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Tillage and crop residue management practices on crop productivity, phosphorus uptake and forms in wheat (*Triticum aestivum*)-based cropping systems*

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Intensive tillage practices are contributing to declining air, water and soil quality. Reducing soil disturbance by implementing conservation tillage may improve this situation. Research on zero and minimum tillage has illustrated the greater opportunity to increase soil organic carbon, microbial activity, nutrients and extractable phosphorus due to accumulation of crop residues at the soil surface compared with conventional tillage (Vu *et al*. 2009). Today, in the country, the area under conservation tillage has increased to more than 2 million ha. However, there has been little corresponding change in the application rates and management of nutrients, especially phosphorus. Conservation tillage or zero tillage may have positive, negative or no effect on grain yield of crops depending on soil, crop, cropping system and climatic conditions. Therefore, site-specific suitability of various crops and cropping systems for conservation agriculture needs extensive investigations.

Tillage practices, cropping systems and nutrient sources influence the behaviour of the different forms of P in soil and hence its availability to crops. Suitable cropping systems, if practised in a particular area according to soil and environment could be very helpful to restore the P status of soil. Indiscriminate use of phosphorus results in its build-up in the soil. Residual phosphorus in soil can lead to imbalance of nutrient availability to crop plants, pollution of terrestrial and aquatic ecosystems (Erich *et al*. 2002). Hence, there is a need to evaluate conservation agriculture-based cropping systems for efficient use of added P so that accumulation of unutilized P in soil could be minimized and contamination of water bodies could be avoided. In view of the issues discussed above in this study we examined the effect of wheat-based cropping systems and tillage methods and crop residue management on performance of maize, pigeonpea, soybean, groundnut and cotton, their P requirements and changes in soil P forms.

A field experiment was conducted during *kharif* 2007 on pigeon pea (*Cajanus cajan,* var P 992), groundnut (*Arachis hypogaea,* var. TAG 24), maize (*Zea mays,* var. PEMH 2), soybean (*Glycine max,* var. D 9814) and cotton (*Gossypium hirsutum,* var. SCH 22) under different tillage and crop residue management (TCRM) practices, in an on-going long-term conservation tillage field experiment on wheat-based cropping systems started in *kharif*-2004 at IARI, New Delhi. Above five *kharif* crops were raised alternately with wheat (var. PBW 343) in *rabi* under the main plots and the sub-plot treatments were zero tillage with residue (ZT+R), zero tillage without residue (ZT-R), conventional tillage with residue (CT+R) and conventional tillage without residue (CT-R). The treatments were allocated randomly in a split plot design having three replications. The residues of different *kharif* crops were applied @ 2 tonnes/ha before sowing of wheat and wheat residue @ 3 tonnes/ha was applied before sowing of *kharif* crops in the respective fields. Recommended fertilizer doses of $N:P_2O_5:K_2O$ at the rate of 120:60:40, 25:60:40, 25:60:40, 120:60:40, 25:60:40 and 160:80:80 were applied for wheat, pigeonpea, groundnut, maize, soybean and cotton, respectively. Weeds were controlled by application of herbicide paraquat @ 1 kg ai/ha in zero tillage plots before sowing of *kharif* crops. Other agronomic operations were carried out as and when required.

The experimental soil was sandy loam in texture, neutral in reaction (*p*H 7.5), low in organic carbon (0.48%) and available nitrogen (194 kg/ha), medium in available potassium (186 kg/ha), low in available phosphorus (9.9 kg/ha) and

* Short note

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sulphur (16.8 kg/ha), and free from salinity (0.35 dS/m). Taxonomically (USDA) it belongs to Typic Haplustept sub-group. The plot-wise surface (0–15 cm) soil samples collected before the sowing of *kharif* 2007 crops along with the initial soil samples were analysed for Olsen's, total (ignited at 550°C), inorganic (unignited) and organic P (Walker and Adams 1958). The phosphorus content in the extracts was measured by ascorbic acid reduction of the ammonium phosphomolybdate complex method (Watanabe and Olsen 1965).

Phosphate content of plant samples in di-acid digest was determined colorimetrically as vanadomolybdophosphate yellow complex in nitric acid medium. Statistical analysis was carried out as per the standard methods for split-plot design at 5% level of significance.

Grain yield, stover yield and total P uptake of crops were significantly influenced by main plot, sub-plot treatments and their interactions (Table 1). Maximum grain yields of maize (2.72 tonnes/ha), pigeonpea (1.31 tonnes/ha), soybean (1.15 tonnes/ha) and groundnut (1.34 tonnes/ha) were observed in CT+R treatment, whereas cotton lint yield (1.95 tonnes/ha) was maximum in ZT+R. The lowest mean grain yields (1.26 tonnes/ha) of crops were obtained in ZT-R and the highest (1.59 tonnes/ha) in CT+R. Conventional tillage with residue (CT+R) was statistically at par with ZT+R. Except maize and cotton lint, grain yields of pigeonpea, soybean and groundnut were non-significantly affected by TCRM practices (Table 1). Significantly higher yield of maize was observed in CT+R (2.72 tonnes/ha), followed by CT-R (2.41 tonnes/ha) and latter was statistically at par with ZT+R (2.36 tonnes/ha). Cotton lint yield (1.95 tonnes/ha) was significantly higher in ZT+R and rest of the three treatments were statistically at par with each other. Almost similar trend was observed for stover yield and total P uptake

Table 1 Effect of varying tillage and crop residue management (TCRM) practices on grain/cotton lint, stover yield and total P uptake of different *kharif* crops in wheat-based cropping systems

Tillage and crop residue management	Crop					Mean
	Maize	Pigeonpea	Soybean	Groundnut	Cotton	
			Grain/cotton lint yield (tonnes/ha)			
CT-R	2.41	1.11	0.93	1.26	1.35	1.41
CT+R	2.72	1.31	1.15	1.34	1.45	1.59
ZT-R	2.06	1.09	0.76	1.09	1.31	1.26
ZT+R	2.36	1.23	0.96	1.27	1.95	1.55
Mean	2.39	1.18	0.95	1.24	1.51	
	Crop (C)	TCRM	C × TCRM			
SEm(±)	0.07	0.04	0.10 (A)	0.11 (B)		
CD (*P=0.05*)	0.24	0.13	0.29 (A)	0.34 (B)		
			Stover yield (tonnes/ha)			
CT-R	6.85	9.83	2.17	1.91	9.92	6.14
CT+R	6.87	9.76	2.39	2.11	11.75	6.58
ZT-R	5.87	8.59	2.11	1.77	9.72	5.61
ZT+R	6.08	9.84	2.28	1.91	13.30	6.68
Mean	6.42	9.51	2.24	1.92	11.18	
	Crop (C)	TCRM	C × TCRM			
SEm(±)	0.21	0.19	0.42 (A)	0.43 (B)		
CD (*P=0.05*)	0.70	0.55	1.23 (A)	1.27 (B)		
			Total P uptake (kg/ha)			
CT-R	19.1	13.2	12.6	10.9	34.1	18.0
CT+R	20.7	14.1	14.9	11.9	40.0	20.3
ZT-R	16.2	11.8	10.9	9.6	33.2	16.4
ZT+R	17.8	14.0	13.0	11.0	46.9	20.6
Mean	18.4	13.3	12.8	10.9	38.6	
	Crop (C)	TCRM	C × TCRM			
SEm(±)	0.81	0.56	1.26 (A)	1.36 (B)		
CD (*P=0.05*)	2.64	1.62	3.64 (A)	4.12 (B)		

CT-R, Conventional tillage without residue; CT+R, conventional tillage with residue; ZT-R, zero tillage without residue; ZT+R, zero tillage with residue; A, for comparing two sub-plot treatment means at a given main plot treatment; B, for comparing two main plot treatment means, either at a given sub-plot treatment or at different sub-plot treatments of different crops. Total mean P uptakes of groundnut (10.9 kg/ha), soybean (12.8 kg/ha) and pigeonpea (13.3 kg/ha) were statistically at par with each other and were significantly lower than cotton (38.6 kg/ha) and maize (18.4 kg/ha). The interaction between crop and TCRM caused significantly higher total P uptake at sub-plot treatments at the same main plot or within two main plots treatments (Table 1). At same or different TCRM practices, total P uptake of groundnut, soybean and pigeonpea were statistically at par with each other.

The grain/lint and stover yield differences between two crops at same or different TCRM treatments were due to their genetic potential differences. Except cotton, dry matter yield of other crops were reduced in zero tillage conditions. It showed that cotton is much adapted for conservation agriculture cultivation than other crops studied. Yield of maize grain and stover were significantly higher in CT than in ZT. Astier *et al*. (2006) has found that zero tillage was associated with less biomass at anthesis and maturity and less leaf chlorophyll concentration, suggesting lower nitrogen uptake by maize. Irrespective of type of tillage practices higher yield of all the crops were observed in tillage treatments receiving crop residues. This might be due to alternation in soil's hydrothermal regime by lowering the temperature and reducing evaporation losses and increase in leaf area index, chlorophyll content of leaves and number of pods/plant (Sekhon *et al*. 2005). Contradictory to this finding Costa *et al*. (2010) reported that corn yield was not affected by long-term tillage system. A number of factors regulate plant growth and crop yield response to residue management systems. Application of residue increased yields of crops as surface residues have several beneficial effects which include water conservation, soil erosion control, and maintenance or enhancement of soil organic matter with its attendant improvements in the soil environment. Therefore, no significant influence of these treatments was expected in the initial years of the experimentation that could be the reason for the lowest grain/lint and stover yield of all the crops in ZT-R. In some instances, the effect of conservation tillage may require several years before their positive influence on crop yield becomes evident.

Higher total P uptake in case of cotton and maize might be explained in terms of higher dry matter yield (grain/lint and stover yield) produced by these two crops (Table 1) which is governed by their genetic ability. Total P uptake was significantly higher in tillage treatments receiving crop residue than tillage treatments without residue which may be due to significant increase in Olsen's P content (Table 2) and consequently higher biomass production by the crops in the above treatments. In case of cotton, higher dry matter yield (Table 1) resulted in higher uptake in zero-tilled plots having crop residue. In most cases, roots grow under ZT crop remain active in the surface soil layer where P concentration is the highest, and where there is a larger proportion of available forms of P, leading to a more efficient use of P (Rheinheimer and Anghinoni 2003). Rapid turnover of active soil organic matter that releases nutrients in synchrony with plant demand could be reason for higher grain yield and P uptake in maize (Astier *et al*. 2006) under CT+R.

Significant change in Olsen's P contents of surface soil was observed due to crops as well as TCRM practices (Table 2). The highest mean Olsen's P content in surface soil was in cotton plots (18.3 kg/ha), followed by pigeonpea (16.9 kg/ha), soybean (16.1 kg/ha), groundnut (15.6 kg/ha) and maize (14.6 kg/ha), respectively, which were more than initial Olsen's P content (9.9 kg/ha). Olsen's P content of cotton plots was statistically at par with that of pigeonpea and similar non-significant differences were observed among maize, soybean and groundnut. Application of crop residue to tillage treatments significantly increased phosphorus availability of surface soil irrespective of kind of tillage (Table 2). The highest mean content of Olsen P in surface soil was observed in ZT+R plots (18.4 kg/ha), followed by CT+R (17.2 kg/ha), ZT-R (15.4 kg/ha) and CT-R (14.1 kg/ha). ZT+R was statistically at par with CT+R treatment. Though crop × TCRM interaction affect was statistically non-significant, however, the highest content of Olsen's P was found in surface soil of ZT+R, followed by CT+R plots of all the crops (Table 2).

Significantly higher mean content of Olsen's P in tillage treatments having crop residues and in also ZT-R showed that the chemical nature of soil P is affected by cultivation practices which conserve organic matter in soil. It showed that phosphorus solubility increased under conservation tillage which may be attributed to greater microbial activity during the decomposition of crop residues (Zibilske and Brandford 2003). Organic matter reduces activities of Ca^{2+}, Fe^{3+} and $A1^{3+}$ by forming stable complexes and thus increases P availability by reducing phosphate fixation and by decreasing P sorption and immobility of P in soil system. This finding is in conformation with the findings of Zamuner *et al*. (2008). They reported a higher concentration of labile inorganic P at the surface layer in no tillage (NT) compared with CT as a result of accumulation of P fertilizer and crop residues. The significantly higher content of Olsen's P in spite of the highest amount of P removal by cotton (Table 1) in cotton plots may be attributed to the highest rate of inorganic P application (80 kg P_2O_5/ha) than other crops. Secretion of exudates from pigeonpea roots containing malonic and piscidic acids solubilized P bound to Fe and Al (Otani *et al*. 1996) which ultimately increased P availability. The significant increase in Olsen's P of surface soil in ZT+R may have substantial impact on surface water quality in long-term conservation tillage system.

The largest proportion of P in surface soil (60%) was in inorganic form, followed by organic P (40%). TCRM practices caused significant change in mean inorganic and organic P content of soil whereas crops and crop × TCRM effects were

Table 2 Effect of varying tillage and crop residue management (TCRM) practices on Olsen's, inorganic, organic and total phosphorus content of surface soil (0–15 cm)

Tillage and crop residue management	Crop					Mean
	Maize	Pigeonpea	Soybean	Groundnut	Cotton	
			Olsen's phosphorus content (kg/ha)			
CT-R	12.5	14.0	13.4	14.0	16.8	14.1
CT+R	15.4	18.7	16.8	16.3	18.8	17.2
ZT-R	13.9	15.1	15.4	14.6	17.9	15.4
ZT+R	16.7	19.7	18.9	17.4	19.6	18.4
Mean	14.6	16.9	16.1	15.6	18.3	
	Crop (C)	TCRM	C × TCRM			
SEm(±)	0.68	0.44	0.99 (A)	0.98 (B)		
CD (*P=0.05*)	2.23	1.27	NS	NS		
			Inorganic phosphorus content (kg/ha)			
CT-R	904	915	923	933	905	916
CT+R	889	897	897	905	854	888
ZT-R	858	866	874	876	854	866
ZT+R	815	819	820	827	767	810
Mean	867	874	878	885	845	
	Crop (C)	TCRM	C × TCRM			
SEm(±)	41.7	22.4	50.0 (A)	60.1 (B)		
CD (*P=0.05*)	NS	64.6	NS	NS		
			Organic phosphorus content (kg/ha)			
CT-R	513	519	524	529	514	520
CT+R	573	579	578	584	550	573
ZT-R	575	580	585	587	572	580
ZT+R	656	659	660	666	618	652
Mean	579	584	587	591	563	
	Crop (C)	TCRM	C × TCRM			
SEm(±)	27.9	15.7	35.0 (A)	41.2 (B)		
CD (*P=0.05*)	NS	45.2	NS	NS		
			Total phosphorus content (kg/ha)			
CT-R	1 417	1 435	1 446	1 462	1 419	1 436
CT+R	1 461	1 476	1 475	1 489	1 404	1 461
ZT-R	1 433	1 446	1 458	1 463	1 425	1 445
ZT+R	1 472	1 478	1 480	1 493	1 385	1 462
Mean	1 446	1 459	1 465	1 477	1 408	
	Crop (C)	TCRM	C × TCRM			
SEm(±)	69.4	38.0	84.9 (A)	101 (B)		
CD (*P=0.05*)	NS	NS	NS	NS		

CT-R, Conventional tillage without residue; CT+R,conventional tillage with residue; ZT-R, zero tillage without residue; ZT+R, zero tillage with residue; A, for comparing two sub-plot treatment means at a given main plot treatment; B, for comparing two main plot treatment means, either at a given sub-plot treatment or at different sub-plot treatments

non-significant (Table 2). The highest significant mean content of inorganic P in soil was found in CT-R (916 kg/ha) followed by CT+R (888 kg/ha), ZT-R (866 kg/ha) and ZT+R (810 kg/ha). Except in ZT-R, the mean inorganic content in rests of the three treatments, viz. CT-R, CT+R and ZT+R were statistically at par with each other. Zero tillage having crop residue (ZT+R) was also statistically at par with without residue (ZT-R). Lower inorganic P content of soil was observed in case of cotton (845 kg/ha) and maize (867 kg/ha) after completion of three cropping cycles of cotton–wheat and maize–wheat cropping system than the initial soil (870 kg/ha). Organic P content significantly increased in tillage treatments having crop residue than without residue. Significantly the highest mean organic P content was in ZT+R (652 kg/ha), followed by ZT-R (580 kg/ha), CT+R (573 kg/ha) and CT-R (520 kg/ha). However, ZT-R was statistically at par with CT+R. Organic P content of soil appreciably increased under all the crops than initial soil organic P content of 537 kg/ha.

Significantly low content of inorganic P in ZT+R could be partially explained in terms of significantly high total P uptake by crops in ZT+R than CT-R (Table 1). The content of organic P increased significantly in tillage treatments having crop residue and inorganic P decreased without significantly affecting total P content which indicated transformation of some part of inorganic P into organic P by the activities of microbes and resulted in decreased content of inorganic P. This fact is supported by highly significant negative correlation (–0.80**) between inorganic and organic P (data not reported). Selles *et al*. (2002) showed that continuous wheat rotations under zero tillage decreased inorganic P content of soil. These results also support observations from previous study by Díaz-Zorita and Grove (2002). Marginal decrease in inorganic P content under cotton and maize might be explained in terms of higher total P removal by cotton (38.6 kg/ha) and maize (18.4 kg/ha) than other crops studied (Table 1) in spite of the highest rate of fertilizer P application to cotton (80 kg/ha). Significantly higher surface accumulation of organic P in zero tillage treatments applied with crop residue can presumably be explained by the high gradient of organic matter input through crop reside addition (5.65g/kg organic carbon) and greater root densities in surface soil (Costa *et al*. 2010), which stimulated microbial growth (Bunemann *et al.* 2006) and increased net P immobilization (Lupwayi *et al*. 2007). These results are in agreement with those of Rheinheimer and Anghinoni (2003). Significantly lower content of organic P was also found in CT+R plots (5.38 % Organic Carbon) than ZT-R plots (5.15g/kg organic carbon), could be resulted from organic matter mineralization due to soil tilling (Costa *et al*. 2010).

Total P content of a soil provides the total P reservoir in soil although only a small fraction of this is removed by crops. Total P content of surface soil was remained almost same or slightly increased (Table 2) due to crop and TCRM treatments than the initial soil content (1407 kg/ha). Higher content of total P was in tillage plots which received crop residues due to addition of P from organic. The lowest content of total P in surface soil was observed under cotton (Table 2).

Appreciably higher content of total P was found in tillage treatments receiving crop residue. The stratification of P found in soil under ZT management compared with CT has been attributed to the accumulation of residual fertilizer P reaction products and also to increased accumulation of organic residues at the soil surface (Díaz-Zorita and Grove 2002). Higher levels of total P in superficial soil layer under no tillage were also observed by Essington and Howard (2000). The lowest P content in surface soil observed under cotton might be explained in terms of higher P removal by cotton (38.6 kg/ha) than other crops. In case of cotton, total P inputs through fertilizer (34.9 kg P/ha) and wheat crop residue (2.1 kg P/ha) was less as compared to P removed (38.6 kg/ha), whereas in other crops P inputs through fertilizer and crop residue were considerably higher than P removed by crops (Table 1).

SUMMARY

This study was conducted to investigate the effect of crops and tillage (conventional and zero) and crops residue management (TCRM) practices on crops yield, P uptake and P forms. The experiment was laid out in split-plot design in which pigeonpea, cotton, soybean, maize and groundnut constituted the main plot treatments and combination of TCRM, viz zero tillage with residue (ZT+R), zero tillage without residue (ZT-R), conventional tillage with residue (CT+R) and conventional tillage without residue (CT-R) constituted sub-plot treatments. Conventional tillage with crop residue (CT+R) was found suitable for higher yields of maize, pigeonpea, soybean and groundnut, and for cotton lint yields it was zero tillage with residue (ZT+R). Crops and tillage systems did not affect the total soil P content; however, Olsen's, inorganic and organic fractions changed significantly due to application of crop residue in both zero and conventional tillage systems. Organic phosphorus content significantly increased in zero tillage system as compare to conventional tillage irrespective of crop residue application, whereas reverse trend was observed for inorganic P fraction. Crop residue increased Olsen's P content in both convention and zero tillage systems; however, tillage systems without crop residue had no effect on Olsen's P content. Different crops affected only soil Olsen's P fraction and appreciable build-up had been observed under all the crops on application of recommended doses of P and crop residue than initial soil Olsen's P content (9.9 kg/ha) but contents were still below the critical level of sufficiency (20 mg P/kg) in soil for all the crops after completion of three cropping cycles. Irrespective of crops and TCRM treatments, all P fractions increased in surface soil than their initial content due to fertilizer and residue application except under cotton, whereas appreciable decrease in inorganic P content and no change in total P content had been observed. This trend indicated that adaptation of zero tillage and crop residue addition for longer duration may require gradual adjustment in recommended doses of P application. From the results of this study, it may be concluded that soil phosphorus management decisions may differ according to the nature of cropping system and tillage and crop residue management practices.

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CORRECTION

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