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Effect of conservation agriculture on soil hydro-physical properties under diversified maize (*Zea mays*)-based cropping systems

BRIJESH YADAV[1], PRAMEELA KRISHNAN[2], C M PARIHAR[3] and SURESH YADAV[4]

ICAR-Indian Agricultural Research Institute, New Delhi 110 012 , India

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ABSTRACT

Rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) cropping system of the Indo-Gangetic Plains is under threat due to multiple challenges of degrading soil structure, depleting soil organic carbon, declining water level and increasing multi-nutrient deficiencies making farming uneconomical and unsustainable. Conservation agriculture (CA) based tillage practices along with optimization of cropping systems have shown to produce more with less inputs. Therefore, an experiment was conducted to evaluate the impact of tillage practices, *viz*. zero tillage with residue retention (ZT + R) and conventional tillage with residue incorporation (CT + R), under diversified maize based cropping system (maize-wheat-mungbean and maize-mustard-mungbean) on soil hydro-physical properties at IARI, New Delhi. Compared to CT+R, bulk density (BD) showed significant ($P < 0.05$) decline (3.4-7.7% and 1.2 -2.4 %) under ZT+R at 0–30 and 30-60 cm soil depths but the impact of cropping system was non-significant. The saturated hydraulic conductivity (K_{sat}) was significantly ($P < 0.05$) increased by 12.1, 13.9, 20.0 and 17.6% under ZT+R for 0–15, 15–30, 30-45 and 45-60 cm soil depths, respectively as compared to CT+R. Initial and final infiltration rate and cumulative infiltration were significantly higher in ZT+R than CT+R. Overall, our results suggest that adoption of zero tillage with residue retention under maize-wheat-mungbean (MWMb) systems can improve the soil hydro-physical properties.

Key words: Conservation agriculture, Bulk density, Hydraulic conductivity, Soil infiltration rate

Conservation agriculture (CA), which has residue cover on the soil surface at least 30%, could be one of the potential practice to improve the soil physical environment (Salem *et al.* 2015; Singh and Malhi 2006). The CA practices improve stability of soil aggregates (Sheehy *et al.* 2015), total porosity and groundwater movement (Jemai *et al.* 2013; Wang *et al.* 2009), and plant root growth (Grzesiak *et al.* 2013). Conservation agricultural practices therefore lead to a sustainable increase in the effective use of water by increasing infiltration and soil water retention and reducing the loss of evaporation, as well as enhancing the availability of nutrients and their balance (Dahiya *et al.* 2007; Govaerts *et al.* 2007; Verhulst *et al.* 2010). It is characterized by greater sequestration of SOCs (Dick *et al.* 1992), such as better soil aggregation (Lal *et al.* 1994), and improved pore size distribution (Bhattacharyya *et al.* 2006).

Tillage is the practice of physical manipulation of soil for the establishment of crops. Optimizing tillage activities results in better soil quality. Tillage practices significantly affect the soil properties, it makes the soil either porous or compact and changes the mass-volume relationship of soil (Allmaras 1966). Such changes have an effect on soil hydro-thermal regime, soil erodibility, mechanical impedance and soil aeration. However, under conventional tillage practices such as deep mouldboard plowing, excessive and indiscriminate tillage may cause loss of soil organic matter, degradation of soil structure, extensive wind and water erosion leading to deterioration of soil quality. Most, if not all, of these impeding factors will likely to be significantly mitigated by replacing conventional tillage with zero tillage or minimum tillage (Abid and Lal 2008; Bandyopadhyay and Lal 2015).

Some studies have found that zero-tillage with residue greatly reduced bulk density due to higher organic carbon, better soil aggregation and improved root growth under zero-tillage system (Unger and Jones 1998). Several researchers, by contrast, reported higher values of BD in ZT than CT (Kumar *et al.* 2002; Wilkens *et al.* 2002). Conversion from conventional tillage (CT) to conservation tillage improves the soil water retention parameters, plant available water content and infiltration rate (McGarry *et al.* 2000) and decreases the runoff (Wright *et al.* 1999). Some studies have shown that tillage interferes with pore continuity and decreases water infiltration rate (Shukla *et al.* 2003), while other reports shown either no changes (Ankeny *et al.* 1990)

[1]Ph D Scholar, Division of Agricultural Physics (brijesh8104@gmail.com),[2]Head & Principal Scientist and corresponding author, Division of Agricultural Physics, (prameelakrishnan@yahoo.com), [3]Senior Scientist, Division of Agronomy, (pariharcm@gmail.com), [4]Ph D Scholar, Division of Genetics (sureshiari.genetics@gmail.com).

or decreased rate (Azevedo *et al.* 1998).

Rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) cropping system is the major cropping system in the Indo-Gangetic Plains and plays a crucial role in food security for the region. At the same time, this cropping system is responsible for poor soil health, low crop yields, multi-nutrient deficiencies and water resource depletion (Jat *et al.* 2013, Parihar *et al.* 2016a). Apart from this, conventional crop management practices for the rice-wheat system require high cost of production (Jat *et al.* 2013) and are highly inefficient in input usage (Saharawat *et al.* 2010). Diversifying rice - wheat system with maize-based system and alternative soil and crop management practices could help improve system productivity, sustain soil health and environmental quality (Meelu *et al.* 1979), and save water and labour costs for irrigation (Aulakh and Grant 2008). Therefore, we hypothesized that adoption of zero tillage and diversified maize based crop rotation can improve soil hydro-physical properties compared to conventional tillage.

MATERIALS AND METHODS

A long-term field experiment established during the monsoon season of 2008 under a set of tillage and crop establishment practices in four diversified maize-based cropping systems at the research farm (28°40’ N, 77°12’ E and 228.6 m elevation) of the ICAR-IARI, Pusa Campus, New Delhi, India. The climate is semi-arid with dry hot summer and cold winter. Annual rainfall is 710 mm of which 80% is received during the southwest monsoon from July to September, and rest through the ‘Western Disturbances’ during December to February. The soil at the experimental site belongs to Typic Haplustept. Surface soil (0-15 cm) has sandy loam texture while the subsurface soil (15-60cm) is a sandy clay loam.

The experiment was carried out with two main-plot treatments, *viz*. zero tillage (ZT) with residue retention (ZT+R) and conventional tillage (CT) with residue incorporation (CT+R) along with two sub-plot treatments of diversified maize based systems, maize-wheat-mungbean (MWMb), and maize-mustard-mungbean (MMuMb).The experimental design was split-plot and replicated thrice. The size of experimental plot was 16.5 m × 4.0 m. CT was done by ploughing with disc harrow followed by rotavator and spring tyne cultivator. No tillage was done in ZT+R and it involved direct drilling of seed using ZT planter with inverted 'T' tynes. Approximately 30% of the previous crop-maize residue was maintained in ZT+R plots at harvest, while 30% of the residue was incorporated in CT+R plots and the remaining crop residues were removed from the experimental site.

Wheat seeds of cultivar HD-2967, were sown on 3rd November 2018 with a prescribed seed rate of 100 kg/ha and row spacing of 22.5 cm both in ZT+R and CT+R treatments. The mustard crop (Pusa Mustard 30) was sown on 22 October 2018 with a seed rate of 5 kg ha^{-1}maintained at rows spacing of 30 cm in CT and ZT plots. The crop was sown with a zero-till multi-crop planter in ZT+R and multi-crop planter in CT+R plots.

The Blake and Hartge (1986) method was used to determine the bulk density of soil. For this, undisturbed soil samples were collected from 0 to 60 cm depth at 15 cm interval using core sampler. In the laboratory fresh soil cores were processed and oven-dried for 48 h at 105°C. The dry soil weight was divided by the core volume to compute the bulk density of soil. For each treatment, soil water contents (θ) at 0. 33 and 15 bar were measured for 0-15, 15-30, 30-45 and 45-60 cm soil layers by keeping saturated rings of undisturbed soil in pressure plate apparatus.

The ponding method was used to measure the infiltration rate of the soil using a double ring infiltrometer. The two concentric rings with a diameter of 30 and 45 cm were inserted 5 cm deep into the soil by hammering on the wooden item, mounted on top of the rings. The fall of water in the inner ring, i.e. soil intake was determined by measuring the addition of water to the ring to keep the water level stable.

A standard procedure of Klute and Dirksen (1986) based on Darcy's Law was followed to determine soil Saturated Hydraulic Conductivity (Constant Head Method). In this method a constant head was maintained on saturated soil samples, and water was allowed to flow through the sample until a constant value was reached by the measured outflow. The hydraulic conductivity was calculated using the following formula:

$$\text{Hydraulic conductivity, K (cm min}^{-1}) = Q*L/A*t*(h+L) \quad (1)$$

where, Q is the volume of water collected (cm^3), L is the Length of soil column (cm), A is the cross-sectional area of the permeameter (cm^2), t is the time interval of collection (min) and h is the depth of water above the soil (cm).

The statistical analysis was performed using the split block design analysis in SAS 9.4 (Indian NARS Statistical Computing Portal). Means were compared using significant difference where the analysis of variance was analysed using Tukey’s HSD at $p<0.05$.

RESULTS AND DISCUSSION

Bulk density of soil

The effects of zero tillage on bulk density (BD) was significant ($P < 0.05$) at 0-30 cm soil depths (Fig 1a). The BD under ZT+R was lowered by 3.4-7.7% and 1.2 -2.4% in 0-30 and 30-60 cm, respectively than CT plots. The surface layer (0-15 cm) of soil has low BD as compared to the deeper layer in both treatments. The surface layer of CT +R had higher BD significantly (1.51 Mg/m^3) than the ZT+R (1.46 Mg $/m^3$). The maximum BD was found at 30-45 cm soil depth in both treatments and was higher for CT+R (1.7 Mg/m^3) than ZT+R (1.66 Mg/m^3). The decrease in BD under ZT+R may be attributed to higher organic matter, better soil aggregation, greater root proliferation and higher biomass (Aggarwal *et al.* 2017). Similar findings were reported by Yang and Wander (1999) and Salem *et al.* (2015). The main effect of cropping systems and interaction effects of tillage and cropping systems on BD were non-

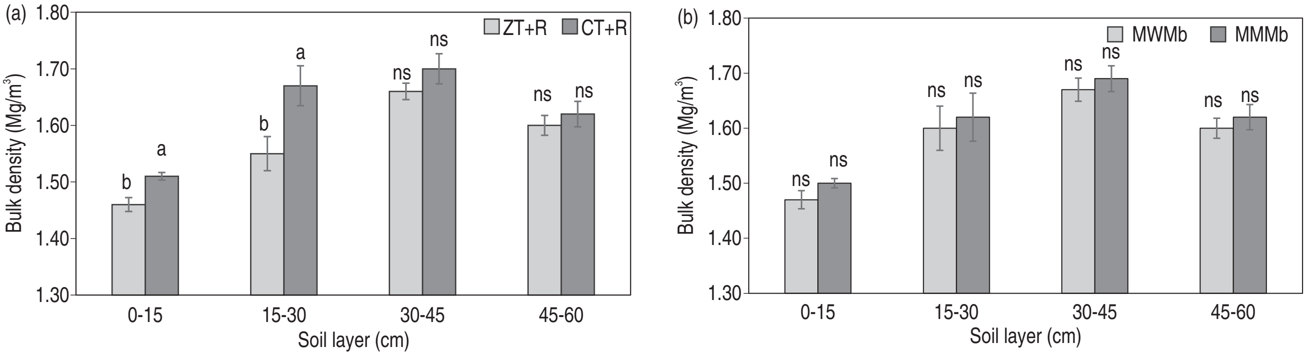

Fig 1 Bulk density of soil under different tillage practices (a) and cropping systems (b).

significant (P < 0.05) throughout the profile (0–60 cm) (Fig 1b). Some researcher reported similar finding that soil BD does not differ significantly with crop rotation (Unger and Jones 1998). Though, higher BD values were observed under MMuMb than MWMb rotation and it could be due to the low organic matter content in MMuMb plots (Parihar *et al.* 2016b).

Field capacity and permanent wilting point

The values of field capacity (FC) was significantly higher for 0-15 cm depth under ZT+R as compared to CT+R. However, the impact of tillage was non-significant for 15-60 cm depth (Fig 2a). FC of 0-15 cm soil depth showed an increase of 12 % under ZT+R (25.78% v/v) as compared to CT+R (22.95% v/v). This increase in FC under ZT+R could be due to residue retention over soil surface resulting in high organic matter content. Many researchers observed similar finding that conservation agriculture practices lead to better soil physical environment resulting in higher soil water retention parameters (Gupta *et al.* 2011; Shafeeq, 2018; Rai, 2017). Crop rotation impact was non-significant on FC among the treatments (Fig 2b). But, FC was slightly higher in MMuMb system (24.61% v/v) over MWMb (24.12% v/v) for 0-15 cm layer.

Permanent wilting point (PWP) was not significantly affected by the tillage practices(Fig 3a).PWP values were almost similar in the top layer (0-15 cm) in both the treatments considered in this study, but was marginally higher at 15-30 and 45-60 cm depths in ZT+R as compared to CT+R treatment. In contrast, 30-45 cm showed higher PWP in CT+R. Crop rotation impact was also non-significant but values were slightly higher in MWMb (9.32-10.14 % v/v) as compared to MMuMb (9.44-9.86% v/v) (Fig 3b).

Saturated hydraulic conductivity

The saturated hydraulic conductivity (K_{sat}) was significantly (P < 0.05) higher for 0-45 cm soil depth under ZT+R as compared to CT+R (Fig 4a). However, the impact of tillage was non-significant for 45-60 cm depth. The K_{sat} increased by 12.1, 13.9, 20.0 and 17.6% in ZT+R for 0–15, 15–30, 30-45 and 45-60 cm soil depths, respectively as compared to CT+R. It was also observed that K_{sat} decreased with increase in soil depth. In both ZT+R and CT+R treatments surface layer (0-15 cm) showed highest K_{sat} (0.99-1.11 cm/hr) and soil layer at 45-60 cm depth showed lowest K_{sat}(0.68-0.80 cm/hr). Higher K_{sat} in ZT+R was mainly attributed to the low BD, high porosity and pore continuity and better soil aggregation due to the effect of residue retention (Aggarwal *et al.* 2017). Similar results were shown by Bhattacharya *et al.* (2006) and Rasool *et al.* (2007).

The impact of cropping system on K_{sat} was significant (P < 0.05) up to 45 cm soil depth (Fig 4b). The K_{sat} of 45-60 cm soil depth did not differ significantly. The K_{sat} increased by 5.8, 6.2, 8.1 and 5.5% in MWMb for 0–15, 15–30, 30-45 and 45-60 cm soil depths, respectively as compared to MMuMb treatment. Lower values of K_{sat} in MMuMb cropping system could be due to higher BD

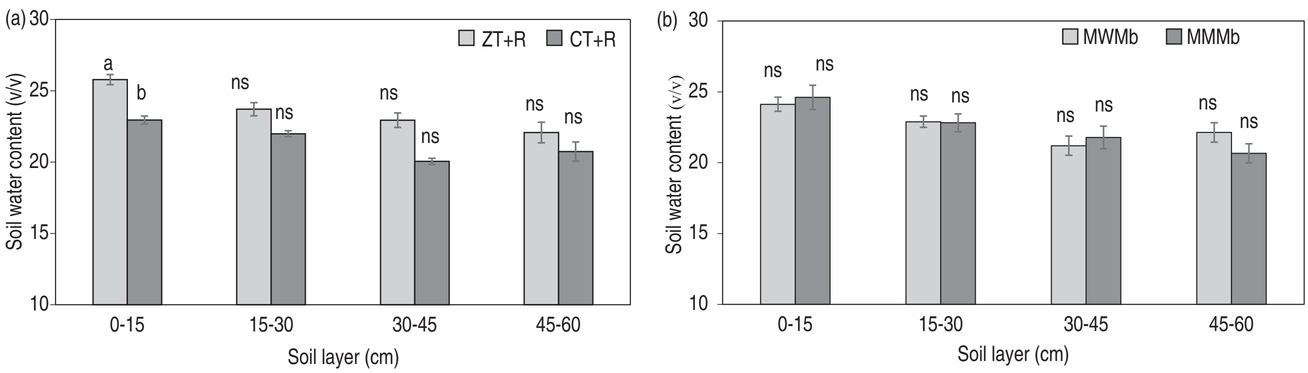

Fig 2 Field capacity of soil under different tillage practices (a) and cropping systems (b).

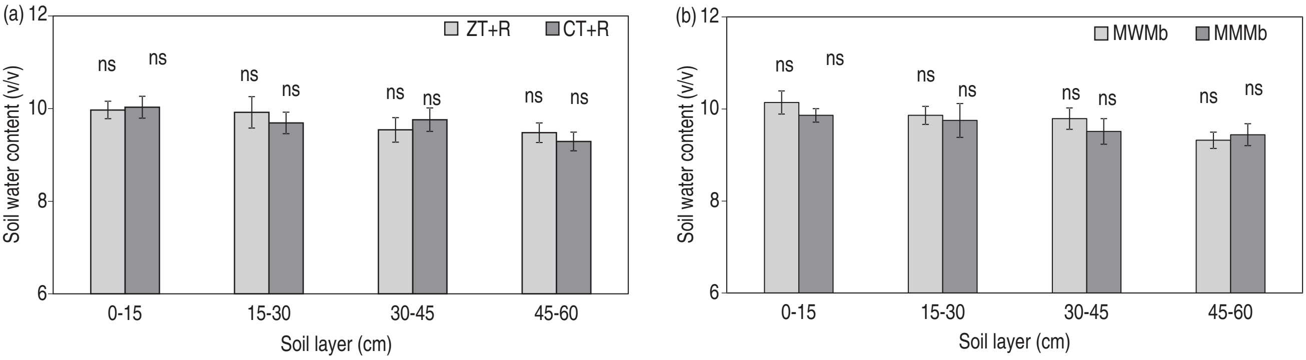

Fig 3 Permanent wilting point of soil under different tillage practices (a) and cropping systems (b).

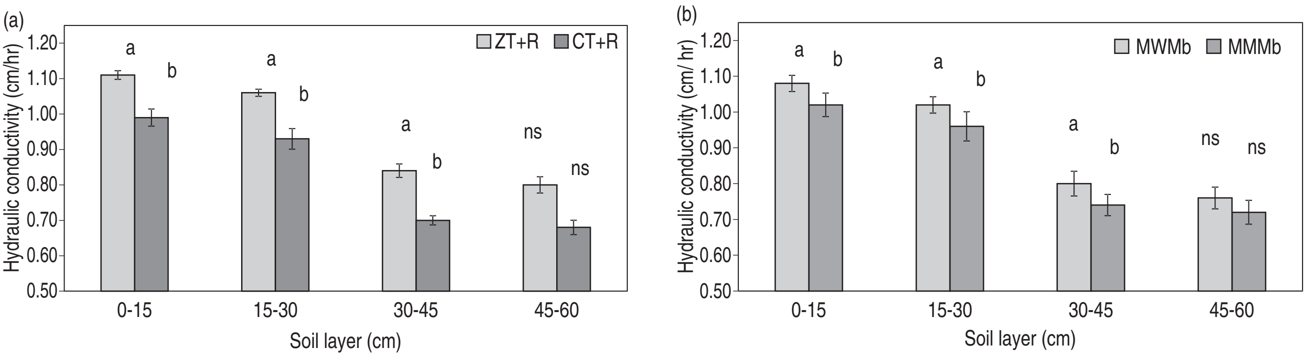

Fig 4 Saturated hydraulic conductivity of soil under different tillage practices (a) and cropping systems (b).

values, destruction of soil structure and low accumulation of organic matter (Parihar *et al.* 2016b). The interaction effect of tillage and cropping system was non-significant ($P < 0.05$) at all soil depths.

Soil infiltration rate

Initial infiltration rates (IR) were significantly ($P < 0.05$) higher under ZT+R (5.32cm/hr) than CT+R (4.56cm/hr) treatment (Table 1).Similar results were observed by Rai *et al.* (2018) that CA practices improve the soil infiltration rate over conventional tillage. The impact of cropping system on initial IR was also significant ($p<0.05$). It was observed to be high for MWMb (5.01cm/hr) as compared to MMuMb (4.87cm/hr).

The final or steady-state infiltration rate which is profile controlled, differed significantly ($p<0.01$) between ZT+R (1.16cm/h) and CT+R (1.03cm/h). The impact of cropping system on final infiltration rate was non-significant and it was high for MWMb (1.12 cm h^{-1}) as compared to MMuMb (1.07cm/h).The higher steady state infiltration rate in ZT+R may be attributed to higher organic matter content and better mean weight diameter (MWD) (Bhattacharya *et al.* 2008). These favourable soil structural parameter led to better porosity and pore continuity and thus higher infiltration rates. The cumulative infiltration was significantly ($p<0.05$) higher in ZT+R (6.66 cm) compared to CT+R (5.48 cm). Higher values of cumulative infiltration in ZT+R was mainly due to higher organic matter and better soil aggregation, abundant macro pore and their continuity (De Rouw *et al.* 2010) and relatively more porous soil structure (Aggarwal *et al.* 2017). Cumulative infiltration rate was significantly high in MWMb (6.28 cm) than MMuMb (5.86 cm) but interaction effect of tillage and cropping systems was non-significant.

Table 1 Initial, steady state infiltration rate and cumulative infiltration under different tillage practices

Treatment	Initial infiltration rate (cm/hr)	Steady state infiltration rate(cm/hr)	Cumulative infiltration (cm)
ZT+R	5.32^a	1.16^a	6.66^a
CT+R	4.56^b	1.03^b	5.48^b
SE(d)	0.10	0.01	0.16
Tukey's HSD at 1%	0.99	0.08	1.56
p-value	0.0164	0.0042	0.0171
MWMb	5.01^a	1.12	6.28^a
MMMb	4.87^b	1.07	5.86^b
SE(d)	0.05	0.02	0.14
Tukey's HSD at 1%	0.23	NS	0.64
p-value	0.0405	0.1142	0.0407
p-value interaction	NS	NS	NS

This study narrates the potential of conservation agriculture in improving the soil physical environment under diversified maize based cropping system. We observed decrease in BD by 3.4-7.7% and 1.2 -2.4 % in 0-30 and 30-60 cm soil depths, respectively in ZT+R compared to CT+R. It was also observed that the adoption of ZT with residue retention over soil surface, significantly improved the hydraulic conductivity and infiltration rate compared to CT+R. Among the cropping system, maize-wheat-mungbean (MWMb) performed better in improving soil hydro-physical properties than maize-mustard-mungbean(MMuMb). Improved soil hydro-physical properties facilitated better water availability to the crop. Such results are important from the perspective of rising the crop productivity and soil health in Indo-Gangetic Plains.

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