Journal of the Indian Society of Soil Science, Vol. 63, No. 1, pp 30-38 (2015)
DOI: 10.5958/0974-0228.2015.00005.5

Short-Term Tillage and Residue Management Impact on Physical Properties of a Reclaimed Sodic Soil

S.K. Chaudhari*[1], Gopali Bardhan, Parveen Kumar, Rakesh Singh, Ajay Kumar Mishra, Poornima Rai, Kailash Singh and D.K. Sharma
Central Soil Salinity Research Institute, Karnal, 132 001, Haryana

Water is the most limiting factor for crop production both in dry land and irrigated farming. A better understanding of the long-term impact of tillage and residue management systems on soil structure and water infiltration is necessary for development of conservation tillage practices to improve water-use efficiency. The objectives of this study were to assess the influence of conventional tillage with one-third residue incorporation (T_1); Farmers' practice of tillage with full residue removal (T_2); zero-tillage with one-third residue retention (T_3); zero-tillage with full residue retention using turbo seeder (T_4) on soil properties and soil water transmission characteristics in a winter wheat (*Triticum aestivum* L. cultivars KRL 213 and HD 2894) under tillage and residue management practices. Soil physical properties were studied in the top 0-15 and 15-30 cm depth during April 2011 after one year under the four tillage and residue management treatments**.** In both the soil layers, soil water availability increased in T_4 treatment compared to other treatments. The decline of unsaturated hydraulic conductivity (K_θ) and soil-water diffusivity (D_θ) was very sharp in T_2 treatment (farmers' practice) as compared to zero-tillage with full residue retention (T_4). Tillage and residue management had no significant effect on water retention characteristics (h_θ) in both the soil layers. In addition, plant drainable water, available water and residual water content were greater in T_4 treatment as compared to rest of the treatments. The improved soil physical parameters *viz.,* soil water retention, unsaturated hydraulic conductivity and diffusivity from this one year experiment indicated that zero-tillage with residue retention is a promising agro-practice for sustaining the soil physical health in Indo-Gangetic Plains of India.

Key words: Conservation tillage, zero-tillage, residue retention, water retention characteristics, unsaturated hydraulic conductivity, soil-water diffusivity

The Indo-Gangetic Plains (IGP) with about 13% geographical coverage of India produces nearly 50% of food grains to feed 40% of the total population of India. The IGP is an important agricultural region of the country with total area of about 44 million ha (Mha) represented by well classified agro-ecological sub-regions (Velayutham *et al*. 1999) and covers the states of Punjab, Haryana, Delhi, Uttar Pradesh, Bihar, West Bengal and parts of a few other states. The main crop in Indo-Gangetic Plains in India during *rabi* season is wheat (*Triticum aestivum* L.). Over the past 40 years, however, wheat yields have been increased by fertilizer application, thus increasing water consumption as well. It is documented that some soil physical properties, such as bulk density, porosity, *etc*. which affect crop production, may be influenced by tillage practices (Cassel and Nelson 1985; Schwen *et al.* 2011). Raczkowski *et al.* (2012) reported that tillage had no effect on soil bulk density (0-15 cm layer) after 10 year of continuous zero and conventional tillage treatments in Kentucky. Chaney *et al.* (1985) and van Doren *et al.* (1977) found that the bulk density and cone penetration resistance of the soil in Ohio, USA (11 year) and Leeds, England (7 year) were significantly affected by various tillage treatments.

Conventional tillage practices based on mouldboard ploughing and preparing fine seedbeds with residue removed or buried have resulted in poor soil fertility and degraded soil structure as indicated by soil surface sealing, low mesoporosity (pores of diameter <60 µm), unstable soil aggregates, and low soil organic matter (SOM) content, all of which affect

*Corresponding author (Email: adgswm@gmail.com; surchaudhari@hotmail.com)
Present address
[1]Natural Resource Management Division, ICAR, KAB-II, New Delhi, 110 012

water infiltration and soil water retention (Elliott 1986; Fabrizzi *et al.* 2005). Water use efficiency (WUE) can also be improved by appropriate management strategies such as no-tillage, mulching and conservation tillage (Du *et al.* 2005).

The retention of surface residues can conserve SOM and nutrients, decrease water runoff and increase infiltration, increase water stable aggregates and water holding capacity, decrease evaporation, and control weeds. Conservation tillage (no-tillage with standing stubble and residue retention) has been shown to improve soil properties, therefore, enhancing water transmission and facilitating water retention. Baumhart and Lescano (1996) indicated that soil under no-tillage treatment have greater infiltration rate and water storage capacity than tilled soil. Conservation tillage was also shown to improve soil water content and crop yields in many environments (Hemmat and Eskandari 2004; Munoz *et al.* 2007), but Wilhelm *et al*. (1987) and Hammel (1995) observed negative effects of no-tillage on crop yields in arid areas of the United States. The objective of the study reported here was to determine the effects of tillage and residue management on water retention, unsaturated hydraulic conductivity and diffusivity of the soil after one year of experimentation.

Materials and Methods

Site Description

The study was conducted during 2011-2012 in Central Soil Salinity Research Institute, Karnal (at 29°43' N latitude, 76°58' E longitude and 245 m above the mean sea level). The district is a part of the Ganga-Indus (Indo-Gangetic) plains and has a well spread network of Western Yamuna canal. Karnal has a typical sub-humid and sub-tropical type of climate with extreme weather conditions. The mean annual precipitation is about 670 mm, out of which 80% is received during June-September and the rest during October-May. June is the hottest month of the year, whereas July and August are the wettest months. The daily minimum and maximum temperature and evaporation rates increase from February to June, decrease during July to September and suddenly drop in January. The relative humidity increases from June to September and gradually decreases reaching the minimum during January.

Experimental Design and Details

At the beginning of the experiment, the entire field was ploughed to a depth of 30 cm. The experiment was designed in factorial randomized block design with four tillage and residue management systems (T_1: conventional tillage with one-third residue incorporation; T_2: Farmers' practice of tillage with full residue removal; T_3: zero-tillage with one-third residue retention; T_4: zero-tillage with full residue retention using turbo seeder) and two wheat variety (KRL 213 and HD 2894) with three replications. Each plot was 15 m long and 10.5 m wide. Experimental crop was sown on 19 November 2011 at 20 cm row-to-row distance. In T_1, the seeds were sown in line with fertilizer-cum-seed drill; in T_2, the seeds were sown by broadcasting method; in T_3, seeds were sown in line with zero-till machine and in T_4, seeds were sown in line with turbo seeder in full residue retention conditions. The recommended dose of fertilizer (150:26.2:24.9 NPK kg ha^{-1}) was used for this study. Full dose P and K along with 1/3 dose of N were applied as basal at the time of sowing and remaining 2/3 dose of N was applied in two equal splits along with 1st and 2nd irrigation. Five irrigations of 6 cm each were applied during the crop span. Harvesting of the crop was done on 18 April 2012.

Soil Sampling and Preparation

Undisturbed soil cores were collected from randomly located points in all the plots in April 2012 for bulk density, soil physicochemical properties, soil-water retention characteristics, unsaturated hydraulic conductivity and soil-water diffusivity measurements immediately after the harvesting of wheat. The 50.4 mm diameter × 50 mm long cores were taken with a manual stainless steel core sampler. Three disturbed soil samples were also collected at each of the 0–15 and 15–30 cm soil depths in each plot and mixed to form a single composite sample for each depth for laboratory analysis. Each composite soil sample was gently broken apart and passed through a 8-mm sieve. Clods and aggregates >8 mm were discarded. After sieving, each composite soil sample was divided into three sub-samples and air dried for 24 h in the laboratory before analysis.

Physicochemical Properties

Soil pH and electrical conductivity (EC) was determined by a glass electrode pH meter in 1:2 soil-water suspension as given by Page *et al.* (1982). Soil organic carbon (SOC) content was determined by wet oxidation method of Nelson and Sommer (1982). Hydrometer method (Day 1965) was used to determine sand, silt and clay percentages in soil. The $CaCO_3$ was determined by a method described by Richards (1954).

Table 1. Basic physicochemical properties of soils under different tillage and residue management treatments.

Tillage and residue management	Soil depth (0-15 cm)					Soil depth (15-30 cm)				
	pH	EC (dS m^{-1})	Bulk density (Mg m^{-3})	$CaCO_3$ (%)	SOC (g kg^{-1})	pH	EC (dS m^{-1})	Bulk density (Mg m^{-3})	$CaCO_3$ (%)	SOC (g kg^{-1})
T_1: CT+1/3 RI	7.26	0.19	1.59	0.17	8.1	7.54	0.17	1.53	0.40	6.6
T_2: TFP+FRR	7.29	0.20	1.59	0.25	7.1	7.48	0.17	1.58	0.29	6.4
T_3: ZT+1/3 RA	7.33	0.18	1.56	0.35	7.9	7.54	0.16	1.61	0.42	6.6
T_4: ZTT+FRA	7.26	0.23	1.56	0.39	8.4	7.71	0.19	1.49	0.27	6.3
Variety										
KRL 213	7.22	0.21	1.59	0.26	8.0	7.55	0.18	1.62	0.37	7.0
HD 2894	7.34	0.19	1.55	0.31	7.8	7.58	0.16	1.48	0.31	5.9

CT=Conventional tillage (harrow + tiller); RI= Residue incorporation; TFP= Tillage as per farmers practice (harrow + rotavator); FRR= Full residue removal; ZT=Zero tillage; RR= Residue anchored/retention; ZTT=Zero tillage with turbo machine; FRA= Full residue anchored/retention

Bulk Density

Bulk density and soil water content measurements were made on three undisturbed soil cores from each of the 0–15 and 15–30 cm soil layers in each plot. The wet cores were weighed, oven dried at 105 °C for 48 h, and again weighed after drying. A method described by Yaduvanshi *et al.* (2009) was followed for bulk density determination.

Soil Water Retention

Soil water retention was determined following the procedure of Klute and Dirksen (1986). Soil cores were wetted to saturation by capillary action on a ceramic plate and then placed on a laboratory pressure plate extractor to drain them to soil-water suction of 0, –10, –33, –50, –100, –300, –500, –1000, and –1500 kPa. The weights of each sample were recorded after reaching equilibrium at each matric potential and after oven drying. Soil-water retention measurements were made on three undisturbed cores from each of the 0–15 and 15–30 cm depths for each plot. Gravimetric water contents were converted to volumetric term by multiplying with the respective bulk density values. A relationship was developed between soil-water suction (h) and volumetric water contents (θ). From h-θ function, different water constants were calculated as drainable water, available water and residual water. Drainable water represented the water retained between 0 and 33 kPa, available water between 33 and 1500 kPa and residual water at 1500 kPa.

Unsaturated Hydraulic Conductivity and Soil-Water Diffusivity

Unsaturated hydraulic conductivity and soil-water diffusivity were estimated using the retention curve computer code (RETC) (van Genuchten *et al.* 1991), which analyzes the soil-water retention and hydraulic conductivity functions of unsaturated soils. The program uses the parametric models of Brooks-Corey and van Genuchten to represent the soil-water retention curve, and the theoretical pore-size distribution models of Mualem and Burdine to predict the unsaturated hydraulic conductivity function from observed soil-water retention data. The RETC-manual gives a detailed discussion of the different analytical expressions used for quantifying the soil-water retention and hydraulic conductivity functions. The program was used to predict the hydraulic conductivity from observed soil-water retention data with the actual saturated hydraulic conductivity values.

Results and Discussion

Physicochemical Properties

Basic soil properties are presented in table 1. Soil bulk density in the 0-15 cm layer under four tillage treatments ranged from 1.56 to 1.59 Mg m^{-3} and in the 15-30 cm layer from 1.49 to 1.61 Mg m^{-3}. Soil pH ranged from 7.26 to 7.33, EC from 0.18 to 0.23 dS m^{-1}, $CaCO_3$ from 0.17 to 0.39%, and SOC from 0.71 to 0.84 g kg^{-1} in 0-15 cm layer and soil pH from 7.48 to 7.71, EC from 0.16 to 0.19 dS m^{-1}, $CaCO_3$ from 0.27 to 0.42%, and SOC from 6.3 to 6.6 g kg^{-1} in 15-30 cm layer. Soil bulk density values indicate development of a compact layer beneath tillage depth, caused by the traffic associated with tillage because this experimental plot was under rice-wheat cropping system for a long time. Experimental soil was clay in texture (Table 2).

Volume Water Content

Volumetric water retained on various soil-water suction points in the 0-15 and 15–30 cm depths under

Table 2. Sand, silt and clay percentages in different treatments

Tillage and residue management	Soil depth (0-15 cm)			Soil depth (15-30 cm)		
	Sand (%)	Silt (%)	Clay (%)	Sand (%)	Silt (%)	Clay (%)
T_1: CT+1/3 RI	24.8	25.7	49.5	24.3	26.7	49.0
T_2: TFP+FRR	23.5	27.4	49.0	24.6	26.4	49.0
T_3: ZT+1/3 RA	20.8	29.0	50.2	22.0	27.3	50.7
T_4: ZTT+FRA	23.6	26.6	49.8	24.1	27.8	48.1
Variety						
KRL 213	22.0	28.6	49.4	23.9	26.7	49.4
HD 2894	24.3	25.8	49.9	23.7	27.3	49.0

CT=Conventional tillage (harrow + tiller); RI= Residue incorporation; TFP= Tillage as per farmers practice (harrow + rotavator); FRR= Full residue removal; ZT=Zero tillage; RR= Residue anchored/retention; ZTT=Zero tillage with turbo machine; FRA= Full residue anchored/retention

Table 3. Effect of tillage and residue management treatments on soil volume water content at various soil-water suction points

Tillage and residue management	Water content (cm^3 cm^{-3})																	
	Soil depth (0-15 cm)									Soil depth (15-30 cm)								
	Soil-water suction (kPa)									Soil-water suction (kPa)								
	0	10	33	50	100	300	500	1000	1500	0	10	33	50	100	300	500	1000	1500
T_1: CT+1/3 RI	0.40	0.37	0.28	0.27	0.22	0.16	0.14	0.12	0.11	0.43	0.41	0.31	0.29	0.24	0.18	0.16	0.14	0.13
T_2: TFP+FRR	0.39	0.36	0.29	0.25	0.20	0.16	0.14	0.12	0.10	0.44	0.41	0.32	0.28	0.23	0.18	0.16	0.14	0.12
T_3: ZT+1/3 RA	0.41	0.39	0.33	0.27	0.24	0.19	0.17	0.15	0.13	0.47	0.44	0.35	0.31	0.27	0.21	0.19	0.17	0.16
T_4: ZTT+FRA	0.57	0.54	0.38	0.30	0.24	0.18	0.16	0.15	0.14	0.63	0.60	0.43	0.35	0.28	0.21	0.19	0.18	0.17

CT=Conventional tillage (harrow + tiller); RI= Residue incorporation; TFP= Tillage as per farmers practice (harrow + rotavator); FRR= Full residue removal; ZT=Zero tillage; RR= Residue anchored/retention; ZTT=Zero tillage with turbo machine; FRA= Full residue anchored/retention

conventional tillage with one-third residue incorporation (T_1), farmers practice of full residue removal (T_2), zero tillage with one-third residue retention (T_3), and zero tillage with full residue retention with turbo seeding (T_4), after harvesting in 2012 is presented in table 3. Volumetric water content declined exponentially with increase in soil-water suction in all the tillage treatments. In 0–15 cm soil layer, zero tillage with full residue retention (turbo seeding) increased soil-water retention as compared with other treatments. The same trend was observed in 15-30 cm soil. In 15–30 cm soil layer more water was retained, in all treatments than that of 0-15 cm. This improvement, particularly at 15–30 cm, which is below the ploughing depth, could be attributed to the lower soil bulk density and higher mesoporosity of zero tillage treatment (Yang and Wander 1998). This suggests that zero tillage with full residue retention with turbo seeding is effective in improving soil-water retention capacity, which is of particular importance for the growth of winter wheat in Indo-Gangetic Plains of India.

Soil Water Retention Characteristics

The differences in soil water content at any given suction were not significant between zero tillage (turbo seeding) and farmers' practice in the 0–15 and 15-30 cm soil layer (Fig. 1), which was consistent with the findings of Hill *et al.* (1985). This similarity can be attributed to similar mesoporosity in zero tillage and other two tillage practices (conventional tillage and farmer practice). As soil depth increased, mesoporosity in conventional tillage reduced, resulting in reduced soil-water retention capacity under conventional tillage compared with zero tillage treatment. In the 0–15 cm soil layer, drainable water (between the saturation and –33 kPa) increased by 42 per cent in KRL 213 and 20 per cent in HD 2894 variety under zero tillage and full residue retention (turbo seeding) than under and farmers' practice of full residue removal. Similarly in 15-30 cm, it was increased by 28 per cent in KRL 213 and 21 per cent in HD 2894. Increased water retention in this layer continued up to soil-water suction of –500 kPa. This may be attributed to uniform pore-size distribution, an attribute that

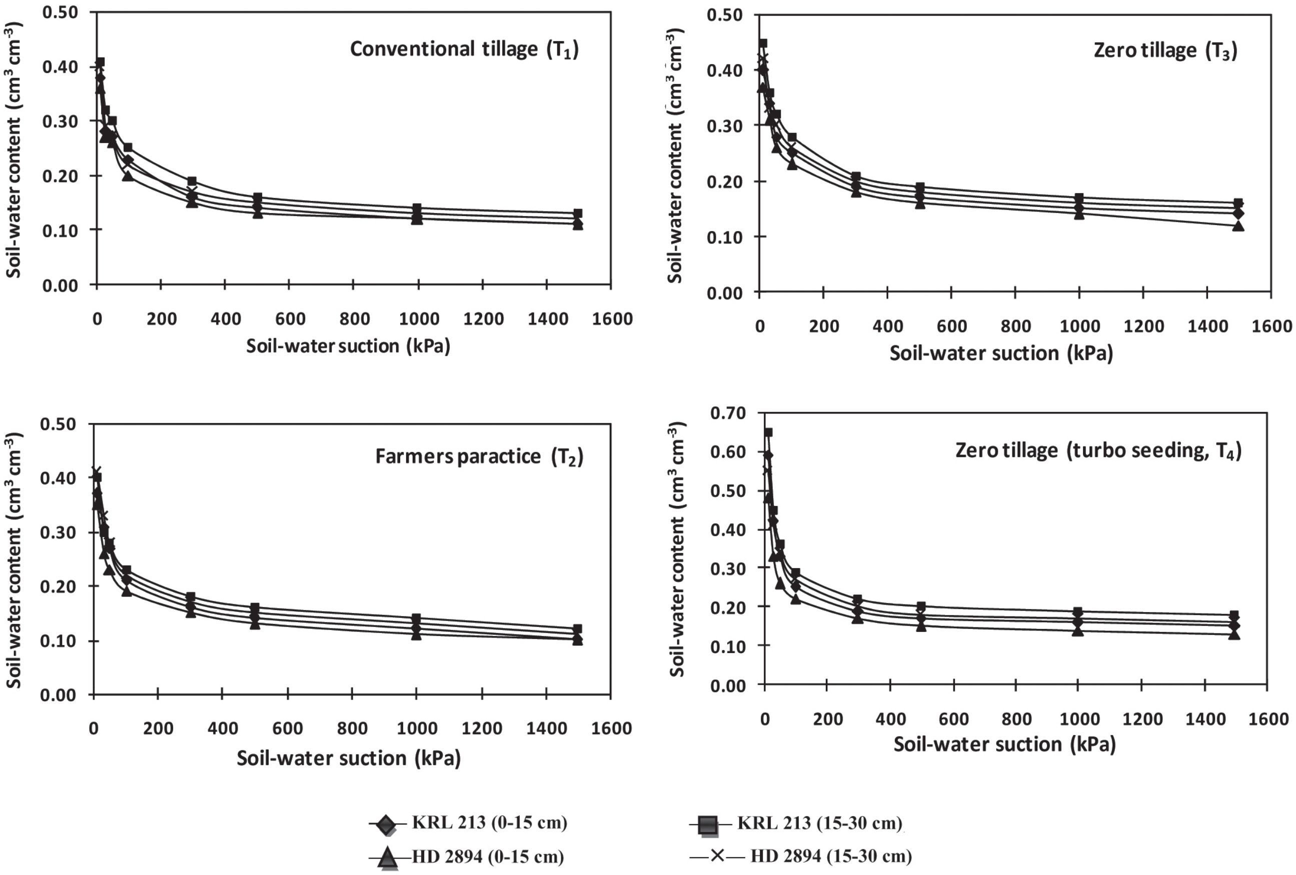

Fig. 1. Soil moisture characteristics curve as influenced by different tillage and residue management treatments

does not reflect in macroscopic values like bulk density (Gupta *et al.* 1989). The small difference in soil water retention between zero tillage with full residue retention (turbo seeding) and farmers' practice in the upper 15 cm layer indicated that tillage had only little effect on pore-size distribution, but was more indicative of the destructive effects of traffic and tillage and the consolidating nature of soil on macropores in a short period of one year. Bescansa *et al.* (2006) also reported that retention of water was significantly greater in untilled soils than in tilled soils in the 15–30 cm soil layer.

Unsaturated Hydraulic Conductivity and Soil-Water Diffusivity

Using water retention data and values of saturated hydraulic conductivity (h_θ), unsaturated hydraulic conductivity (K_θ) and soil-water diffusivity were computed using RETC. In fig. 2 comparison has been made for the unsaturated hydraulic conductivity in two tillage and residue management treatments in 0-15 and 15-30 cm soil depths in wheat varieties (KRL 213 and HD 2894). The results of K_θ exhibited the same trend as that of h-θ. In general, values of K_θ declined exponentially with decreasing water content. This decline was very sharp in farmers' practice ($T\text{-}_2$) as compared to zero tillage with full residue retention (turbo seeding) in both 0-15 and 15-30 cm soil layer. Results for soil water diffusivity (D_θ), depicted in fig. 3, and confirmed the same trend as that of unsaturated hydraulic conductivity.

Distribution of retained water in the soil is expressed in drainable, available and residual soil-water ranges (Table 4). Compared to drainable and residual soil-water ranges, soil retained more water in available water range irrespective of tillage treatments and varieties. Zero tillage practice with full residue retention resulted in higher water retention in all the ranges over all the other tillage treatments. Multiple regressions of water retention on important soil properties at a water potential of 33 kPa and 1500 kPa did not show significant relationship in one year of study. However, their values obtained for 0-15 cm (0.71 and 0.67 kPa) layer were greater than 15-30 cm (0.56 and 0.26 kPa) soil layer.

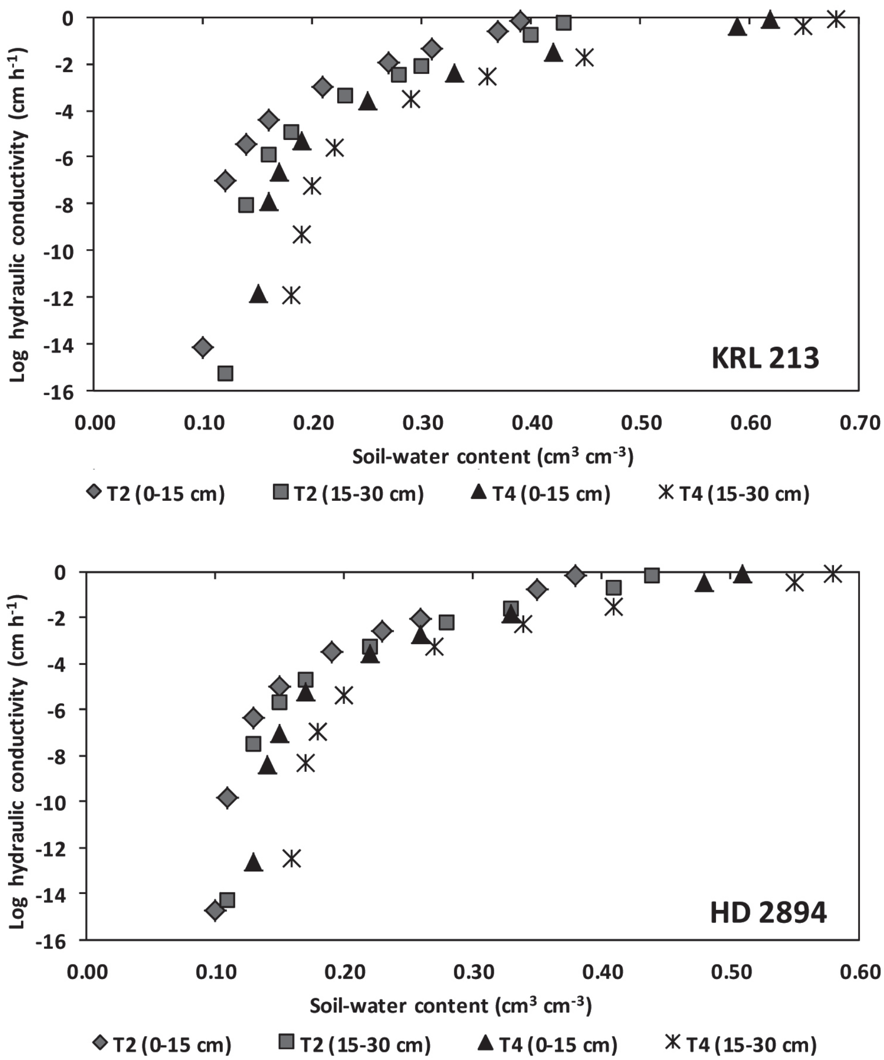

Fig. 2. Unsaturated hydraulic conductivity as a function of volumetric water content as influenced by different tillage and residue management treatments

Table 4. Distribution of retained water in different soil-water ranges under different tillage and residue management treatments

Tillage and residue management	Soil depth (0-15 cm)			Soil depth (15-30 cm)		
	Drainable water ($cm^3\ cm^{-3}$)	Available water ($cm^3\ cm^{-3}$)	Residual water ($cm^3\ cm^{-3}$)	Drainable water ($cm^3\ cm^{-3}$)	Available water ($cm^3\ cm^{-3}$)	Residual water ($cm^3\ cm^{-3}$)
T_1: CT+1/3 RI	0.12	0.17	0.11	0.12	0.18	0.13
T_2: TFP+FRR	0.10	0.19	0.10	0.12	0.20	0.12
T_3: ZT+1/3 RA	0.09	0.20	0.13	0.12	0.19	0.16
T_4: ZTT+FRA	0.19	0.24	0.14	0.20	0.26	0.17
Variety						
KRL 213	0.12	0.21	0.13	0.15	0.21	0.15
HD 2894	0.13	0.18	0.12	0.13	0.21	0.14

CT=Conventional tillage (harrow + tiller); RI= Residue incorporation; TFP= Tillage as per farmers practice (harrow + rotavator); FRR= Full residue removal; ZT=Zero tillage; RR= Residue anchored/retention; ZTT=Zero tillage with turbo machine; FRA= Full residue anchored/retention

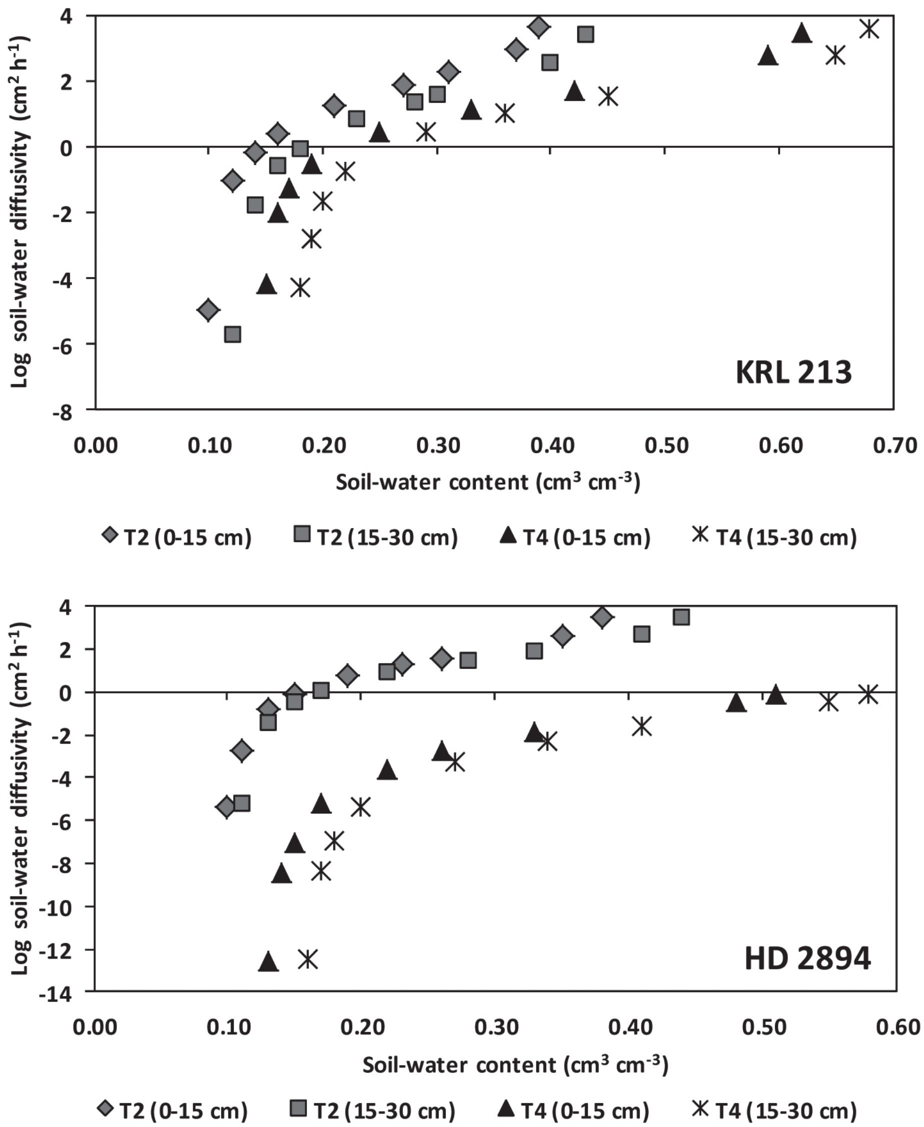

Fig. 3. Soil-water diffusivity as a function of volumetric water content as influenced by different tillage and residue management treatments

Conclusions

Comparison of plots after one year of continuous tillage and residue management treatments on the CSSRI farm of Karnal has provided the evidence that reduced soil disturbance and increased residue retention under zero tillage have the potential to improve soil physical properties and water retention. No statistical significance was obtained because the study is limited to one year data. Improvements were more pronounced in the deeper layer than the upper layer. This was mainly because development of pore continuum in zero tillage system as compared with the farmers' practice. There was no change in bulk density by the adoption of tillage and residue management system in both 0-15 cm and 15–30 cm soil layer in one year. Mean values of these parameters suggested that zero tillage with residue retention might also have positive effects on soil physical structure in the surface soil, but the differences were small and non-significant. These improvements in soil physical properties and water transmission under zero tillage system have profound implications for crop production in the Indo-Gangetic Plains of India, which are presently experiencing rapid soil degradation and decreasing water availability. Our data demonstrate that tillage management has a potential to influence soil hydraulic properties. Zero tillage with residue retention proved to be an effective method for improving soil physical properties and therefore, should benefit long-term productivity and sustainability. Zero tillage with full residue retention (turbo seeding) improved water transmission behavior in the 15–30 cm soil layer. Long-term research on the relationships between tillage, residue, and productivity is required. Furthermore, from a sustainable development perspective, more information is needed on the impact of zero tillage with full residue retention (turbo seeding) on soil hydro-physical properties.

Acknowledgements

We express our sincere gratitude to the Department of Science and Technology, New Delhi, for providing financial support to conduct this study. We thankfully acknowledge the help and support of Director and Head Soil and Crop Management, CSSRI. Thanks to Mr. Girraj and Mr. Charan Singh for assistance in lab and field work.

References

Baumhart, R.L. and Lescano, R.J. (1996) Rain infiltration as affected by wheat residues amount and distribution in ridged tillage. *Soil Science Society of America Journal* **60**, 1908–1913.

Bescansa, P., Imaz, M.J., Virto, I., Enrique, A. and Hoogmoed, W.B. (2006) Soil water retention as affected by tillage and residue management in semiarid Spain. *Soil and Tillage Research* **87**, 19–27.

Cassel, D.K. and Nelson, L.A. (1985) Spatial and temporal variability of soil physical properties of Norfolk loamy sand as affected by tillage. *Soil and Tillage Research* **5**, 5-17.

Chaney, K., Hodgson, D.R. and Braim, M.A. (1985) The effects of direct drilling, shallow cultivation and ploughing on some soil physical properties in a long-term experiment on spring barley. *Journal of Agricultural Sciences* **104**, 125-133.

Day, P.R. (1965) Particle fractionation and particle size analysis. In *Methods of Soil Analysis* (C.A. Black *et al.,* Eds.), Part I. *Agronomy* **9**, 54-567.

Du, Y.J., Li, Z.Z. and Li, W.L. (2005) Effect of water control and plastic-film mulch on growth and the range of size inequalities in spring wheat (*Triticum aestivum*) populations. *New Zealand Journal of Agricultural Research* **33**, 251–260.

Elliott, E.T. (1986) Aggregate structure and carbon, nitrogen and phosphorus in native and cultivated soils. *Soil Science Society of America Journal* **50**, 627–633.

Fabrizzi, K.P., Garcia, F.O., Costa, J.L. and Picone, L.I. (2005) Soil water dynamics, physical properties and corn and wheat responses to minimum and no-tillage systems in the southern Pampas of Argentina. *Soil and Tillage Research* **81**, 57–69.

Gupta, S., Sharma, P. and De Franchi, S. (1989) Compaction effects on soil structure. In *Advances in Agronomy* (E.C. Brady, Ed.). Sydney, Academic Press. pp. 311–337.

Hammel, J.E. (1995) Long-term tillage and crop rotation effects on winter wheat production in Northern Idaho. *Agronomy Journal* **87**, 16–22.

Hemmat, A. and Eskandari, I. (2004) Conservation tillage practices for winter wheat-fallow farming in the temperate continental climate of northwestern Iran. *Field Crops Research* **89**, 123–133.

Hill, R.L., Horton, R. and Cruse, R.M. (1985) Tillage effects on soil water retention and pore size distribution of two Mollisols. *Soil Science Society of America Journal* **49**, 1264–1270.

Klute, A. and Dirksen, C. (1986) Hydraulic conductivity of saturated soils. In *Methods of Soil Analysis* (A. Klute, Ed.). American Society of Agronomy and Soil Science Society of America, Madison, United States. pp. 694–700.

Munoz, A., Lopez-Pineiro, A. and Ramirez, M. (2007) Soil quality attributes of conservation management regimes in a semi-arid region of south western Spain. *Soil and Tillage Research* **95**, 155–265.

Nelson, D.W. and Sommer, L.E. (1982) Total carbon, organic carbon, and organic matter. In *Methods of Soil Analysis.* Part II. *Chemical and Microbiological Properties* (A.L. Page, R.H. Miller and D.R. Keeney, Eds.). 2nd edition, ASA-SSSA, Madison, USA, pp. 539-579.

Page, A.L., Miller R.H. and Keeney, D.R. (1982) *Methods of Soil Analysis*. Part II. *Chemical and Microbiological Properties*. 2nd Edition. ASA-SSSA, Madison, USA.

Raczkowski, C.W., Mueller, J.P., Busscher, W.J., Bell, M.C. and McGraw, M.L. (2012) Soil physical properties of agricultural systems in a large-scale study. *Soil and Tillage Research* **119**, 50-59.

Richards, L.A. (1954) Diagnosis and improvement of saline and alkali Soils. Agricultural Hand Book No. 60, USDA, U.S. Govt. Printing Office, Washington D.C. pp. 1-160.

Schwen, A., Bonder, G., Scholl, P., Buchan, G.D. and Loiskandl, W. (2011) Temporal dynamics of soil hydraulic properties and the water-conducting porosity under different tillage. *Soil and Tillage Research* **113**, 89–98.

van Doren, D.M., Jr., Triplett, G.B., Jr. and Henry, J.E. (1977) Influence of long-term tillage and crop rotation combinations on crop yields and selected soil parameters for an Aeric Ochraqualf soil. *Ohio Research Bulletin:* 1091/1977. Ohio Agricultural Research and Development Center, Wooster, pp. 1-27.

van Genuchten, M., Th. Leji., F.J. and Yates, S.R. (1991) The RET code for quantifying hydraulic functions of unsaturated soil. Technical Report IAG-DW 12933934, pp. 83, US Salinity Laboratory, US Department of Agricultural Research Service, Riverside, CA.

Velayutham, M., Mandal, D.K., Mandal, C. and Sehgal, J. (1999) Agro-ecological Subregion of India for Planning and Development. NBSS Publication 35, NBSS&LUP, Nagpur, pp. 1-372.

Wilhelm, W.W., Schepers, J.S., Mielke, L.N., Doran, J.W., Ellis, J.R. and Stroup, W.W. (1987) Dry land maize development and yield resulting from tillage and nitrogen fertilization practices. *Soil and Tillage Research* **10**, 167–179.

Yaduvanshi, N.P.S., Chaudhari, S.K., Lal, Khajanchi., Bundela, D.S., Dey, P. and Singh, Gurbachan (2009) *Methods of Soil, Plant and Climatic Analysis*. Central Soil Salinity Research Institute, Karnal, pp. 1-110.

Yang, X.M. and Wander, M.M. (1998) Temporal changes in dry aggregate size and stability: tillage and crop effects on a silty loam Mollisol in Illinois. *Soil and Tillage Research* **3**, 173–183.

Received 15 April 2014; Accepted 20 February 2015