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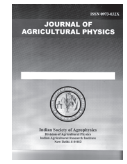

Research Article

Impact of Long-Term Zero Tillage in Wheat on Physical Quality Indices of Different Textured Soils under Rice-Wheat Cropping System

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ABSTRACT

The adverse impact of intensive tillage practices on soil physical quality and soil organic carbon status in rice-wheat growing areas of Indo-Gangetic plains (IGP) of India is a major challenge for sustainable agriculture and food security of the country and subsequently demands the need for sustainable and environmental friendly agricultural management practices. The conservation tillage is advocated as promising alternate to conventional tillage practices. The long-term (20 years) impact of zero tillage (ZT) in wheat under rice–wheat cropping system in semi-arid region of Indo-Gangetic Plains (IGP) was evaluated for physical properties, organic carbon stock and physical quality indices in different textured soils. The ZT increased soil organic carbon significantly of 0-30 cm soil depth in sandy loam, loam and clay loam soil by 35.3, 28.9 and 17.8%, respectively over conventional tillage (CT). The carbon stock in 0-30 cm layer increased by 35.2, 27.6 and 17.6% over CT in 20 years in sandy loam, loam and clay loam soil, respectively. The ZT resulted in reduction in sub surface compaction though not significantly in all the three texturally different soils. The soil physical properties like total porosity increased under zero tillage in loam soil, aeration porosity significantly increased by 5, 8.2 and 22.8% in sandy loam, loam and clay loam soils, respectively, in 0-30 cm soil depth under ZT as compared to the CT. The long- term ZT reduced the penetration resistance in root zone up to 20 cm depth providing favorable conditions for root growth. The soil moisture content at field capacity of 0-15 cm soil layer was higher (27.12-34.40%) in ZT as compared to CT (25.0-29.0%) in all the experimental soils. The long-term zero tillage also improved the soil physical quality in terms of increasing the values of least limiting water range ($LLWR_{fcpw}$) in all the experimental soils and almost maintaining the values of S-index more than 0.035. The long-term zero tillage for 20 years in wheat under rice- wheat cropping system resulted in non-significant increase in yield of rice in all the three soils and wheat in sandy loam and loam soils, whereas, significant increase in yield of wheat (2.1%) in clay loam soil in addition to the improved soil physical properties, soil organic carbon content and physical quality parameters. The study concludes that the ZT practice in wheat under rice–wheat system of semi-arid region of IGP in Haryana might be popularized and adopted for sustaining productivity of the system and environment.

Key words: Zero tillage, Physical properties, Physical quality index, Rice-wheat, Soil organic carbon

Introduction

Soil quality plays a key role for the sustainability of the agricultural production under different agricultural management and cropping systems. Rice–wheat cropping system (RWCS) is one of the most prevalent cropping systems occupying around 12.3 M ha in India and about 85 per cent of which falls in Indo-Gangetic plains (IGP) of India (Singh

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et al., 2005; Katyal *et al.*, 1998; Ladha *et al*., 2003). Wheat is traditional mainstay of food security in the northwest Indo-Gangetic Plains. Rice cultivation in the northwest area is introduced and widespread in recent decades during the Green Revolution. The system witnessed significant increase in its productivity during the Green Revolution but recent studies indicated either stagnation or slowdown in the growth of its productivity (Kumar *et al*., 2002) due to intensive mining of nutrients from soil, degradation of soil structure, reduction in soil organic matter, formation of hard pan, increased use of imbalanced inorganic fertilizers and agro-chemicals, increased cost of cultivation, etc. The adoption of modern and heavy mechanized farming on large farms (*i.e.* >8 ha) in India has led to the serious sub-surface soil compaction problems (Foster and Rosenzweig, 2011) in general and more severe in rice–wheat systems in particular due to puddling practice in rice. The soil compaction causes increase in bulk density and consequently increases soil penetration resistance, obstructs root development and induces root deformations (Nawaz *et al*., 2013), which ultimately adversely affect the crop productivity. However, critical values of soil compaction that severely restrict root growth depend on the soil, water content and crop type. Furthermore, soil penetration resistance varies with soil water content irrespective of variation in other soil characteristics (Kukal and Aggarwal, 2003). All these soil physical quality parameters have their significance towards the sustainable soil productivity; hence, there is a need to evaluate the most significant quality parameters and suitable management practices under different cropping systems.

The soil quality indices estimate changes in the production capacity of soils (Dexter, 2004). The non-limiting water range or least limiting water range, LLWR (da Silva *et al*., 1994) and S-index (Tormena *et al.*, 2008) are among the most significant soil physical quality indicators. The LLWR describes integrated effect of soil water content (SWC), soil air and soil strength on plant growth and represents a great significance in biophysical studies of soils. The SWC at permanent wilting point (-1.5 MPa) or SWC at a threshold soil strength value (2 MPa) whichever is higher, considered as lower water content limit in the LLWR (Thompson, 2001). The LLWR had been validated as a soil physical quality indicator for a wide variety of soils, crops, and management systems (de Oliveira, 2019; Wu *et al*., 2003). The S-index evaluates the structural quality of soils i.e., soil physical quality which is a measure of soil micro-structure (Dexter and Bird, 2001; Dexter, 2004) and considered as useful for the overall assessment of soil quality.

The soil structure and quality are strongly influenced by the intensive tillage practices. It is quite evident that different tillage practices modify soil physical properties depending upon the type of soil, climatic conditions of the region, cropping history and previous tillage system used (Halvorson *et al.*, 2002). The conservation tillage including zero tillage (ZT) has potential for increasing aggregate stability, soil organic carbon and maintaining soil structure over traditional tillage practices (Saharawat *et al*., 2010; Bhattacharyya *et al*., 2013b).

Rice and wheat are the major cereal crops in the Indo-Gangetic Plains (IGP), grown in rotation on almost 13.5 M ha of land and provides food for 400 million people (Sharma and Bhushan, 2001). Due to intensive tillage practices in rice-wheat cropping system of Northwest India, natural resource degradation coupled with residue burning is deteriorating the soil quality resulting in low organic carbon, low soil biota, stagnant yields and low farm income in both rainfed and irrigated ecosystems (Lal, 2007). In rice-wheat cropping system of South Asia, farmers prefer clean cultivation and till the soil several times in a year which accelerates the soil erosion by breaking down the soil aggregates.

In addition to soil and water conservation, zero tillage offers beneficial alternative for establishing good crop of wheat after rice in Indo-gangetic plains (IGPs), particularly, in northwest India (Laxmi *et al.,* 2007) along with economical, time saving and energy efficient agricultural management practice (Erenstein and Laxmi, 2008). The area under conservation agriculture in Asia is around 13.9 M ha (7.7%). The conservation agriculture systems are widely practiced in different ecologies in area of 1.5 M ha India (Jat, *et al*., 2021). Conservation tillage also favours in reducing sub-surface compaction (Sayre and Hobbs, 2004).

In literature, work had been done to study the influence of conservation tillage practices on improving the soil physical properties, still information on the effects of short-to medium-term adoption of zero tillage in different cropping systems on LLWR and S-index in soils of arid and semi-arid regions is limited. Hence, the present study was carried out to evaluate the effects of zero tillage in wheat under rice-wheat system on soil physical properties and quality indices as LLWR and S-index of different textured soils of IGPs of Haryana State.

Material and Methods

The study was carried out at farmers' fields in village Pirthala of Fatehabad, Uchana of Karnal and Teek of Kaithal districts of the Haryana State, where long-term tillage experiments are being conducted since 1996-97 in rice–wheat cropping system. The soil at villages viz., Pirthala, Uchana and Teek was sandy loam, loam and clay loam in texture, respectively. The experimental soils were normal in soluble salt contents and medium in soil organic carbon content (Table 1).

The fields (0.4 ha) under zero-tilled (ZT) wheat and adjoining conventionally tilled (CT) wheat under rice–wheat system were selected for investigating the physical quality indices, organic carbon build up and yield of wheat. In ZT fields, the residues of the rice harvested by combine harvester were left on the surface, and wheat was sown with zero till machine. In CT fields, the residues after harvest of rice were manually removed, and wheat was sown by preparing the field using conventional tillage system. The fields under both the tillage treatments were continuously puddled during *kharif* season. Five plots (1 m × 1 m) were randomly selected in each tillage treatment at all the three sites, and soil samples were collected at 0-15 and 15-30 cm depths at harvest of wheat crop during 2015–16.

Table 1. Physico-chemical properties of soils at the experimental sites

Property	Site		
	Pirthala (Fatehabad)	Uchana (Karnal)	Teek (Kaithal)
Sand (%)	68.3	63.6	47.5
Silt (%)	14.5	17.1	21.2
Clay (%)	17.2	19.3	31.3
Textural class	Sandy loam	Loam	Clay loam
$EC_{(1:2)}$ (dS m^{-1})	0.64	0.52	0.58
Organic carbon (%)	0.49	0.56	0.68

Measurement of soil properties

The bulk density (Mg m^{-3}) of the soil was determined using core method. The undisturbed soil samples of 0–15 and 15–30 cm depths were collected using metallic cores (internal diameter = 5 cm and height =5 cm) at the harvest of wheat from all the treatments during the study period and bulk density was calculated from the ratio of dry weight of soil to the internal volume of the metallic core (Bodman, 1942). The undisturbed soil samples of 0–15 and 15–30 cm depths collected for bulk density were also used for determination of soil moisture retention curve. The soil moisture retention curves were obtained by measuring the water content (g/100g) of soil samples at 0.1, 0.3, 1.0, 3.0, 5.0 and 15.0 bar pressure using hanging water column and pressure plate apparatus (Richards, 1954) in laboratory. The volumetric water content was obtained from the product of gravimetrical water content and bulk density of the respective soil depth.

The soil strength was measured after harvest of wheat crop in each treatment at different soil depths near field capacity moisture using cone penetrometer (Davidson, 1965). Readings from eight random positions per plot were averaged for each depth and mean value of cone penetration resistance is expressed in MPa.

For aeration porosity, the soil cores were saturated overnight by 0.01 M $CaCl_2$ solution and brought to equilibrium in the hanging water column at a suction of 50 cm. Volume of water released per unit volume of soil was used as a fraction of pore space filled with air and expressed in percentage as aeration porosity.

The soil organic carbon was determined using wet digestion method (Walkley and Black, 1934). The soil organic carbon stock was estimated as follows:

$$\text{SOC (Mg ha}^{-1}\text{)} = \text{SOC (\%)} \times \text{bulk density} \times \text{soil depth} \times 10^2 \quad (1)$$

where SOC is soil organic carbon in percent.

Least limiting water range

The least limiting water range (LLWR) of soil sample was determined using following relationship (Silva *et al.,* 1994).

$$LLWR_{fcpw} = \theta_{fc} - \theta_{PW} \quad (2)$$

The upper limit of LLWR $_{fcpw}$ was water content at field capacity (θ_{fc}) while the lower limit was the water content at –1.5 MPa (θ_{PW}) matric potential.

S-index

The *S* index corresponds to the angular coefficient (slope of the tangent) at the inflection point of the soil moisture retention curve. The soil moisture retention curve was determined by fitting the experimental moisture data obtained at different matric potentials to the function (eq. 3) proposed by van Genuchten (1980):

$$\theta = \theta_r + \left((\theta_s - \theta_r)/(1 + (\alpha\varphi)^n)^{1-1/n}\right) \quad (3)$$

where θ is gravimetric moisture at each matric potential, θ_r is soil moisture at matric potential of -1.5 Mpa, θ_s is saturated soil moisture, φ is matric potential, α and *n* are coefficients of the equation.

The *S* index was determined using eq. 4 as proposed by Dexter (2004) derived from the Eq.3.

$$S = -n(\theta_s - \theta_r)(2n-1)/(n-1)^{\left(\left(\frac{1}{n}\right)-2\right)} \quad (4)$$

Where *S* is angular coefficient of water retention curve at inflection point. The critical limit for physical quality of S index is 0.035, delimiting soils with good and bad structural quality; values below 0.002 represent very bad structural quality.

Crop yield and yield attributes

The yields of wheat, rice and yield attributes were also recorded during 2015-16.

Results and Discussion

Soil physical properties

Soil bulk density

The long- term zero tillage (ZT) in wheat for 20 years did not significantly affect the bulk density of soil at 0-15 and 15-30 cm depths in the different textured soils (Table 2). However, the ZT resulted in slight decrease in bulk density at 15-30 cm depth as compared to conventional tillage (CT) in the texturally different soils indicating formation of plough sole in sub-surface soils under CT in rice-wheat cropping system of the Haryana State but the effect was not statistically significant. Though, the bulk density of the surface 0-15 cm soil depth was found lower in CT as compared to ZT. Under CT, the bulk density of the surface layer was 1.56, 1.52 and 1.50 Mg m^{-3} in sandy loam, loam and clay loam soil, respectively, which increased to 1.66, 1.64 and 1.62Mg m^{-3} in respective 15-30 cm soil layer. The interaction between tillage and depth was observed non-significant in sandy loam but significant in loam and clay loam soils. The studies carried out by other researchers (Tebrugge and During, 1999; Fuentesa *et al*., 2009; Parihar, *et al*., 2016) reported increase in compaction of surface soil under zero tillage, however, Salem *et al.* (2015) reported sub surface compaction under conventional tillage. On the other hand, Martínez *et al*. (2008) found that zero tillage in a sandy clay alluvial soil under wheat (*Tritcum*

Table 2. Effect of zero (ZT) and conventional tillage (CT) on soil bulk density (Mg m^{-3}) of texturally different soils at 0-15 and 15-30 cm soil depths

Tillage	Sandy loam			Loam			Clay loam		
	0-15cm	15-30cm	Mean	0-15cm	15-30cm	Mean	0-15cm	15-30cm	Mean
CT	1.56	1.66	1.61	1.52	1.64	1.58	1.50	1.62	1.56
ZT	1.57	1.64	1.60	1.54	1.61	1.57	1.51	1.60	1.55
Mean	1.56	1.65		1.53	1.62		1.50	1.61	
CD (P = 0.05)									
Tillage (T)		NS			NS			NS	
Depth (D)		0.02			0.04			0.04	
T × D		NS			0.05			0.05	

Table 3. Effect of zero (ZT) and conventional tillage (CT) on soil organic carbon (%) of texturally different soils at 0-15 and 15-30 cm soil depths

Tillage	Sandy loam			Loam			Clay loam		
	0-15cm	15-30cm	Mean	0-15cm	15-30cm	Mean	0-15cm	15-30cm	Mean
CT	0.44	0.24	0.34	0.50	0.27	0.38	0.58	0.33	0.45
ZT	0.60	0.32	0.46	0.62	0.36	0.49	0.66	0.41	0.53
Mean	0.52	0.28		0.56	0.31		0.62	0.37	
CD (P = 0.05)									
Tillage (T)		0.09			0.06			0.04	
Depth (D)		0.09			0.06			0.04	
T × D		NS			NS			NS	

aestivum L.) did not significantly affect soil bulk density.

Organic carbon content

The long-term ZT practice in wheat significantly increased soil organic carbon (SOC) content as compared to the CT up to 30 cm soil depths in sandy loam, loam and clay loam soils (Table 3). The SOC content in the surface 0-15 cm soil depth was 0.44, 0.50 and 0.58% under CT which increased to 0.60, 0.62 and 0.66% with adoption of ZT practice in wheat for 20 years in sandy loam, loam and clay loam soils, respectively. As expected, the highest amount of organic carbon was observed in finer textured soil and followed the order of clay loam > loam > sandy loam. Overall, the long-term ZT practice resulted in increase in 35.3, 28.9 and 17.8% SOC in 0-30 cm soil as compared to CT in sandy loam, loam and clay loam soils, respectively. The higher build up of organic carbon under ZT attributed to the addition of crop residue and less oxidation of *in situ* organic matter (Kaiser *et al*., 2014; Aziz *et al*., 2015). Similar results have also been reported from other studies carried out under zero tillage (Mishra *et al.,* 2010; Nandan *et al.,* 2019). Parihar *et al.* (2016) also observed that long term zero tillage resulted in enhancing the soil organic carbon of a sandy loam soil up to 30 cm depth in north-western Indo-Gangetic Plains. The interaction between tillage and depth was observed non-significant in all the three soils. The results also indicated that the SOC significantly decreased with depth under both the tillage practices in all the three experimental soils.

The soil organic carbon stock in 0-30 cm depth under both the tillage practices is presented in Fig. 1. The SOC stock was 35.2, 27.6 and 17.6% higher

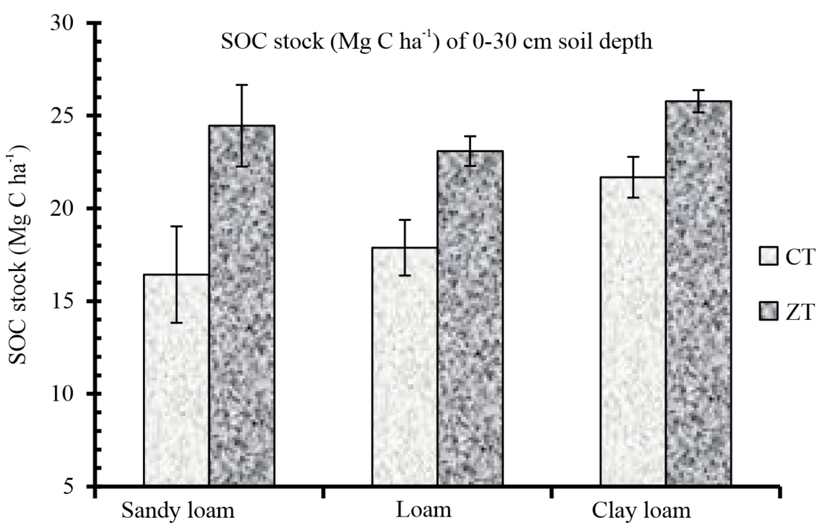

Fig. 1. Effect of zero (ZT) and conventional tillage (CT) on soil organic carbon (SOC) stock (Mg C ha^{-1}) of texturally different soils at 0-30 cm soil depth

Table 4. Effect of zero (ZT) and conventional tillage (CT) on total porosity (%) of texturally different soils at 0-15 and 15-30cm soil depths

Tillage	Sandy loam			Loam			Clay loam		
	0-15cm	15-30cm	Mean	0-15cm	15-30cm	Mean	0-15cm	15-30cm	Mean
CT	41.26	37.48	39.37	41.63	36.98	39.30	42.51	37.35	39.93
ZT	40.75	37.61	39.18	41.05	37.73	39.39	40.75	38.24	39.49
Mean	41.00	37.54		41.34	37.35		41.63	37.79	
CD(P = 0.05)									
Tillage (T)		NS			NS			NS	
Depth (D)		0.62			3.1			2.3	
T × D		NS			NS			NS	

under zero tillage as compared to conventional tillage in sandy loam, loam and clay loam soils, respectively, in rice-wheat cropping system. It indicates that zero tillage offers opportunity to enhance the soil organic carbon storage in soils under rice-wheat cropping system and similar results were reported by other researchers (USDA NRCS, 2011; Mishra *et al*., 2015).

Total porosity

Long-term zero tillage in wheat for 20 years under rice-wheat cropping system did not affect the soil porosity significantly (Table 4) similar to the soil bulk density. The total porosity of soil in the surface 0-15 cm soil layer was observed as 41.26, 41.63 and 42.51% in sandy loam, loam and clay loam soils, respectively, under CT but observed as 40.75, 41.05 and 40.75%, respectively under ZT. However, long- term adoption of zero tillage in wheat under rice-wheat cropping system showed trend of increasing total porosity in sub-surface soil of 15-30 cm layer in all the three texturally different soils. The results of the present study indicated that though the long term zero tillage increased the soil organic carbon content of the soil significantly but it could not result into decrease in the bulk density and total porosity of the soil significantly. As obvious, the total soil porosity significantly decreased with depth under both the tillage practices in all the soil types. The interaction between tillage and depth was also observed non-significant in all the experimental soils. Similar results of higher soil porosity under minimum tillage were also reported by Blanco *et al*. (2007). Alam *et al*. (2014) indicated that minimal tillage could increase the porosity in soil layers where organic matter accumulation could enhance aggregation. According to Lal *et al*. (2007), more stable aggregates in the upper surface of soil had been associated with no-till soils than tilled soils which consequently resulted in high total porosity under no-tilled plots.

Aeration porosity

The average aeration porosity over 0-15 and 15-30 cm depths was observed to be significantly higher in zero tillage as compared to the conventional tillage in sandy loam and loam soils (Table 5). The aeration porosity was observed higher in zero tilled clay loam soil but not significantly in the present investigation. The aeration porosity in ZT was observed highest in sandy loam of 10.13%, followed by in loam (9.80%) and clay loam (8.23%) in 0-15 cm soil layer. This may be due to reduced soil dispersion and formation of stable micro-aggregates in ZT system compared to CT (Six *et al.,* 2000). However, the long-term zero tillage resulted in increase in aeration porosity by 5, 8.2 and 22.8% in sandy loam, loam and clay loam soils, respectively, in 0-30 cm soil depth as compared to the conventional tillage. Schaffer *et al.* (2007) reported that tillage implements decreased both the porosity and connectivity of macro-pores. The aeration porosity decreased significantly with depth in conventional and zero tilled soils. However, the interaction between tillage and depth was found to be non-significant in sandy loam, loam and clay loam soils.

Soil penetration resistance

The soil penetration resistance (MPa) values measured in conventional and zero tillage practices

Table 5. Effect of zero (ZT) and conventional tillage (CT) on aeration porosity (%) of texturally different soils at 0-15 and 15-30 cm soil depths

Tillage	Sandy loam			Loam			Clay loam		
	0-15cm	15-30cm	Mean	0-15cm	15-30cm	Mean	0-15cm	15-30cm	Mean
CT	9.27	9.02	9.15	8.77	8.33	8.55	6.11	5.04	5.58
ZT	10.13	9.10	9.61	9.80	8.70	9.25	8.23	5.47	6.85
Mean	9.70	9.06		9.28	8.52		7.17	5.25	
CD(P = 0.05)									
Tillage (T)		0.41			0.42			1.3	
Depth (D)		0.41			0.42			1.3	
T × D		NS			NS			NS	

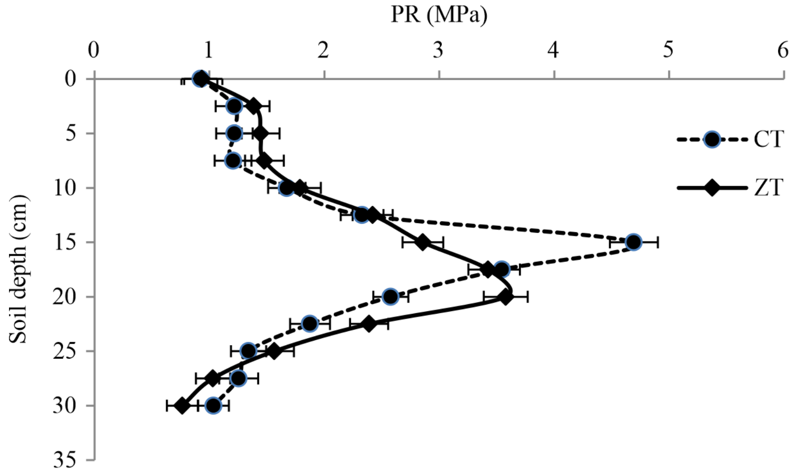

Fig. 2. Penetration resistance (PR) in loam soil under zero (ZT) and conventional tillage (CT) at different soil depths

in loam (Fig. 2) and clay loam (Fig. 3) soils at different depths revealed that zero tillage resulted in favorable soil physical condition by reducing soil penetration resistance as compared to conventional tillage. Under conventional tillage, the maximum value of soil penetration resistance (PR) was observed as 4.69 MPa in loam soil at 15 cm and 4.32 MPa in clay loam soil at 12.5 cm depth; however, under ZT the maximum PR was observed as 3.58 MPa in loam and 3.64 MPa in clay loam soils at 20 cm depth. The results indicated that long- term ZT reduced the penetration resistance in root zone up to 20 cm depth providing favourable conditions for root growth. Effect of tillage systems on soil penetration resistance reported in literature is highly variable. It was reported that soils under ZT may have lower (Blanco-Canqui *et al.,* 2005; Parihar *et al*., 2016), equal (Katsvairo *et al*., 2002), or higher (Boyda and Turgut, 2007) penetration resistance than those under conventional tillage. It suggests that effect of tillage on soil PR depends on the soil and the time of last tillage operation.

Soil moisture at field capacity

The soil moisture at field capacity (FC) of three textually different soils under ZT and CT practices at different depths are given in Fig. 4. The ZT resulted in increase in field capacity moisture content of 0-15 cm soil layer as compared to CT in all the experimental soils from 25.0 to 27.12%, 27.25 to 32.50% and 29.0 to 34.40% in sandy loam, loam and clay loam soils, respectively, as compared to CT. The data on soil moisture content at field capacity (Fig. 7) indicated that effect of ZT diminished with soil depth in the soils. Alam *et al.* (2014) found higher water content at FC zero tillage as compared to

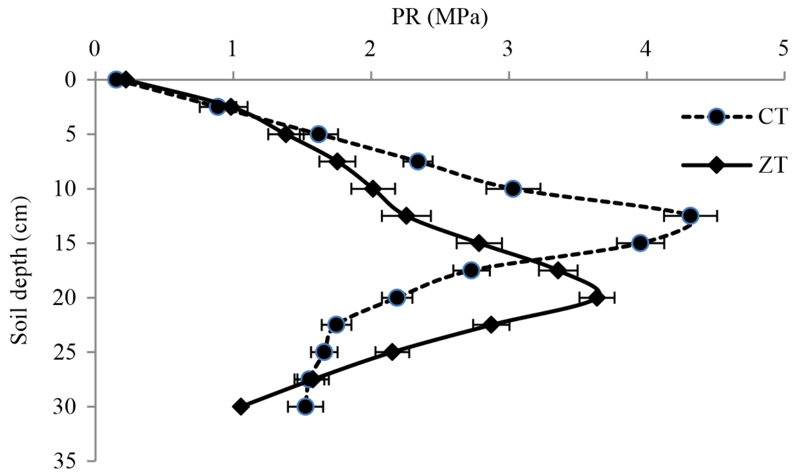

Fig. 3. Penetration resistance (PR) in clay loam soil under zero (ZT) and conventional tillage (CT) at different soil depths

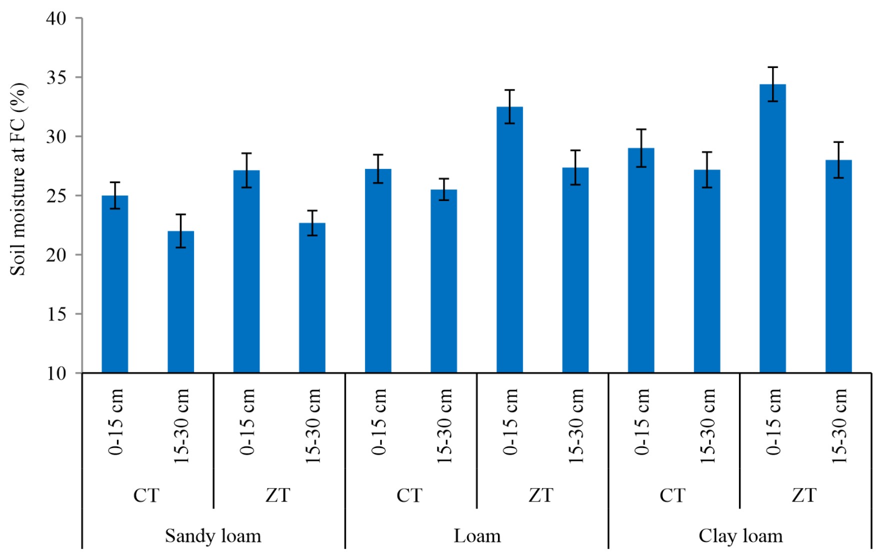

Fig. 4. Soil moisture at field capacity (FC) under zero (ZT) and conventional tillage (CT) in texturally different soils

conventional tillage. Similar results of zero tillage on increasing soil moisture retention were reported by other workers (Schwen *et al.,* 2011; Castellini and Ventrella, 2012).

Soil physical quality indices

Least limiting water range

The least limiting water range ($LLWR_{fcpw}$) of the soils under conventional and zero tillage practices at different depths are presented in Fig. 5. The LLWR was observed to be higher in ZT as compared to the conventional tillage. The LLWR value was observed highest in clay loam, followed by loam and sandy loam soils. Zero tillage practice resulted in higher LLWR in 0-15 cm soil layer as compared to the 15-30 cm soil layer by 17.42%, 21.3% and 22.8% in sandy loam, loam and clay loam soils, respectively, from the corresponding LLWR values under conventional tillage. The results illustrated that improvement in soil physical properties under zero tillage had positive effect on the LLWR of soil and indicated that the soil physical quality was at favourable conditions for plant growth. de Oliveira *et al.* (2019) reported that increase in BD caused negative effects on LLWR

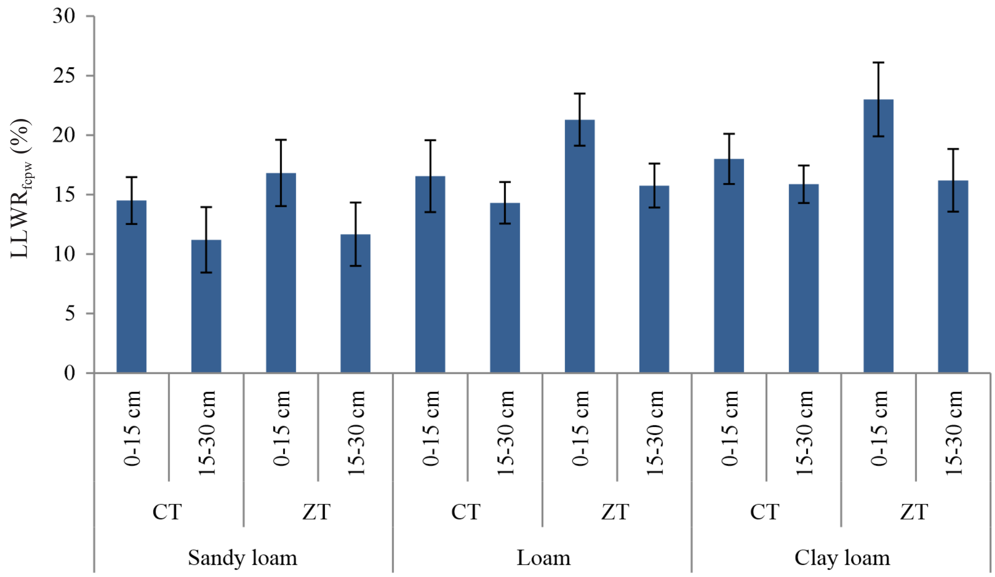

Fig. 5. Effect of tillage on least limiting water range, $LLWR_{fcpw}$ (%) of texturally different soils at 0-15 and 15-30 cm depths

S- index

The values of S- index under zero and conventional tillage for the three soils at both the soil depths are presented in Fig. 6. The values of S-index were observed more than 0.035 in both the tillage practices under all the three texturally different soils at 0-15 and 15-30 cm depths except at 15-30 in clay loam soil. Hence, long-term zero tillage in wheat under rice-wheat cropping system maintained the soil physical quality due to improvement in soil physical properties. The highest S-index values were observed in sandy loam followed by loam and clay loam soils. Andrade and Stone (2009) also reported a positive correlation between macro-porosity and the S index indicating that S index is an important indicator of soil physical quality. Reynolds *et al*. (2009) found S index as a good indicator of soil physical quality for a structured loamy soil.

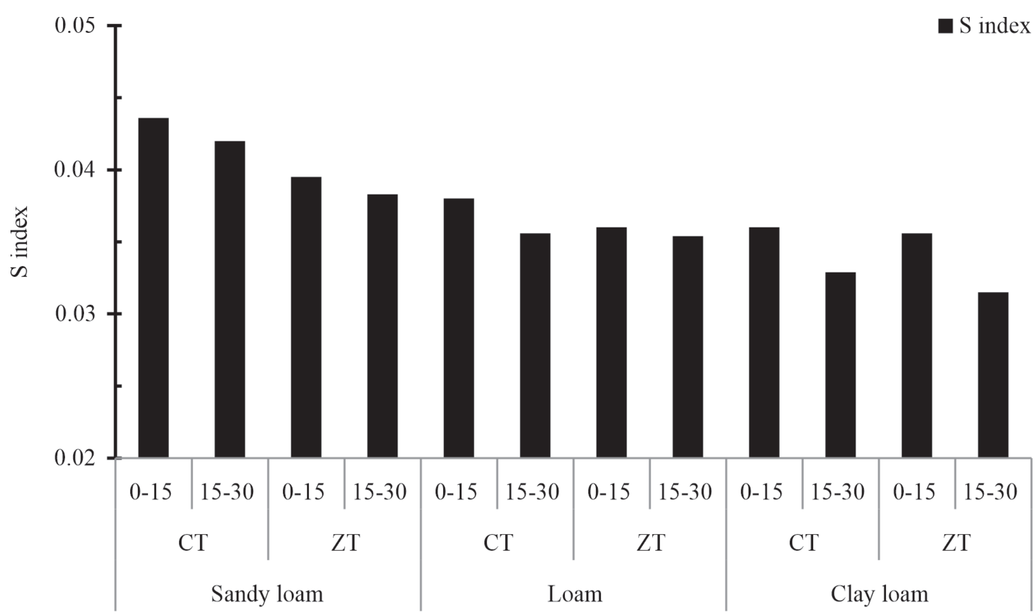

Fig. 6. Effect of tillage on S index of texturally different soils at 0-15 and 15-30 cm depths

Table 6. Effect of tillage on yield and yield attributes of wheat in texturally different soils

Tillage	Grains/spike			1000 grains mass (g)			Yield (t ha^{-1})		
	Sandy loam	Loam	Clay loam	Sandy loam	Loam	Clay loam	Sandy loam	Loam	Clay loam
CT	63.5	63.7	64.8	34.9	34.2	36.8	5.94	6.12	6.15
ZT	63.3	62.6	66.2	35.1	35.4	37.6	6.09	6.19	6.28
LSD(p=0.05)	NS	NS	0.82	NS	0.58	0.65	NS	NS	0.12

Table 7. Effect of tillage on yield and yield attributes of rice in texturally different soils

Tillage	Grains/spike			1000 grains mass (g)			Yield (t ha^{-1})		
	Sandy loam	Loam	Clay loam	Sandy loam	Loam	Clay loam	Sandy loam	Loam	Clay loam
CT	89.8	99.8	94.6	22.6	25.8	20.2	4.10	4.17	4.26
ZT	90.4	100.3	96.8	23.3	26.4	22.3	4.14	4.20	4.33
LSD(p=0.05)	NS	NS	1.6	NS	NS	1.9	NS	NS	NS

Yield and yield attributes of wheat and rice

The zero tillage increased the grain yield of wheat (2.1%) significantly over conventional tillage in clay loam soil due to significant increase in the test weight of grains, however zero tillage did not show significant increase in the yield in the loam soil in spite of significant increase in test weight (Table 6). Thus, zero tillage in wheat under rice-wheat cropping system was found more effective in fine textured soils as compared to coarse textured. The zero tillage also significantly increased grains/panicle and test weight of rice in clay loam soils (Table 7) but not significantly increased the yield of rice. Acharya and Sharma (1994) reported a decrease in yield of maize and wheat with reduction in intensity of soil tillage to zero while Romaneckas *et al*., 2012 reported increase in yield of wheat under zero tillage.

Conclusion

The rice-wheat cropping system is one of the most prominent cropping systems in the Indo-Gangetic plains (IGP) of India in spite of declining water table, soil health and productivity. The present study indicates the results of long term effect of zero tilled wheat for 20 years in sandy loam, loam and clay loam soils of Indo-Gangetic plains of Haryana State mainly under rice-wheat cropping systems. The results illustrated that long-term zero tillage resulted in improvement in physical properties of all the three textured soils up to 30 cm depth by decreasing the bulk density (0.62 to 0.64%) and penetration resistance, increasing soil organic carbon (17.8-35.3%) and carbon stock (17.6 to 35.2%), soil moisture retention, total porosity (5-22.8%), and aeration porosity as compared to the conventional tillage. The long-term zero tillage also improved the soil quality in terms of physical quality indices $LLWT_{fcpw}$ and S-index and resulted in higher values of yield attributes in rice and wheat as well as higher yields of rice and wheat in sandy loam, loam and clay loam soils. However, the practice was found more suitable in fine textured soils as compared to medium or coarse textured soils by increasing the grain yield significantly over conventional tillage in clay loam. The results imply that zero tillage in wheat has potential to improve physical quality and productivity of sandy loam, loam and clay loam soils of Indo-Gangetic plains of Haryana state under rice-wheat cropping system in addition to ensuring the soil conservation and sustainable environment by mitigating emissions of greenhouse into the atmosphere due to stopping of burning of crop residue for seed bed preparations.

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