 cm apart.	1. Conventional till wheat after removal of rice residue (CTW-R). Residues of previous rice removed. Tillage operations for CTW included two passes of harrows and two passes of Tyne plough[γ] followed by planking.
T_3. ZT transplanted rice using mechanical trans planter (ZT-DTR). Residues of previous wheat crop were removed.	2. Zero till wheat after removal of rice residue (ZTW-R). Wheat was direct seeded in the no till plots using zero till drill.
T_4.Conventional till puddled transplanted rice (PTR): Residues of preceding wheat crop removed. Puddling (wet tillage) was done twice in 6-8 cm of standing water using a tractor-mounted puddler followed by planking.	3. Zero till wheat + residues (ZTW+R) Residues of previous rice crop retained. Wheat was directly seeded into residues using Turbo Happy Seeder (Sidhu *et al*., 2015).*

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Table 2. Methods used for analysis of soil samples for different soil parameters

Soil properties	Method used	Reference
Organic carbon	Wet digestion method	Walkley and Black (1934)
Olsen P	0.5 M $NaHCO_3$-extractable	Olsen *et al*., (1954)
Available K	1M NH_4OAc-extractable	Jackson (1973)
DTPA- Fe, Mn, Cu and Zn	DTPA extractable	Lindsay and Norwell (1978)
Dehydrogenase activity (DHA)	Triphenylformazan (TPF) produced by the reduction of 2, 3, 5-triphenyltetrazolium chloride (TTC).	Tabatabai (1982)
Fluorescein di-acetate activity (FDA)	Fluorescein released by the hydrolysis of fluorescein di-acetate.	Adam and Duncan (2001)
Alkaline phosphatase activity (APA)	p-nitrophenyl method.	Tabatabai and Bremner (1969)
Phytase activity (PA)	Inorganic phosphate released by hydrolysis using sodium phytate	Ames (1966)
Urease activity (UA)	2M KCl- Phenyl mercuric acetate	Douglas and Bremner (1970)

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Table 3. Effect of rice establishment, tillage and rice straw management on dehydrogenase (μg TPF g^{-1} 24 hr^{-1}) activities at various soil layers.

Treatments	Soil layers (cm)		
	0-5	**5-10**	**10-15**
Rice establishment systems			
DSR-ZT-DSR	303	177	77.4
DSR-CT-DSR	275	168	76.2
ZT-DTR	290	163	74.7
PTR	286	159	72.4
LSD(0.05)	NS	NS	NS
Tillage and rice straw management practices			
CTW-R	265	158	73.4
ZTW-R	291	167	73.8
ZTW+R	309	175	78.4
LSD (0.05)	25.8	NS	NS

Table 4. Effect of rice establishment, tillage and rice straw management on flourescein diacetate (μg fluorescein g^{-1} dry soil) activities at various soil layers

Treatments	Soil layers (cm)		
	0-5	**5-10**	**10-15**
Rice establishment systems			
DSR-ZT-DSR	3.32	2.68	2.45
DSR-CT-DSR	3.24	2.74	2.45
ZT-DTR	3.16	2.73	2.50
PTR	3.12	2.74	2.42
LSD(0.05)	NS	NS	NS
Tillage and rice straw management practices			
CTW-R	3.02	2.69	2.42
ZTW-R	3.15	2.72	2.41
ZTW+R	3.47	2.76	2.52
LSD (0.05)	0.120	NS	NS

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Table 5. Effect of rice establishment, tillage and rice straw management on alkaline phosphatase (µg p-nitrophenol g^{-1} dry soil hr^{-1}) activities at various soil layers

Treatments	Soil layers (cm)		
	0-5	**5-10**	**10-15**
Rice establishment systems			
DSR-ZT-DSR	49.4	42.2	33.9
DSR-CT-DSR	42.5	39.0	34.3
ZT-DTR	43.8	39.1	30.5
PTR	41.4	34.7	28.7
LSD(0.05)	NS	NS	NS
Tillage and rice straw management practices			
CTW-R	41.4	37.6	31.2
ZTW-R	43.6	37.6	31.7
ZTW+R	47.8	41.0	32.7
LSD (0.05)	3.72	NS	NS

Table 6. Effect of rice establishment, tillage and rice straw management on Phytase (µg inorganic P released g^{-1} dry soil hr^{-1}) activities at various soil layers

Treatments	Soil layers (cm)		
	0-5	**5-10**	**10-15**
Rice establishment systems			
DSR-ZT-DSR	0.341	0.273	0.238
DSR-CT-DSR	0.340	0.265	0.234
ZT-DTR	0.328	0.268	0.233
PTR	0.340	0.262	0.237
LSD(0.05)	NS	NS	NS
Tillage and rice straw management practices			
CTW-R	0.303	0.254	0.232
ZTW-R	0.310	0.269	0.232
ZTW+R	0.398	0.277	0.241
LSD (0.05)	0.031	NS	NS

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Table 7. Effect of rice establishment, tillage and rice straw management on urease (μg urea g^{-1} dry soil min^{-1}) activities at various soil layers

Treatments	Soil layers (cm)		
	0-5	5-10	10-15
Rice establishment systems			
DSR-ZT-DSR	2.60	2.13	1.68
DSR-CT-DSR	2.55	2.14	1.70
ZT-DTR	2.58	2.17	1.60
PTR	2.51	2.18	1.66
LSD(0.05)	NS	NS	NS
Tillage and rice straw management practices			
CTW-R	2.40	2.12	1.63
ZTW-R	2.54	2.16	1.64
ZTW+R	2.75	2.20	1.72
LSD (0.05)	0.070	NS	NS

Table 8. Effect of rice establishment, tillage and rice straw management on OC (g kg^{-1}) content at various soil layers

Treatments	Soil layers (cm)		
	0-5	5-10	10-15
Rice establishment systems			
DSR-ZT-DSR	5.88	4.65	3.37
DSR-CT-DSR	5.49	4.93	3.17
ZT-DTR	5.90	4.65	3.43
PTR	5.82	5.03	3.58
LSD(0.05)	NS	NS	NS
Tillage and rice straw management practices			
CTW-R	5.18	4.56	3.32
ZTW-R	5.79	4.86	3.43
ZTW+R	6.35	5.02	3.41
LSD (0.05)	0.30	0.36	NS

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Table 9. Effect of rice establishment, tillage and rice straw management on Olsen P (kg ha^{-1}) content at various soil layers

Treatments	Soil layers (cm)		
	0-5	5-10	10-15
Rice establishment systems			
DSR-ZT-DSR	9.98	8.35	6.24
DSR-CT-DSR	9.69	7.14	4.72
ZT-DTR	10.1	8.32	5.66
PTR	9.13	7.02	5.72
LSD(0.05)	NS	NS	NS
Tillage and rice straw management practices			
CTW-R	8.90	6.82	5.23
ZTW-R	9.64	7.81	6.03
ZTW+R	10.7	8.49	5.50
LSD (0.05)	0.799	0.687	NS

Table 10. Effect of rice establishment, tillage and rice straw management on available K (kg ha^{-1}) content at various soil layers

Treatments	Soil layers (cm)		
	0-5	5-10	10-15
Rice establishment systems			
DSR-ZT-DSR	44.8	38.1	34.8
DSR-CT-DSR	45.4	37.3	37.8
ZT-DTR	47.0	39.1	38.3
PTR	42.7	34.4	36.9
LSD(0.05)	NS	NS	NS
Tillage and rice straw management practices			
CTW-R	42.6	35.1	36.1
ZTW-R	40.7	35.3	34.9
ZTW+R	51.6	41.3	39.8
LSD (0.05)	6.34	4.01	NS

Table 11. Effect of rice establishment, tillage and rice straw management on DTPA micronutrients in 0-5 cm soil layer after three cycles of rice-wheat system.

Treatments	DTPA- extractable micronutrients (mg kg^{-1})			
	Zn	Mn	Fe	Cu
Rice establishment systems				
ZT-DSR	5.17	8.32	30.0	1.34
CT-DSR	4.95	8.20	28.4	1.29
ZT-DTR	4.87	8.12	29.9	1.23
PTR	4.77	8.30	29.4	1.38
LSD (p=0.05)	NS	NS	NS	NS
Tillage and rice straw management practices				
CTW-R	4.85	8.19	28.0	1.25
ZTW-R	4.85	8.04	28.5	1.26
ZTW+R	5.14	8.47	31.8	1.43
LSD (p=0.05)	0.24	0.30	2.40	0.09

Table 12. Yield and yield attributing parameters of wheat as influenced by rice establishment systems, tillage and rice straw management practices under rice-wheat system (Kharia *et al* 2017).

Treatment	Grain yield (Mg ha^{-1})	Spike length (cm)	Grains spike^{-1}	Grain weight spike^{-1} (gram)	1000 grain weight (gram)
Rice establishment systems					
ZT-DSR	4.84	10.5	53.5	2.08	38.0
CT-DSR	4.84	10.8	52.7	1.97	38.0
ZT-DTR	4.88	10.7	53.7	2.04	35.7
PTR	4.77	11.0	52.9	2.01	37.8
LSD (0.05)	NS	NS	NS	NS	NS
Tillage and straw management practices					
CTW-R	4.77	10.5	53.1	2.01	36.8
ZTW-R	4.47	10.9	52.1	1.90	35.8
ZTW+R	5.26	10.8	54.3	2.16	39.6
LSD (0.05)	0.19	0.30	1.10	0.08	2.20

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Table 13. Correlation between soil enzyme activities, grain yield of wheat, pH, organic carbon and Olsen-P in 0-5 cm soil layer after three cycles of rice-wheat cropping system

Properties	DHA	FDA	APA	PA	UA	GY	pH	OC	Olsen-P
0-5 cm layer									
DHA	1	0.826**	0.843**	0.742**	0.896**	0.488	-0.198	0.674*	0.739**
FDA		1	0.787**	0.886**	0.910**	0.690**	-0.232	0.608*	0.824**
APA			1	0.624*	0.775**	0.500	-0.006	0.497	0.652*
PA				1	0.892**	0.857**	-0.283	0.694*	0.759**
UA					1	0.710**	-0.381	0.717**	0.831**

DHA-Dehydrogenase activity, FDA-Fluorescein di-acetate, APA-Alkaline phosphatase activity, PA-Phytase activity, UA-Urease activity, GY-Grain yield, OC-Organic carbon.

** Significant at p<0.01, * Significant at p<0.05

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Table 14. Correlation between soil enzyme activities and DTPA-extractable micronutrients (mg kg^{-1}) in 0-5 cm soil layer

Parameter	Fe	Mn	Cu	Zn
Dehydrogenase (DHA)	0.775**	0.453	0.650*	0.627*
Fluorescein di-acetate (FDA)	0.760**	0.624*	0.717**	0.782**
Alkaline phosphatase activity (APA)	0.685*	0.428	0.519	0.771**
Phytase activity (PA)	0.820**	0.747**	0.847**	0.643*
Urease (UA)	0.857**	0.505	0.681*	0.657*

** Significant at p<0.01, * Significant at p<0.05

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