

Long-term Conservation Tillage Effect on Soil Organic Carbon and Available Phosphorous Content in Vertisols of Central India

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Received: 14 September 2015 / Accepted: 24 June 2016 / Published online: 23 August 2016
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Abstract Efficient nutrient management in conservation tillage is one of the major concerns in vertisols as residue retention on soil surface and reduction in tillage operation can have a major impact on nutrient dynamics and stratification. The present study examined profile distribution of soil organic carbon (SOC) and available phosphorous under long-term (12 years) imposition of four different tillage systems, namely conventional tillage (CT), mouldboard tillage (MB), reduced tillage (RT), no tillage (NT) and three nitrogen levels, viz. N_{50%}, N_{100%} and N_{150%}. In 0- to 5-cm soil layer, highest and lowest SOC was observed in NT (8.8 g kg⁻¹) and CT (5.9 g kg⁻¹), whereas in 5- to 15-cm soil layer, higher SOC was observed in MB. The stratification ratio of SOC was higher in NT (2.20) followed by RT (1.93), MB (1.68) and CT (1.51). Higher available phosphorous concentration (12.8 g kg⁻¹) was recorded in NT with N_{50%} followed by NT with N_{100%}. Over the year, no significant effect of tillage on soybean and wheat yield was observed. However, effect of N level on yield was significant. Overall, conservation tillage practice imposed no penalty on yield of soybean–wheat system, while it saved energy and time by reducing the number of tillage operations.

Keywords Conservation tillage · Nutrient stratification · Nitrogen level · Soil organic carbon · Available phosphorous · Vertisol

Introduction

Uncertain rainfall pattern, limited water resource, poor nutrient input, soil-related constraints like low infiltration, high runoff and soil erosion, and intensive tillage operations are major constraints to agricultural productivity in vertisols of central India [31]. In India, vertisols cover about 70.3 mha of area, encompassing 22 % of the geographical area of the country, of which Maharashtra and Madhya Pradesh (central India) occupy 34.3 and 30.2 % area of vertisols, respectively. Improved tillage practices are needed for this region to reduce soil losses through

erosion as the soil during the rainy season is highly vulnerable to water erosion due to the prevalent high-intensity rain, very low water transmission characteristics of vertisols and rolling topography of this region. Increased awareness of soil degradation resulting from erosion, soil compaction, and loss of topsoil organic carbon under conventional production systems has encouraged researchers and policy makers in developing conservation agriculture alternatives.

There is an urgent need to understand the dynamics of soil fertility status, nutrient management and factors influencing nutrient behaviour and management in conservation tillage systems for the sustainable nutrient management. One of the most important aspects of conservation tillage systems is the covering of soil surface by the previous crop residues to protect the soil from erosion. Lack of incorporation of residues can have a major impact on the behaviour and management of nutrients. The primary aim of the conventional tillage operations was to

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mix immobile nutrients such as phosphorus with the soil, thus moving them into the rooting zone of crops and to prepare a suitable seedbed with good tilth and control weeds. This movement does not occur with the adoption of conservation tillage systems. Due to the reduction in tillage operations and addition of residues on the surface in conservation tillage, the soil biophysical environment under this tillage practices gets altered. It is thus anticipated that the distribution of nutrients in the soil profile under conservation tillage will be different from that in tilled soil or the conventional tillage system. Immobile nutrients like phosphorus broadcasted at the soil surface tend to accumulate at the surface 0–5 cm under no-tillage system [8]. It has also been reported that the acidifying effect of nitrogen and phosphorus fertilizer will be limited to a shallow surface layer of the soil under NT system.

The reduced tillage operations and retention and recycling of crop residues on or near the soil surface under conservation tillage practices favourably affect the soil properties. Besides this, the stratification of organic matter and nutrients and their accumulation near the soil surface are the other changes noticed under long-term adoption of conservation tillage. The presence of crop residues at the soil surface and application of fertilizers limited to shallow depth due to limited mixing are the two main reasons for such stratification [19]. As compared to conventional tillage, the no-tilled soils showed more *P* in the surface layers and less with depth [24]. Nutrient stratification refers to a non-uniform distribution of nutrients to soil depths, and especially in situations where higher concentrations of nutrients are present near the soil surface. Grove et al. [15] emphasized that nutrient stratification in agricultural soil is at times beneficial and not a problem for plant nutrition. Under conservation agricultural practices, soil organic carbon (SOC) and other nutrients get stratified with depth over time. This is viewed as an improvement in soil quality, as several key soil functions such as water infiltration, nutrient cycling and *C* sequestration from the atmosphere are enhanced. Stratification of soil organic matter in conservation tillage system generally reduces water runoff and soil loss from agricultural fields. Numerous investigators in their study have limited their soil sampling for *C* and *P* to depths either at or just below the deepest tillage treatment. This has been resulted in an overemphasis on dynamics of the SOC and *P* concentration in the near-surface zones, and inadequate knowledge of crop and tillage system impacts below the maximum depth of soil disturbance by tillage implements. Meagre data are available on the effect of conservation tillage and level of N fertilization on soil organic carbon and phosphorus distribution in the major rooting zone of vertisols. The objectives of the present study were (1) to evaluate the effect of long-term application of different tillage, residue

management practices and nitrogen levels on soil organic carbon and available phosphorus concentration and productivity of soybean–wheat cropping system and (2) to estimate the effect of different tillage systems and nitrogen levels on vertical distributions of organic carbon and extractable phosphorus.

Materials and Methods

Sites and Soil

A long-term field experiment on soybean–wheat cropping system was initiated in the rainy season of the year 2000 at the experimental farm of Indian Institute of Soil Science, Bhopal, India (23°18'N, 77°24'E, 485 m above mean sea level), and it continued up to 2012 for twelve crop cycles. The soil of the experimental site was deep heavy clay (isohyperthermic Typic Haplustert). The surface layers of the experimental site had SOC of 0.52 %, available *N* of 102 mg kg⁻¹ and available *P* of 5.6 mg kg⁻¹ and available *K* of 230 mg kg⁻¹. The pH, CEC, and bulk density of the surface soil (0–15 cm) were 7.7, 46 cmol(+) kg⁻¹ soil and 1.34 Mg m⁻³, respectively, while saturation, field capacity and permanent wilting point water capacity of the soil were 62.8, 38.9 and 24.6 % (v/v), respectively. The area receives 1130 mm mean annual rainfall and has a subhumid subtropical climate.

Cultivation Practices

The long-term field experiment was laid out in a split-plot design with three replications. Main plots consisted of four tillage treatments, namely conventional tillage (CT), mouldboard tillage (MB), reduced tillage (RT) and no tillage (NT). The details of the tillage operations applied to soybean and wheat are given in Table 1. The average tillage depth of the duck-foot sweep cultivator, a non-inversion-type plough, was 12 cm, while for the mouldboard plough, average depth of tillage was 22 cm. In rotavator tillage to wheat, soil was stirred up to 10-cm depth. The subplot treatments were done with three nitrogen levels, viz. N_{50%}, N_{100%} and N_{150%} where 50, 100 and 150 %, respectively, of the recommended dose of nitrogen fixed on the basis of the initial soil test values were applied to both soybean and wheat. The recommended doses of nitrogen were fixed for all the 12 years of the study at 30 kg ha⁻¹ for soybean and 100 kg ha⁻¹ for wheat. The subplot size was 15 m × 8 m. Uniform doses of *P* and *K* were applied to all the treatments. The soybean crop was fertilized with 26 kg P ha⁻¹ and 25 kg K ha⁻¹, and the wheat crop was fertilized with 26 kg P ha⁻¹ and 33 kg K ha⁻¹. For wheat, half of the *N* and full dose of *P* and *K* were applied as basal

Table 1 Details of the tillage operation applied in different tillage treatments

Tillage treatment	Tillage applied to	
	Soybean	Wheat
Conventional tillage (CT)	No wheat residue retention, one summer ploughing by duck-foot sweep cultivator and two passes of duck-foot sweep cultivator before sowing and sowing by seed drill	Two passes of duck-foot sweep cultivator before sowing and sowing by seed drill
Mouldboard tillage (MB)	Wheat residue retention, summer ploughing by MB plough, two passes of duck-foot sweep cultivator before sowing and sowing by seed drill	Rotavator tillage one pass and sowing by seed drill
Reduced tillage (RT)	Wheat residue retention, one pass of sweep cultivator and sowing by inverted-T no-till seed drill	Direct seeding by inverted-T no-till seed drill
No tillage (NT)	Wheat residue retention and direct seeding by inverted-T no-till seed drill	Direct seeding by inverted-T no-till seed drill

dose, and the remaining dose of N was applied at crown root initiation stage. The *N*, *P* and *K* were applied in the form of urea, single super-phosphate and muriate of potash, respectively.

Depending on the onset of the monsoon, soybean was sown during the last week of June or first week of July in each *kharif* season at a row spacing of 30 cm. The crop was harvested in the third week of October. Wheat crop was sown in the second fortnight of November each year. The standard cultural management practices were followed for the crop. The wheat crop was irrigated at critical growth stages of the crop. To simulate the condition of residue harvested by the combined harvester, a standing wheat residue of 30-cm height was left at harvest in field for all the treatments except in the conventional tillage. For soybean crop, the plants were harvested from base level as practised by farmers.

Soil analysis

Soil samples were collected from 0- to 5-cm, 5- to 15-cm, 15- to 30-cm and 30- to 45-cm soil depths both in tillage and nitrogen-treated plots after completion of twelve crop cycles in 2012. Depth-wise soil samples were collected in quadruplicate from each plot, and then, they were mixed to get representative soil sample from each depth for all the plots. The air-dried soil samples were grounded and then passed through 2-mm sieve. The grounded and 2-mm-sieved samples were used for soil chemical analysis. The organic carbon content of soil was determined by Walkley and Black method. Stratification ratio of SOC for a treatment was calculated based on the concentration of SOC at 0- to 5-cm soil layer divided by its concentration at 30- to 45-cm soil layer [11]. The available *P* was measured after extracting soil with 0.5 M NaHCO₃ (pH = 8.5) followed by measuring the absorbance of the blue colour of the solution at 880 nm using a spectrophotometer.

Statistical Analysis

The analysis of variance (ANOVA) technique was performed on the data for each parameter as applicable to split-plot design. The significance of the treatment effect was determined using F-test, and to compare the significant differences between the two treatments, least significant differences (LSD) were estimated at 5 % probability level. Pooled analysis of the yield, leaf litter fall and residue addition data of all the 12 year of experimentation were performed, and Duncan's multiple range test was used for comparisons between the treatments at 5 % probability level.

Results and Discussion

Soil Organic Carbon Content

Effect of Tillage Management

The concentrations of SOC after 12 crop cycles showed significant difference among tillage treatments in 0- to 5-, 5- to 15- and 15- to 30-cm soil layers but not in the 30- to 45-cm layer (Table 2). The SOC concentration was the highest in NT (8.8 g kg⁻¹) and was the lowest in CT (5.9 g kg⁻¹) in 0- to 5-cm soil layer. The SOC concentration in RT was significantly higher than that in CT in the same soil layer. However, in 5- to 15-cm soil layer, the highest SOC concentration was recorded in MB (6.5 g kg⁻¹), and it was significantly higher than that in CT (5.0 g kg⁻¹). In 5- to 15-cm soil layer, the SOC concentrations in MB, NT and RT were not different significantly. Similarly in 15- to 30-cm soil layer, SOC concentration was the highest in MB followed by NT and RT, and it was the lowest in CT. But SOC concentration difference in this layer was significant only between MB and CT. The increase in SOC concentration at the soil layer is attributed

Table 2 Effect of long-term tillage management and nitrogen levels on soil organic carbon (SOC) content of the top 45-cm soil

Treatment	SOC concentration (g kg^{-1})				Stratification ratio
	0–5 cm	5–15 cm	15–30 cm	30–45 cm	
Tillage					
NT	8.8	6.3	5.0	4.0	2.20
RT	7.9	5.8	4.9	4.1	1.93
MB	6.9	6.5	5.7	4.1	1.68
CT	5.9	5.0	4.3	3.9	1.51
LSD ($P = 0.05$)	1.1	0.9	1.2	NS	
N levels					
N _{50%}	7.1	5.4	4.7	3.9	1.82
N _{100%}	7.5	5.9	5.0	4.0	1.88
N _{150%}	7.7	6.3	5.2	4.1	1.88
LSD ($P = 0.05$)	0.5	0.7	NS	NS	

to the presence of crop residue and relatively less soil disturbance by tillage operation in NT and RT. Besides this, the organic matter below the surface, including the previous crop's roots, was left undisturbed and thus was under slower decay process owing to less oxidative microclimate in conservation tillage (NT and RT) treatment [32]. The increase in SOC in mouldboard plough treatment at 5- to 15- and 15- to 30-cm depth interval might be the consequence of turning down crop residue to a depth between 15 and 20 cm annually during mouldboard ploughing, while with continuous no-tillage, plant residues remain on the surface [14]. The SOC concentration in MB in top 5-cm soil depth was less compared to NT and RT due to heavy disturbance and fine tith of the surface soil by rotavator tillage before sowing of wheat crop. This might have resulted in breakdown of the topsoil aggregates and promoted faster decomposition of the added residue due to more oxidative environment in the topsoil [17]. Our results are in agreement with a study conducted in silty clay vertisol in North Dakota by Awale et al. [3] who reported that CT increases soil temperature, crop residue–soil contact and also creates a more oxidative soil environment resulting in more rapid decomposition of SOC, relative to minimum and no-till practices. Mrabet et al. [23] reported an increase in SOC by 14 % at 0- to 20-cm depth over a period of 11 years under no-till soil compared to conventional tillage system in a long-term experiment conducted in a semi-arid area of Morocco. Campbell et al. [4] reported 14.5 % higher SOC content with NT than conventional tillage and 19.2 % higher SOC with NT than minimum tillage in Canadian Prairie Province. Similarly, Halvorson et al. [16] documented that the storage of SOC within 0- to 7.6-cm and 7.6- to 15.2-cm soil depths, after 12 years of imposing tillage treatments, was significantly higher with NT than conventional tillage (CT) by 13 and 11 %,

respectively, in silt loam soils in North Dakota. In no-tillage system, the concentration of SOC in surface layer increases and thus alters its distribution within the soil profile. This is because of the presence of plant residues at the soil surface [22]. The increase in SOC in the surface soil is attributed to a combination of reduced rate of residue decomposition and less soil disturbance. Besides this, the previous crop's roots are left undisturbed below the surface layer and thus not subject to decomposition in NT treatments. This combination of adding organic residues to the soil surface, while not disturbing the existing organic matter stocks below the surface, could be the probable reason for the increase in organic carbon in the upper layers of the soil. Abid and Lal [1] and Li et al. [20] reported significant increase in the SOC concentration under NT compared with the conventional tillage system. Paustian et al. [25] compiled data on NT and CT systems from several long-term field studies and found in most cases an increase in carbon content under NT. In addition, the occluded organic matter inside macro-aggregates was protected from decomposition. Tillage operation exposes this protected organic matter and enhances its decomposition [6]. Douglas and Goss [7] reported that after 4–6 years of direct drilling and minimum tillage, aggregate stability along with organic matter content of the top 2.5-cm soil was enhanced on a range of soils in Southern England.

In our study, the increase in organic matter was largest near the surface, but this increase in organic matter concentration below 15-cm soil depth was much less in the NT system. This attribute is regarded as stratification of carbon in the soil profile [11]. Higher stratification ratio was observed under NT (2.20) and RT (1.93) compared to MB (1.68) and CT (1.51). This represents a better soil health and soil ecosystem functioning under no tillage and reduced tillage compared to conventional and MB tillage.

The SOM is essential to control erosion, optimize water infiltration and conserve nutrients [11]. Stratification of SOM occurs when the soils remain undisturbed for a considerable period of time like the case of no-tillage systems. Increasing cropping intensity and management with conservation tillage also result in greater stratification of different organic matter fractions [11]. Less disturbance and mixing of soil preserve crop residues and soil organic matter near the soil surface from decomposition, where it has the most beneficial impact. In a study [12], it was reported that during pasture development, stratification ratio of soil organic C (0- to 15-cm/15- to 30-cm depth) increased from 2.4 at initiation to $3.0 + 0.7$ at the end of 5 years to $3.6 + 0.6$ at the end of 12 years. Franzluebbers [10] also reported that the soil organic C under long-term no-till system is often more stratified with depth than under conventional and mouldboard tillage system. This is attributed to the presence of crop residues left at the soil surface, where it is subjected to less decomposition due to changed temperature and moisture regimes and thus resulted in accumulation of soil organic C. Our study also showed similar effects in RT and NT.

Effect of Nitrogen Level

Among the N treatments, SOC concentration was significantly higher in $N_{150\%}$ as compared to $N_{50\%}$ at 0- to 5- and 5- to 15-cm soil layers. SOC concentration at $N_{100\%}$ was in between the $N_{150\%}$ and $N_{50\%}$. The increase in nitrogen level resulted in the increase in SOC concentration due to better crop growth and addition of more root biomass in soil [28]. In addition to direct effects of fertilizers on C inputs, high N availability also enhances the formation of recalcitrant humic substances in soil [9].

Available Phosphorus Concentration and its Distribution in the Soil Profile

The available phosphorus concentration of the soil was significantly influenced by tillage management, and nitrogen levels at the 0- to 5-cm soil layer, while at 5- to 15- and 15- to 30-cm soil layer, the main-plot effect of tillage was significant, but the subplot effect of nitrogen level was not significant (Tables 3, 4, 5, 6). The treatment effect on soil available phosphorus concentration was not significant at 30- to 45-cm soil layer. Tillage and nitrogen level interaction effect was significant only in the 0- to 5-cm soil layer.

Effect of Tillage Management

Effect of tillage and nitrogen levels and their interaction on available phosphorus concentration of the soil at 0- to 5-cm soil layer was significant (Table 3). Highest available

Table 3 Effect of long-term tillage management and nitrogen levels on available phosphorus content (mg kg^{-1}) of a vertisol under soybean–wheat cropping system at 0- to 5-cm soil layer

Tillage management	Nitrogen level			Mean
	$N_{50\%}$	$N_{100\%}$	$N_{150\%}$	
NT	12.8	12.4	10.4	11.9
RT	11.2	11.0	10.1	10.8
MB	9.9	8.9	9.9	9.6
CT	7.7	8.2	7.6	7.9
Mean	10.4	10.1	9.5	
LSD	Tillage (T): 1.2 N level: 0.8 T X N: 2.1			

($P = 0.05$)

Table 4 Effect of long-term tillage management and nitrogen levels on available phosphorus content (mg kg^{-1}) of a vertisol under soybean–wheat cropping system at 5- to 15-cm soil layer

Tillage management	Nitrogen level			Mean
	$N_{50\%}$	$N_{100\%}$	$N_{150\%}$	
NT	7.2	8.3	7.9	7.8
RT	10.2	9.7	8.2	9.4
MB	9.3	9.2	8.8	9.1
CT	5.5	6.3	6.9	6.2
Mean	8.0	8.4	7.9	
LSD	Tillage (T): 1.5 N level: NS T X N: NS			

($P = 0.05$)

Table 5 Effect of long-term tillage management and nitrogen levels on available phosphorus content (mg kg^{-1}) of a vertisol under soybean–wheat cropping system at 15- to 30-cm soil layer

Tillage management	Nitrogen level			Mean
	$N_{50\%}$	$N_{100\%}$	$N_{150\%}$	
NT	5.1	4.1	3.7	4.3
RT	5.4	6.0	4.6	5.3
MB	7.3	6.4	6.6	6.8
CT	4.6	4.6	4.7	4.7
Mean	5.6	5.3	4.9	
LSD	Tillage (T): 1.4 N level: NS T X N: NS			

($P = 0.05$)

phosphorus concentration (12.8 g kg^{-1}) was recorded in no tillage with 50 % nitrogen application followed by no tillage with 100 % nitrogen application. This indicates that phosphorus is accumulating in the surface of the no-tillage plots where nutrient uptake is less by crop due to lower biomass growth. Among the tillage treatments, available phosphorus concentration averaged over the nitrogen levels was significantly higher in NT (11.9 mg kg^{-1}) and RT

Table 6 Effect of long-term tillage management and nitrogen levels on available phosphorus content (mg kg^{-1}) of a vertisol under soybean–wheat cropping system at 30- to 45-cm soil layer

Tillage management	Nitrogen level			Mean
	N _{50%}	N _{100%}	N _{150%}	
NT	2.8	2.7	3.5	3.0
RT	3.2	2.7	3.9	3.3
MB	3.6	3.0	4.1	3.6
CT	3.4	3.0	2.9	3.1
Mean	3.3	2.9	3.6	
LSD ($P = 0.05$)	Tillage (T): NS N level: NS T X N: NS			

(10.8 mg kg^{-1}) than that in MB (9.6 mg kg^{-1}) and CT (7.9 mg kg^{-1}). Available phosphorus concentration in MB was significantly higher (22 %) than that in CT at 0- to 5-cm soil layer. Compared to the conventional tillage system, the available phosphorus content in no-tillage (NT) and reduced tillage (RT) treatments was 51 and 37 %, respectively, higher. However, in 5- to 15-cm soil layer, the available phosphorus concentration in RT was significantly higher than that in NT. Available phosphorus concentration in MB was also higher than that in NT, though the difference was not significant. Available P concentration at this layer was the lowest in CT, and it was significantly lower than all the other three tillage treatments where wheat residues were either retained on the surface or mixed within the soil. Available phosphorus concentration in 5- to 15-cm soil layer after 12 crop cycles was 51 and 46 % higher in RT and MB than that in CT treatment. MB recorded the highest available phosphorus concentration in 15- to 30-cm soil layer, and it was significantly higher than the other three tillage treatments. In no-tillage system, the availability of surface phosphorus is improved by converting organic phosphorus into available phosphorus. Crops take up phosphorus from deeper part of the soil profile and depositing it on the surface along with crop residues. In conventional tillage systems, phosphorus is usually remixed into the soil profile, whereas in no tillage, it accumulates at the surface [38]. After the 16 years of experimentation, Wang et al. [34] also reported that the available P under no till with straw retention (NTSC) was 97.5 % higher than under conventional till with straw removal (CT) in the 0- to 5-cm layer, while in the 5- to 10- and 10- to –20-cm soil layers, the P content was 19.75 and 54.06 %, respectively, lower under NT than under CT. In the 20- to 30-cm layer, the differences were not significant. The topsoil accumulation of P in NT was attributed to the limited downward movement of particle bound P in no-till soils and the upward movement of nutrients from deeper layers through nutrient uptake by roots [33]. Numerous

studies have reported higher extractable P levels in no tillage than in tilled soil in the surface soil layers [24], and this is due to reduced mixing of the fertilizer P with the soil, leading to lower P -fixation. After 20 years of no-till experiment, Ismail et al. [18] found extractable P was 42 % greater at 0–5 cm, but 8–18 % lower at 5- to 30-cm depth compared with conventional tillage in a silt loam. Higher proportion of residues in the surface under no-till system had increased microbial biomass, leading to higher P content [13]. By promoting microbial activity, no tillage may diminish soil sorption of added P with greater P extractability and, consequently, result in a higher soil test P level at the soil surface and decrease P levels deeper in the soil profile [30]. Phosphorus is an immobile element and usually remains near the site of application unless it is disturbed. But Roldan et al. [27] reported that available P was not affected by tillage system, soil depth or type of crop. Available phosphorus concentration in general was lower at deeper soil layers. Decrease in available phosphorus concentration with increase in soil depth was sharper in NT and RT, while it was more gradual in MB (Fig. 1a). The stratification ratio calculated as the ratio between the available phosphorus concentrations in 0- to 5- and 15- to –30-cm soil layer was 2.3 and 2.2, respectively, for the NT and RT, while it was 1.5 and 1.8, respectively, for the MB and CT. The stratification of P at the soil surface under no tillage may be viewed as a serious pollutant to water bodies [29]. Phosphorus stratification results in high concentration of P in runoff water. However, runoff P loss is often more sensitive to changes in rates of erosion and runoff than to soil P concentration [37]. Thus, reducing the erosion may result in reduction in P concentration in no-till runoff water. Thus, good ground cover and improved soil aggregation in the 0- to 5-cm depth under no-till system helps in improving the quality of the environment [35].

Effect of Nitrogen Level

Effect of nitrogen level on available phosphorus concentration was significant only for the top 5-cm soil layer. Available phosphorus concentration in N_{50%} was significantly higher than that in N_{150%}, and it was in between N_{100%}. This is owing to higher uptake of phosphorus by crops in higher nitrogen level treatments which might have reduced the available phosphorus content in N_{150%} treatment. In 15- to 30-cm soil layer also, the available phosphorus content was higher at lower nitrogen level though the values were not different significantly. The available phosphorus concentration at all the nitrogen levels decreased with increase in soil depth (Fig. 1b) due to low mobility of phosphorus and mining of phosphorus from the lower layers by crop roots and their return to the surface

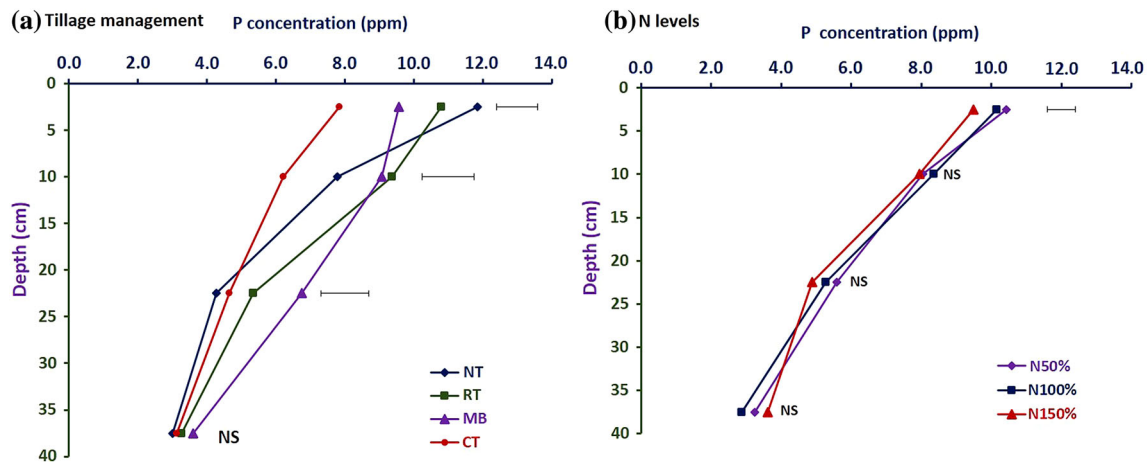


Fig. 1 Effect of long-term tillage management (a) and nitrogen levels (b) on profile distribution of available phosphorus in a vertisol under soybean–wheat cropping system. Horizontal lines represent LSD ($P < 0.05$) between the treatments for a particular depth, NS not significant

Table 7 Effect of tillage treatment and nitrogen levels on yield, leaf litter fall and residue addition from soybean and wheat (pooled over the years)

Treatment	Soybean		Wheat	
	Seed yield (Mg ha^{-1})	Leaf litter fall (Mg ha^{-1})	Grain yield (Mg ha^{-1})	Residue addition (Mg ha^{-1})
Tillage				
NT	1109a	1.145a	2754a	2.114a
RT	1120a	1.205a	2734a	2.003a
MB	1116a	1.157a	2766a	2.049a
CT	1146a	1.195a	2778a	0.724b
N levels				
N _{50%}	1017b	0.910c	2429b	1.524c
N _{100%}	1143a	1.248b	2849a	1.724b
N _{150%}	1216a	1.369a	2997a	1.919a

Different letters within a column indicate significant difference between values at $P < 0.05$

soil through residue addition. The stratification ratio was 1.9 in all the three nitrogen level treatments.

Crop Yield and Residue Addition

The effect of tillage treatments and their interaction effect with N levels did not significantly influence the yield of soybean and wheat pooled over the 12 years of study. Only N levels showed significant effect on yield of both soybean and wheat (Table 7). Seed yield of soybean at N_{150%} and N_{100%} was significantly more than that at N_{50%}. Grain yield of wheat among the N levels followed a similar trend. The results showed that though tillage systems influenced the organic C content and soil available nutrient content and their distribution, it has not significantly influenced the crop yield. This finding is in agreement with Alvarez and Steinbach [2], and Rogrigues et al. [26], who reported no

significant difference in soybean yield due to tillage treatments. Yusuf et al. [36] reported that soybean in NT exhibited a compensatory reproductive growth to the early-season plant development in CT, thereby minimizing the differences between the two tillage systems. On a vertisol in the semi-arid Mediterranean region, Celik et al. [5] also did not find any significant effect of different conservation and conventional tillage systems on yields of soybean, maize and wheat crops. Melero et al. [21] while studying the effects of long-term tillage systems in vertisols of Mediterranean region found equal yield of wheat under wheat–wheat and wheat–sunflower rotation in NT and CT. The average yield of wheat was relatively low for this region as wheat here was grown using recycled rainwater stored in the water harvesting pond. Thus, the irrigation water application rate varied among the years depending upon its availability which also resulted in lower yield in some of the years.

The amount of leaf litter fall from soybean was not different significantly among the tillage treatments but was higher at higher nitrogen levels (Table 4). On the other hand, amount of wheat residue added on the surface was similar in NT, RT and MB, but were significantly higher than that in CT where wheat was harvested manually leaving very less amount of crop residue. The data showed that on an average, 1.3 Mg ha⁻¹ of extra wheat residue per year was added in the tillage plots where wheat residue was harvested at 30-cm height compared to the conventional tillage plots. Addition of wheat residue was also significantly higher in N_{150%} level compared to N_{50%} due to higher biomass yield in N_{150%}.

Conclusions

Conservation tillage practices like no tillage and reduced tillage in soybean–wheat cropping system could sustain yield level similar to that under conventional tillage practice, while it saved energy and time by reducing the frequency of tillage operations. The organic carbon content and available phosphorus concentration under no-tillage and reduced tillage system increased compared to conventional tillage due to retention of residues and minimum disturbance in the former system. The no-tillage system showed a trend to accumulate organic carbon near the soil surface layer. Relatively less movement of soil in the conservation tillage systems seems to be responsible for the greater *P* stratification in the soil profile. Less soil disturbance gave to the reduced tillage system the characteristics of an intermediate tillage system when compared to mouldboard plough and no till, regarding distribution of available *P* in the soil profile. Our study suggested that conservation tillage in soybean–wheat cropping system with balanced fertilizer doses can be a viable option/alternative to conventional tillage system in sustaining productivity, nutrient availability and sequestering more carbon in vertisols.

Acknowledgments The authors are grateful to the ICAR—Indian Institute of Soil Science, Bhopal, for providing research fund and infrastructural facility.

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