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Effect of tillage, residue and nitrogen management on soil physical properties, root growth and productivity of wheat (*Triticum aestivum*)

KOUSHIK BAG[1], K K BANDYOPADHYAY[2]*, V K SEHGAL[3], S P DATTA[4], A SARANGI[5], R PANDEY[6] and P KRISHNAN[7]

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

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ABSTRACT

A study was conducted on a semi-arid climate and sandy loam soils of Indian Agricultural Research Institute farm, New Delhi to evaluate the short-term (5 years) interactions of tillage, residue and nitrogen management on soil physical properties, root growth and yield of wheat (*Triticum aestivum* L.) in a maize-wheat cropping system in a split-split plot design comprising two tillage (No tillage and conventional tillage), two residue levels (no residue, maize residue @ 5 t ha^{-1}) and three nitrogen doses (N60, N120 and N180) as the main plot, sub plot and sub subplot treatments, respectively. It was observed that bulk density (up to 45 cm), penetration resistance (10-27 cm depth) reduced under no tillage and residue applied plots while the porosity (15-60 cm), mean weight diameter (0-15 cm), organic carbon (0-15 cm) improved in these treatments. The hydraulic conductivity was significantly enhanced due to residue applications in the surface layers (0-15cm). Root growth parameters were improved under no tillage and crop residue mulching. Although neither tillage nor residue mulching could significantly influence the grain and biomass yield of wheat on two years of study (2017-18, 2018-19), yield increased significantly with increasing nitrogen doses. Thus no tillage, residue mulching with 150% recommended dose of nitrogen can be practised for maintaining a better soil physical health, root growth without any significant reduction in crop productivity compared to conventional tillage.

Key words: Hydraulic conductivity, Mean weight diameter, No tillage, Penetration resistance, Residue mulching

Input intensive conventional agricultural practices have been found as one of the major causes of soil erosion, soil health deterioration, surface and groundwater pollution and high water consumption (Wolff and Stein 1998). Moreover, this has also been associated with degradation of land resources, reduction of biodiversity and wildlife, low efficiency of inputs and intensification of global warming (Boatman *et al.* 2007). Intensified tillage practices disrupts soil structure and removes organic matter from soil. Use of heavy machinery can produce hard pan and increase the cost of production. Although tillage has profound influence on soil physiochemical properties, environment quality and crop productivity (Keshavarzpour and Rashidi 2008), practising excessive tillage without application of residue mulch can deteriorate soil quality, soil organic carbon and ultimately yield of crops (Ahmad *et al.* 1996). On the other hand conservation agriculture practices based on minimum soil disturbance, crop rotation and residue retention is a sustainable production system. Besides providing an eco-friendly crop production environment, it is found to sustain or increase crop yields, improve soil fertility, reduce land degradation and soil erosion compared to conventional tillage systems (Hobbs *et al.* 2007, Kassam *et al.* 2009). Crop residue on the other hand improves the soil quality by minimizing soil loss, moderating soil temperature, supplying nutrients, reducing evaporation loss, improving soil organic carbon sequestration etc. Therefore, no-tillage combined with residue application can improve the overall soil quality, organic matter content of soil, ecosystem stability and energy use efficiency (Lal 1995, Iqbal *et al.* 2005). With this background a field experiment was conducted to study the effect of five years of tillage and residue application in a sandy loam soil on soil physical health, root growth and productivity of wheat in a maize (*Zea mays* L.)-wheat (*Triticum aestivum* L.) cropping system.

MATERIALS AND METHODS

The field experiment was conducted at the MB-4C farm of ICAR-Indian Agricultural Research Institute, New Delhi (28°37' N, 77°12' E and with an altitude of 228.7 m above the MSL) in an ongoing experiment on conservation agriculture being practised since 2013 in a maize-wheat rotation. The experiment was designed in a split split plot statistical

* Corresponding author e-mail: kk.bandyopadhyay@gmail.com, Division of Agricultural Physics, [4]Division of Soil Science and Agricultural Chemistry, [5] Water Technology Centre, [6]Division of Plant Physiology.

layout where two levels of tillage, i.e. conventional tillage (CT) and no tillage (NT) were the main plot factor, two levels of maize residue (maize residue @ 5 t ha^{-1} (R+) and without residue (R0)) were sub plot factor, and three levels of nitrogen, i.e. 50% (N_{60}),100% (N_{120}) and 150% (N_{180}) of the recommended dose of nitrogen corresponding to 60 kg N ha^{-1}, 120 kg N ha^{-1} and 180 kg N ha^{-1}, respectively as urea, were the sub sub plot factor. The size of sub sub plot was 4.5m × 5m. The soil samples were collected after the harvest of *kharif* maize during the year 2018 from 0-15 cm, 15-30, 30-45 and 45-60 cm soil depths using soil cores for analysis of different properties.

The bulk density (Veihmeyer and Hendrickson 1948), total and air filled porosity, aggregate stability (Yoder 1936), mean weight diameter (Van Bavel 1950), saturated hydraulic conductivity and soil organic carbon (Walkley and Black 1934) for the 0-15, 15-30, 30-45 and 45-60 cm depths were determined using standard procedures. Soil penetration resistance was measured using cone penetrometer (RIMIK CP 20) at CRI stage of wheat. Wheat root samples were collected for 0-15 and 15-30 cm soil depths using core sampler (height of 15 cm and diameter of 7 cm) at flowering stage and analysed in WINRHIZO software. Root length density (RLD), root mass density (RMD) and root volume density (RVD) were calculated by dividing the root length, oven dry (60±5 ºC) root mass and root volume by the core volume (Bandyopadhyay *et al.* 2010).

The grain yield of wheat was recorded after the harvest of the crop. Yield and biomass analysis was done from a representative area of 2 × 2 m^2 from each plot avoiding the boundary effect which was expressed as kg ha^{-1}.

All the data were statistically analyzed using analysis of variance (ANOVA) as applicable to split split plot design (Gomez and Gomez 1984) using SAS software. The significance of the treatment effects was determined using F-test and the difference between the means was estimated by using least significance difference at 5% probability level.

RESULTS AND DISCUSSION

Weather

The crop experienced a higher maximum temperature during the months of December, January, February and March in the year 2017-18 compared to the year 2018-19 by 1.2, 0.6, 3.6 and 4.6 ºC, respectively (Table 1). During 2018-19, the crop received a higher amount of total rainfall (144.1 mm) than 2017-18 (26 mm). Therefore the mean RH during the year 2018-19 (74.7%) was also higher than that of the year 2017-18 (62.1%) and simultaneously the average sunshine hour was higher in the year 2017-18 (5.93 hr) than 2018-19 (5.33 hr).

Bulk density

The bulk density (BD) increased with increasing soil depth. Although there was no significant difference in BD due to CT and NT in the surface layers (0-15 cm), the BD under NT was decreased by 1.7, 2.0 and 3.7% than that of CT at 15-30 (1.72 Mg ha^{-1}), 30-45 (1.76 Mg ha^{-1}) and 45-60 cm (1.77 Mg ha^{-1}) soil depth, respectively suggesting that NT can reduce the subsurface compaction. Due to addition of crop residue mulch (CRM), BD was decreased by 4.3, 5.1 and 2.7% at 0-15, 15-30 and 30-45 cm soil depth compared to no mulch treatments. This may be attributed to higher earthworm activity, better porosity and presence of comparatively higher organic matter in mulch treatments (Acharya *et al.* 2005). It was observed that BD was negatively correlated with SOC (r=-0.502*).

Total porosity and air-filled porosity

The total porosity under NT increased by 3.1, 4.0 and 7.5% at 15-30, 30-45 and 45-60 cm soil depth, respectively over CT but at the surface layer (0-15 cm) no significant difference of total porosity could be observed due to tillage treatments. Application of CRM increased the total porosity by 6.5, 9.9 and 5.5% at 0-15, 15-30 and 30-45 cm soil depth than that of no-mulch treatment.

The air filled porosity was decreased with increase in soil depths. Aeration porosity under NT was higher than that of CT by 8.5, 15.7, 13.8 and 24.1% at 0-15, 15-30, 30-45 and 45-60 cm soil depth, respectively. The aeration porosity due to CRM was higher than that of no mulch treatments by 13, 28 and 18.4% at 0-15, 15-30 and 30-45 cm soils, respectively but at 45-60 cm soil depth aeration porosity under CRM decreased by 12.1% than no-mulch treatments. Lower aeration porosity observed under residue mulch in the lower layer may be due to higher moisture content in this layer. Thus, the aeration porosity was also higher under NT and crop residue mulch retention than that of CT and

Table 1 Prevailing monthly weather during wheat growth season for the year 2017-18 and 2018-19

Month	Max. temp. (°c)		Min. temp. (°c)		Mean RH (%)		Sunshine hours		Rainfall (mm)		Evaporation (mm)	
	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19
Nov	26.8	27.4	10.6	11.8	68.4	73.3	2.5	4.7	0	4	2.3	2.9
Dec	23	21.8	6.8	5	69.0	79.3	4.5	4.4	0	0.2	2.3	2
Jan	20.6	20	4.3	6.4	71.1	80.5	6.3	3.8	6	52	2.4	1.6
Feb	24.9	21.3	8.4	10	61.1	84.8	6.4	3.6	0	72.2	3.5	1.9
Mar	31.6	27	13.4	12.4	57.2	73.4	8.2	7.3	0	10	5.1	3.1
Apr	36.5	37.2	19.9	21.1	46.1	56.9	7.7	8.2	20	5.7	6	5.3

residue removal treatments, respectively. This finding is in agreement with Zhang *et al.* (2009).

Maximum water holding capacity

It was observed that there was no significant difference in maximum water holding capacity at 0-15 cm soil depth due to tillage treatments. However, under NT, maximum water holding capacity increased by 4.7, 4.2 and 21.3% at 15-30, 30-45 and 45-60 cm soil depths, respectively. Due to addition of CRM maximum water holding capacity increased by 3.4, 15.0 and 11.4% than no-mulch treatments at 0-15, 15-30 and 30-45 cm soil depth, respectively.

Saturated hydraulic conductivity (K_{sat})

The mean K_{sat} of soil were 2.11, 0.35, 0.5 and 0.26 cm h^{-1}, at 0-15, 15-30, 30-45 and 45-60 cm soil depth, respectively. So, the saturated hydraulic conductivity decreased with increase in soil depth. The saturated hydraulic conductivity of soil under NT was decreased by 59.6, 44.3, 76.2 and 23.8% at 0-15, 15-30, 30-45 and 45-60 cm soil depth, respectively than CT treatment. Decrease in saturated hydraulic conductivity in NT than CT is in agreement with Tripathi *et al.* (2007). Addition of crop residue mulch significantly increased the K_{sat} of soil by 100.7% than no mulch treatment at 0-15 cm soil depth. However, the effect of crop residue mulching on K_{sat} in the sub-soil layers were not consistent. Increased hydraulic conductivity due to application of residue in surface soil was also reported by Chan *et al.* (1993).

Soil penetration resistance

Soil penetration resistance increased with depth up to 30 cm soil depth. It was observed that there was a hard pan (penetration resistance >2MPa) between 10-35 cm soil depths at the CRI stage of wheat. There was decrease in soil penetration resistance under NT than that of CT at these depths (10-27 cm) indicating NT could reduce soil compaction at these depths. This finding is in agreement with Gathala *et al.* (2011). With addition of crop residue mulch, there was decrease in soil penetration resistance up to 210 mm than no-mulch treatments. Decrease in surface penetration resistance due to residue application is in agreement with Saha *et al.* (2010).

The mean weight diameter

The mean weight diameter (MWD) of soil decreased with increase in soil depth. Under NT, the mean weight diameter increased by 7.9% than CT at 0-15 cm soil depth whereas the effect of tillage on MWD was not consistent in the subsoil layers. Similar finding is also reported by Mondal *et al.* (2013). The soil aggregates were disrupted due to tillage operations under CT, which resulted in lower MWD than that of NT. This finding is in agreement with Mikha and Rice (2004). Addition of crop residue mulch increased the MWD by 3.4% than that of no-mulch treatments at 0-15 cm soil depth. However, the effect of crop residue mulch on MWD of subsoil was not consistent. This finding is in agreement with Acharya *et al.* (2005), who reported that organic mulching improved the MWD due to decomposition by microorganisms, which adds organic matter to soil. Though the effect of N management on soil mechanical properties was inconsistent but with increase in N dose the MWD of soil increased at 0-15 cm and 15-30cm soil depth. With the increase in N dose there was increased root growth. This root biomass might have contributed to better soil aggregation through soil organic matter. It was observed that MWD was positively correlated with SOC (r=0.694*)

Percent water stable aggregates (%WSA)

Under NT the %WSA was increased by 16.9, 16.4, 2.6 and 3.3% at 0-15, 15-30, 30-45 and 45-60 cm soil depth, respectively than that of CT treatments. However, the effect of crop residue mulch on %WSA was not consistent. The percent water stable aggregates increased significantly with increase in N dose up to 30 cm soil depth. However, in the lower layers the effects of N doses on %WSA was not consistent. Application of 180 and 120 kg N ha^{-1} increased the WSA by 6 and 1.6%, respectively than that of 60 kg N ha^{-1} at 0-15cm soil depth. Whereas, at 15-30 cm soil depth 180 and 120 kg N ha^{-1} increased the WSA by 10.3% and 3.4% than that of 60 kg N ha^{-1}, respectively.

Root growth parameters

It was observed that root length density (RLD) of wheat under NT was higher than that of CT by 16.9 and 7% at 0-15 and 15-30 cm soil depth, respectively. Application of CRM significantly improved RLD by 11.3 and 12.8% at 0-15 and 15-30 cm soil depth, respectively, root mass density (RMD) by 34.2% at 0-15 cm soil depth and root volume density (RVD) by 20.9 and 15.7% at 0-15 and 15-30cm, respectively over no mulch treatments. Effect of tillage on RMD and RVD of wheat was not statistically significant. Root surface area density (SAD) and root tip density (RTD) at 0-15 cm soil depth increased by 9.9 and 70.5% under NT and CRM than that of CT and no-mulch treatments, respectively. With the increase in N-dose RLD, RMD, RVD, SAD, RTD and root diameter (RD) increased significantly at 0-15 cm soil depth. Higher BD under CT than NT at 15-30 cm soil depth was responsible for lower RLD (7%) and higher root diameter (8.8%) in this depth. Similarly, higher BD under no-mulch treatment than that of CRM treatments led to higher RLD and lower root diameter under mulch treatments. Higher soil moisture storage under CRM (data not presented) also contributed for better root growth than no-mulch treatment. This finding proves the hypothesis that whenever root meets a compact layer its length decreases but diameter increases (Oussible *et al.* 1993).

Soil organic carbon

The average soil organic carbon (SOC) 0-15, 15-30, 30-45 and 45-60 cm soil depth was 3.8, 3.7, 2.3 and 2.1 g kg^{-1}, respectively. Under NT, SOC content at 0-15 cm soil depth was higher by 3.9% but at 15-30 and 45-60 cm soil depth SOC concentration in NT was lower than that of CT by 7% and 19.3%, respectively. This may be attributed to better aggregation under NT than CT in the surface layer and this finding is in agreement with Bescansa *et al.* (2006). The SOC concentration increased significantly by 11.5% in CRM treatments than no mulch treatments at 0-15 cm soil depth. Whereas, at 15-30 cm soil depth, SOC concentration under CRM was less than that of no mulch treatments by 7.6%. Addition of SOM through crop residue and improvement of soil structure was responsible for higher SOC concentration in the surface layer and this finding is in agreement with Iqbal *et al.* (2011) and Behaeen *et al.* (2018).

Grain and biomass yield of wheat

The grain yield (GY) and biomass yield (BY) of wheat increased by 32.1 and 45.3%, respectively, during the year 2018-19 than that of the year 2017-18 (Table 2). This may be attributed to higher rainfall received and lower maximum temperature experienced by the crop during 2018-19 than 2017-18. The GY and BY of wheat were not influenced significantly by tillage and CRM treatments during both the years of study. However, the GY and BY of wheat increased significantly with increase in N-levels. Application of 180 kg N ha^{-1} significantly increased grain yield than that of 120 and 60 kg N ha^{-1} by 7.2 and 35.5% during the year 2017-18 and by 10.1 and 41.1% during the year 2018-19, respectively. Application of 120 kg N ha^{-1} significantly increased the grain yield of wheat by 26.3 and 28.2% than that of 60 kg N ha^{-1} during the year 2017-18 and 2018-19, respectively. This finding is in agreement with Lopez-Bellido *et al.* (1998). However, Jat *et al.* (2014) reported that there was improvement in wheat yield from second year onwards under conservation agriculture than CT in a maize-wheat systems, whereas Zhang *et al.* (2009), reported that yield increased under conservation agriculture after three years of cropping. The tillage, residue and nitrogen interaction was not significant on grain and biomass yield of wheat in both the years.

Table 2 Grain and biomass yield of wheat (cv HD 2926) as influenced by tillage, residue and nitrogen management

Treatment	Grain yield (kg ha^{-1})		Biomass yield (kg ha^{-1})	
	2017-18	2018-19	2017-18	2018-19
Effect of tillage				
CT	2778 ^{A}	3444 ^{A}	6778 ^{A}	9624 ^{A}
NT	2577 ^{A}	3630 ^{A}	6822 ^{A}	10141 ^{A}
Effect of residues				
R_0	2623 ^{A}	3530 ^{A}	6794 ^{A}	9869 ^{A}
R_+	2732 ^{A}	3545 ^{A}	6806 ^{A}	9896 ^{A}
Effect of nitrogen				
N_{60}	2220^{C}	2873^{C}	5675^{C}	8320^{C}
N_{120}	2805^{B}	3684^{B}	7017^{B}	10258^{B}
N_{180}	3008^{A}	4054^{A}	7708^{A}	11069^{A}
Effect of Tillage ×Residue × Nitrogen				
CTR_0N_{60}	2133 ^{a}	2783 ^{a}	5500 ^{a}	8500 ^{a}
CTR_0N_{120}	2901 ^{a}	3256 ^{a}	7000 ^{a}	9728 ^{a}
CTR_0N_{180}	3027 ^{a}	3978 ^{a}	7500 ^{a}	10309 ^{a}
CTR_+N_{60}	2457 ^{a}	3015 ^{a}	6000 ^{a}	8471 ^{a}
CTR_+N_{120}	2951 ^{a}	3729 ^{a}	7000 ^{a}	9696 ^{a}
CTR_+N_{180}	3201 ^{a}	3902 ^{a}	7667 ^{a}	11038 ^{a}
NTR_0N_{60}	2118 ^{a}	2698 ^{a}	5267 ^{a}	7663 ^{a}
NTR_0N_{120}	2683 ^{a}	4095 ^{a}	7333 ^{a}	11335 ^{a}
NTR_0N_{180}	2879 ^{a}	4366 ^{a}	8167 ^{a}	11678 ^{a}
NTR_+N_{60}	2171 ^{a}	2996 ^{a}	5933 ^{a}	8646 ^{a}
NTR_+N_{120}	2685 ^{a}	3656 ^{a}	6733 ^{a}	10273 ^{a}
NTR_+N_{180}	2926 ^{a}	3971 ^{a}	7500 ^{a}	11249 ^{a}

Values in a column followed by same letters are not significantly different at $p<0.05$ as per DMRT ;The uppercase letters and the lower case letters are used for comparing main plot and subplot effects, respectively

Conclusions

Thus from this study it may be concluded that no tillage and residue retention practices significantly improved the hydrophysical and mechanical properties of soil, *viz.* bulk density, mean weight diameter, saturated hydraulic conductivity, soil penetration resistance and organic matter status of soil. These led to better root growth in these treatments. However, the improved physical properties under no tillage and residue management was not reflected in the grain and biomass yield of wheat. With the increase in nitrogen dose root growth and grain yield of wheat increased significantly. Thus conservation agricultural practices can be an effective energy efficient strategy for improving the soil physical health, carbon accumulation and root growth without any significant reduction in grain yield of wheat compared to conventional tillage in sandy loam soils of semi-arid environment.

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