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Research Article

Soil Physical Characteristics, Productivity and Input Use Efficiency of Wheat (*Triticum aestivum*) as Affected by Different Tillage, Residue Mulch and Nitrogen Management in Maize-Wheat Cropping System

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ABSTRACT

Excessive tillage in conventional agriculture systems causes degradation of soil health and thus adversely affects the crop growth and productivity. On the other hand, adoption of conservation agriculture practices involving no-tillage, crop residue mulch and crop rotation can address this problem. In this backdrop, a long term field experiment was conducted to assess the effect of different tillage, residue and nitrogen management practices on soil physical health, grain and biomass yield and input use efficiency of wheat. It was observed that bulk density under no tillage (NT) (1.53 Mg/m^3) at 0-15 cm soil depth was higher than that of conventional tillage (CT) (1.46 Mg/m^3) by 4.8% whereas the bulk density under crop residue mulch was less than that of no mulch treatment by 1.4% at 0-15 cm soil depth. The MWD at 5-15 cm soil depth under NT was significantly higher than that of CT by 8.5%. Similarly, at 0-5 cm soil depth, MWD under crop residue mulching were significantly higher than that of no mulched condition by 16.9%. Effect of tillage and residue treatment on grain yield, biomass yield and partial factor productivity of nitrogen was not statistically significant. However, grain and biomass yield and water use efficiency of wheat increased but partial factor productivity of N decreased significantly with the increase in nitrogen dose. So, wheat may be grown under no tillage with crop residue mulch and 150% of the recommended dose of nitrogen for improving soil physical health, and crop productivity and water use efficiency without any significant reduction in yield compared to conventional tillage practice.

Key words: Wheat, Conventional tillage, No tillage, Soil physical properties, Partial factor productivity of N, Water use efficiency

Introduction

The overwhelming interest in agricultural sustainability is attributed to several challenges being faced by present day agriculture, such as intensive tillage operation, excessive fertilizer application, risks of environmental pollution and degradation of soil and water resources. Minimum tillage and residue application favourably influence soil properties, environment quality, and crop productivity (Ogban *et al*., 2008; Kumar *et*

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al., 2014). Conservation agriculture (CA) practices involving reduced tillage, residue retention and crop rotation has emerged as a paradigm shift in agricultural practices having favourable effect on soil health, carbon sequestration and sustainable agricultural production and mitigation of climate change (Naresh *et al.*, 2016). In the world, 125 Mha area is under CA practices and among this maximum area is found in South America (45%) (FAO, 2011; Saad *et al.*, 2016). However, in India only 1.5 Mha is under conservation agriculture practice (Kassam *et al.*, 2018). It is a resource saving technology, which ensures efficient utilization of water and nutrients and improves the soil biological, physical and chemical properties through minimal soil disturbance, maintenance of a permanent soil cover and use of varied crop rotations (Farooq *et al.*, 2011).Effects of conservation tillage on soil properties vary and these variations depend on the particular conservation agricultural system chosen, soil type, agroclimatic region and also the cropping system followed. CA system, which maintain high surface soil coverage, have resulted in significant improvement in soil properties, especially in the upper few centimeters (Anikwe and Ubochi, 2007), which influence crop productivity (Lal, 1993). Tillage impact on crop yield is attributed to its effect on soil quality, root growth (Boone and Veen, 1994), and water and nutrient use efficiencies (Davis, 1994).Conservation agriculture reduced soil loss due to enhanced aggregate stability and the protective effect of crop residues left over the soil (Sanderson *et al.*, 2013; Vanlauwe *et al.*, 2014). It is more productive as compared to conventional tillage because it improves soil quality and water use efficiency (Samarajeewa *et al.*, 2006; Brunel *et al.*, 2013). It may temporarily have some adverse impact on soil physical properties like increased bulk density, lower soil temperatures and decreased oxygen diffusion rates (Lampurlanes *et al.*, 2001) during initial years of adoption. However, in the long run conservation tillage practices have been reported to increase the organic matter content of the surface layer, improves microbial and earthworm activity and consequently reduce the bulk density of the soil (Lal *et al.*, 1994). CA practices also lead to sustainable enhancement in the water use efficiency by increasing infiltration and soil water retention, and reducing evaporation loss, as well as by improving nutrient balances and their availability (Dahiya *et al.*, 2007; Govaerts *et al.*, 2007; Verhulst *et al.*, 2010). Keeping this in view, the present study was undertaken to assess the short-term impact of conservation agriculture practices on soil physical health, yield and water and nitrogen use efficiency of wheat in a sandy loam soil.

Materials and Methods

Experimental site

Field experiments were conducted on wheat during *rabi* 2016-17 and 2017-18 in the research farm of ICAR-Indian Agricultural Research Institute, New Delhi (28°35′N latitude, 77°12′E longitude and at an altitude of 228.16 m above mean sea level) as a part of an ongoing long term tillage experiment under maize-wheat cropping system (since 2014).

Climate

New Delhi has a sub-tropical semi-arid climate with dry hot summer and brief severe winter. The average monthly minimum and maximum temperature in January (the coldest month) ranged between 5.9 and 19.9°C. The corresponding temperature in May (the hottest month) ranged between 24.4 and 38.6°C. The average annual rainfall is 651 mm, out of which, 75% is received through south-west monsoon during July to September. The weather condition during crop growth period of the years 2016-17 and 2017-18 is depicted in Fig. 1.

Experimental details

The experiment was laid out in a split-split plot design, with two levels of tillage as main plot factor (Conventional tillage (CT) and No Tillage (NT)), two levels of residue as subplot factor (maize residue @ 5 t/ha (R+) and without residue (R0)), and three levels of nitrogen as sub-

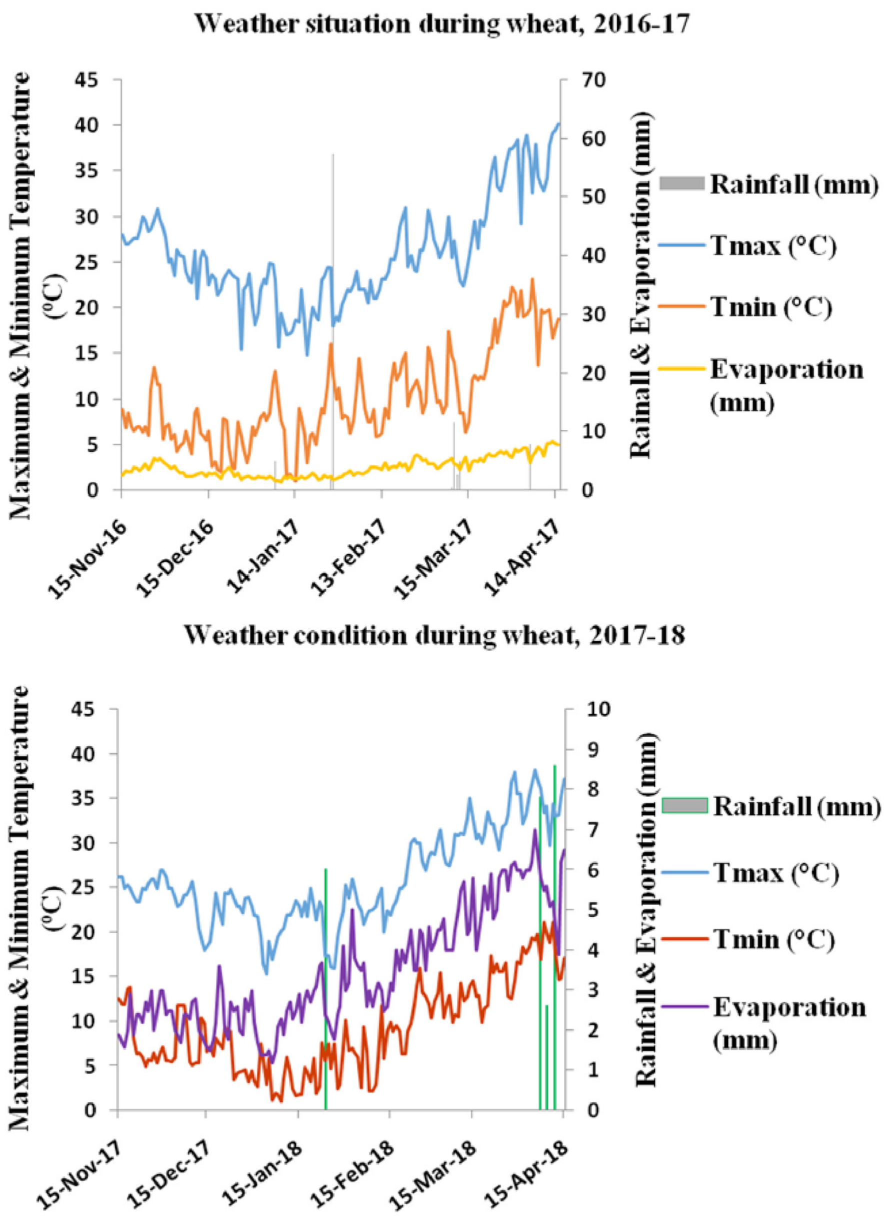

Fig. 1. Daily weather condition during wheat growth period of the years 2016-17 and 2017-18

sub plot factor (60, 120 and 180 kg N/ha, representing 50% (N60), 100% (N120) and 150% (N180) of the recommended dose of nitrogen (RDN) for wheat, respectively), replicated three times. Nitrogen was applied as urea in three splits *i.e.*, 50% at sowing, 25% at CRI stage and remaining 25% at flowering stage. All the plots received a uniform dose of 60 kg P_2O_5/ha as single super phosphate and 60 kg K_2O/ha as muriate of potash applied as basal dose at sowing. The sub-sub plot-size was 4.5 m × 5 m. Wheat crop (cv. HD 2967) was sown on 21st and 23rd November in 2016 and 2017, respectively by a tractor drawn no-till seed drill (at a depth of 4-5 cm) with a row spacing of 22.5 cm at a seed rate of 100 kg/ha and harvested on 7th April, 2017 and 16th April, 2018, respectively. In CT treatment, the plot was ploughed once with disc plough and once with duck-foot tine cultivator followed by leveling and sowing by seed drill whereas in NT treatments, the seed was directly sown using an inverted T type no-till seed drill. Maize residue was applied manually at the rate of 5 t/ha under R+ treatment after crown root initiation (CRI) stage. All the plots received five irrigations at critical growth stages *viz*., CRI, Tillering, Jointing, Flowering and Milk stage.

Measurements

Bulk density

Soil bulk density (BD) was determined by undisturbed core method (Veihmeyer and Hendrickson, 1948). For this purpose, a core cutter of 5.5 cm diameter and 15 cm height was used. Core cutter has an assembly of a sectional cylinder (core) of 5 cm internal diameter and 6 cm height with 2 rings of same diameter of 2 cm height on either side of it and was screwed to the collar of sampler (2.5 cm high) from the upper side. Cores with filled soil were dried at 105°C in the oven till constant weight and weighed. Bulk density (Mg m^{-3}) of soil was calculated using the formula:

$$BD = (x - y)/v \qquad \ldots(1)$$

where, x= weight of core with oven dry soil (g); y= weight of the core (g); v = volume of the core (cm^3)

Mean weight diameter and water stable aggregates

The aggregate size distribution of soil (0-5, 5-15 and 15-30 cm) was determined by wet sieving method using Yodder's apparatus (Yodder, 1936).The mean weight diameter (MWD) was calculated as an index of aggregation (Van Bavel, 1949) using the following formula (Kemper and Roseneau, 1986)

$$MWD = \Sigma xiwi \qquad \ldots(2)$$

where, w_i is the proportion of the weight of the aggregates retained over the sieves in relation to the whole soil and x_i is the mean diameter of the size class (mm).

Water-stable aggregates (WSA) were computed by adding the sand free aggregates of different size fractions (0.25-8 mm), and expressing them as percentage of the total weight of soil taken for analysis. Water stable aggregation for each size class was determined as,

$$WSA_i = [(W_a - W_c)/W_o] \times 100 \qquad \ldots(3)$$

where, W_a = weight of material on the sieve after wet sieving of size i; W_c = weight of sand fraction in size i; W_o = weight of aggregates placed on the sieve prior to wet sieving of size i. The sand fraction in each size group was determined by dispersing the aggregates using 5% Sodium Hexameta phosphate and sieving through the same size sieve.

Seasonal evapotranspiration

Soil moisture content was determined gravimetrically in the soil samples collected from 0-15, 15-30, 30-45, 45-60, 60-90 and 90-120 cm soil depths at 15 days intervals during crop growth. Seasonal evapotranspiration (ET) by wheat crop was computed using water balance method.

$$ET = P + I + C_p - D - R - \Delta S \qquad \ldots(4)$$

$$ET = P + I + C_p - D - (S_i - S_f) \qquad \ldots(5$$

where P is precipitation, I is depth of irrigation, C_p is contribution through capillary rise from the water table, D is deep percolation loss, R is runoff, ΔS is change in soil moisture storage in the profile, S_f is final moisture storage in the profile at harvest, S_i is initial moisture storage in the profile at sowing.

As the groundwater table was very deep (8–10 m depth), C_p was assumed to be negligible. There was no runoff (R) from the field plots as they were bunded to a sufficient height (40 cm height) and also no case of bund overflow was observed during the period of study. As soil moisture studies were made up to a soil depth of 120 cm and the profile was loamy with a clay loam layer having a high bulk density of 1.71–1.72 Mg m^{-3} below 60 cm, deep percolation out of the 120 cm profile (D) was assumed to be negligible (Pradhan *et al*., 2014a; Bandyopadhyay *et al*., 2009).

$$\text{So, } ET = P + I - (S_i - S_f) \qquad \ldots(6)$$

Water use efficiency and Partial factor productivity of nitrogen

Water use efficiency was computed using the following formulae

$$WUE = GY/ET \quad \ldots(7)$$

where, WUE = Water use efficiency (kg/ha-mm), GY = Grain yield (kg ha^{-1}) and ET = Evapotranspiration (mm)

Partial Factor Productivity of Nitrogen (PFPN) was computed as:

$$PFPN = GY/FN \quad \ldots(8)$$

where, FN is the dose of nitrogen fertilizer applied (kg N/ha).

Grain and biomass yield

For the measurement of grain and biomass yield, crop was harvested from two representative areas of one square meter each in the center of each plot after leaving the border area to avoid boundary effect. The biomass yield was recorded after air drying the sample. These samples were threshed using mechanical thresher. The grain yield was expressed on 14% moisture basis. Both the biomass and grain yield were expressed as kg ha^{-1}.

Statistical analysis

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

Bulk density

Soil bulk density did not vary significantly among different tillage, residue and nitrogen management practices (Fig. 2). However, it was observed that bulk density under no tillage (1.53 Mg/m^3) at 0-15 cm soil depth was numerically higher than that of conventional tillage (1.46 Mg/m^3) by 4.8% whereas at 15-30 cm soil depth bulk density under no tillage (1.66 Mg/m^3) was lower than that of conventional tillage (1.69 Mg/m^3) by 1.8%. Lower bulk density at surface soil under conventional tillage may be attributed to the loosening of soil due to tillage operation. Higher bulk density at surface soil and lower at subsurface soil under no tillage than conventional tillage has also been reported by Hati *et al*. (2014) and Bajpai and Tripathi (2000). The bulk density under crop residue mulch was less than that of no mulch treatment by 1.4% at 0-15 cm soil depth. Lower bulk density under mulched condition than that of un-mulched condition may be due to comparatively high organic matter in the mulched plots. The similar finding was also reported by Acharya *et al.* (2005).

Mean weight diameter and water stable aggregates

Mean weight diameter ranged from 0.73 to 1.17 mm (mean=1.00 mm), 0.74 to 1.07 mm

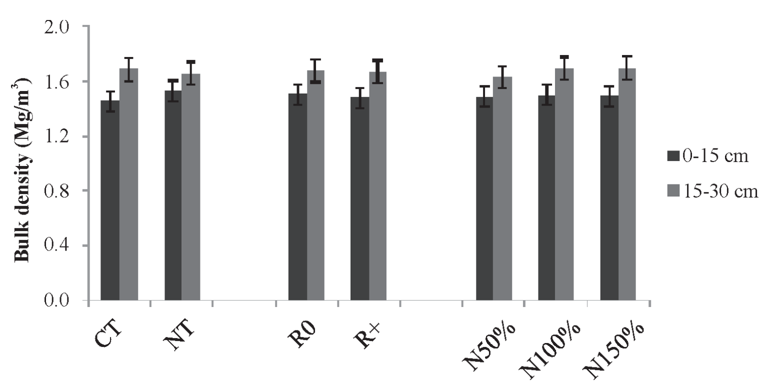

Fig. 2. Bulk density of soil at 0-15 and 15-30 cm soil depths as influenced by tillage, residue and nitrogen management

(mean=0.91mm) and 0.61 to 0.96 mm (mean=0.8 mm) for 0-5, 5-15 and 15-30 cm soil depths, respectively. It was observed that at 5-15 cm soil depth, mean weight diameter under NT was significantly higher than that of CT by 8.5% whereas due to application of maize residue mulch, the mean weight diameter at 0-5 cm soil increased significantly over no mulch treatment by 16.9% (Fig. 3). However, in other depths though the mean weight diameter under residue mulch was higher than no mulch treatment, but the effect was not statistically significant. Least soil disturbance may be attributed to the higher MWD under NT treatment. Higher MWD under NT than that of CT was also reported by Acar *et al*. (2018), Hati *et al*. (2015), Abid and Lal (2008). Higher MWD under residue mulch treatment may be attributed to organic matter addition and protection of soil aggregates from raindrop impact by crop residue mulch. The similar result was also reported by Rani *et al*. (2017). The effect of different nitrogen doses on mean weight diameter was statistically at par at 0-5, 5-15 and 15-30 cm soil depth. The percentage water stable aggregate ranged from 43.7 to 60.7% (mean=50.3%), 51.9 to 62.7% (mean=56.8%) and 46.0 to 65.9% (mean=57.2%) at 0-5, 5-15 and 15-30 cm soil depth, respectively. CT practices disrupt the soil aggregates and hence significantly reduced macro-aggregates with a significant redistribution of aggregates into micro-aggregates. The water stable aggregate was not influenced significantly due to different tillage, residue and nitrogen levels at 0-5, 5-15 and 15-30 cm soil depths.

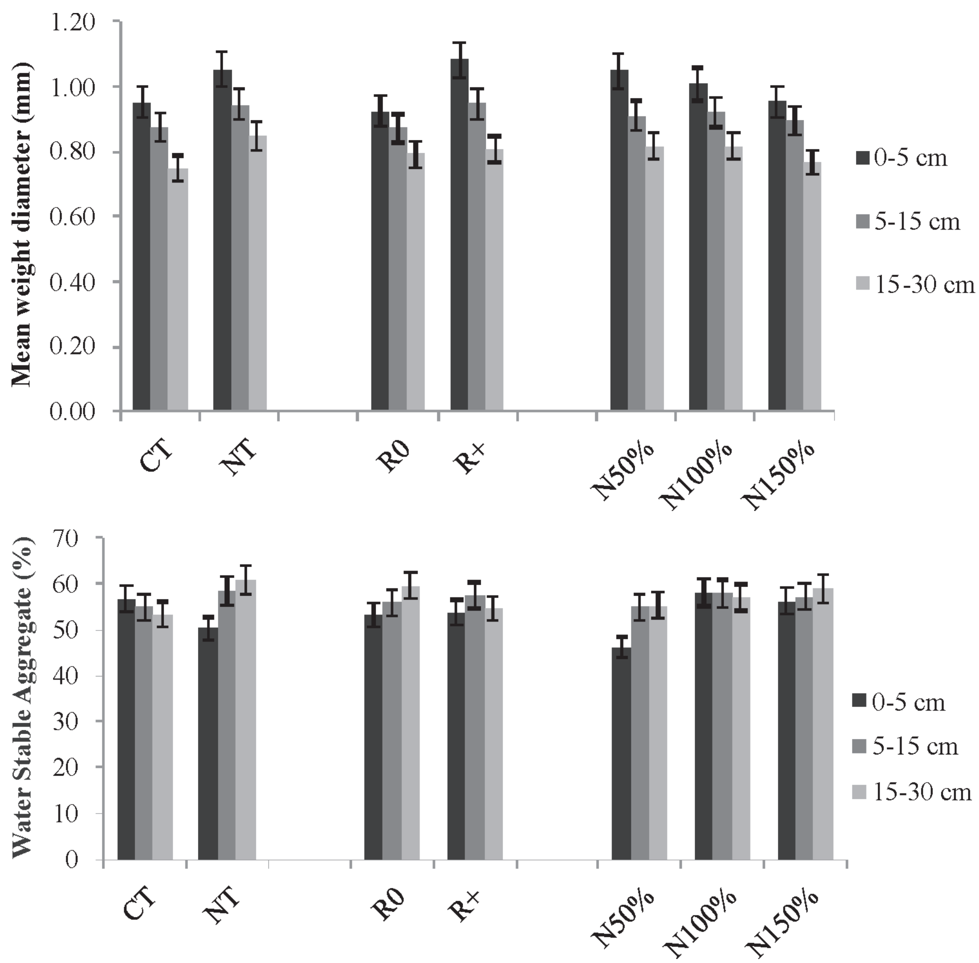

Fig. 3. Mean weight diameter and water stable aggregate percentage at 0-5, 5-15 and 15-30 cm soil depths as influenced by tillage, residue and nitrogen management

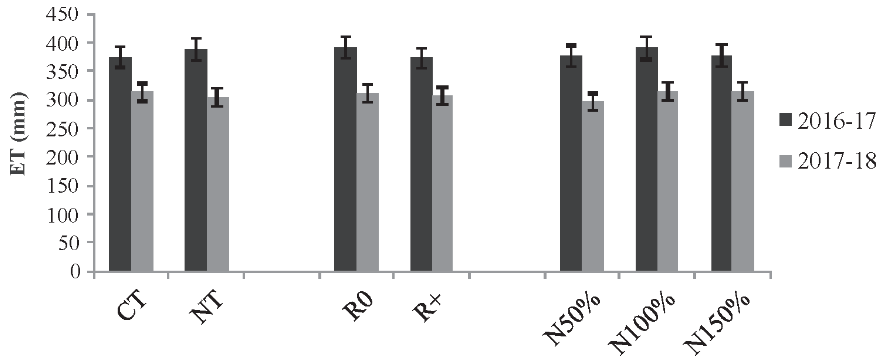

Fig. 4. Seasonal evapotranspiration of wheat during the year 2016-17 and 2017-18 as influenced by tillage, residue and nitrogen management

Seasonal evapotranspiration

The seasonal ET ranged between 347 to 424 mm (mean =382 mm) during the year 2016-17 and between 283 to 330 mm (mean=309 mm) during the year 2017-18 (Fig. 4). Higher rainfall received during 2016-17 (92.7 mm) than that of 2017-18 (26 mm) was responsible for higher ET during the year 2016-17. In both the years, ET decreased under mulching but the effect was not statistically significant. Lower ET under residue mulch treatment may be attributed to the lower soil temperature and lower evaporation loss. The similar finding was reported by Eberbach *et al.* (2011). There was no significant difference between CT and NT with respect to ET in both the years. Application of 100% RDN significantly increased ET than that of 50% RDN but there was no significant difference in the ET due to 100% and 150% RDN. Increased biomass resulting from high nitrogen fertilizer was responsible for higher transpiration.

Grain and biomass yield of wheat

It was observed that in both the years, the grain and biomass yield of wheat was not influenced significantly due to tillage and residue management but increased significantly with the increase in nitrogen levels (Table 1). Application of 180 kg N ha^{-1} significantly increased the grain yield of wheat than that of 120 kg N ha^{-1} and 60 kg N ha^{-1} by 10.6 and 36.2%, respectively during the year 2016-17 and 7.2 and 35.5%, respectively during the year 2017-18. Application of 120 kg N ha^{-1} significantly increased the grain yield of wheat than that of 60 kg N ha^{-1} by 23.1 and 26.3%, respectively during the year 2016-17 and 2017-18. With the application of 180 kg N ha^{-1} the biomass yield of wheat increased significantly over 120 kg N ha^{-1} and 60 kg N ha^{-1} by 10.7 and 37.9%, respectively during the year 2016-17 and 9.9 and 35.8%, respectively during the year 2017-18. Application of 120 kg N ha^{-1} significantly increased the biomass yield than that of 60 kg N ha^{-1} by 24.7 and 23.6%, respectively during the year 2016-17 and 2017-18. Increase in grain and biomass yield with the increase in nitrogen level has been reported by Bandyopadhyay *et al*. (2016), Habbib *et al*. (2017) and Qamar *et al*. (2013). Though the grain and biomass yield under mulched condition was numerically higher than that of no mulched condition, yet the effect was not statistically significant. Similar findings have been reported by Kumar and Yadav (2005). There was no significant difference between CT and NT with respect to grain and biomass yield of wheat. This may be attributed to the fact that the experiment was only four years old and hence the favourable changes in soil environment due to no tillage is yet to be achieved. This finding is in agreement with Kahlon (2014) and Rani *et al*. (2017).There was a reduction in grain and biomass yield of wheat in the year 2017-18 by 23.6 and 34.2%, respectively compared to the year 2016-17. It was mainly attributed to lower rainfall received in 2017-18 (26 mm) than that of 2016-17 (92.7 mm) and higher maximum temperature experienced by crop during the month

Table 1. Grain and biomass yield of wheat as influenced by tillage, residue and nitrogen management

Treatment	Grain yield (kg/ha)		Biomass yield (kg/ha)	
	2016-17	2017-18	2016-17	2017-18
		Effect of tillage		
CT	3349$^{A\#}$	2778^{A}	8980^{A}	6778^{A}
NT	3270^{A}	2577^{A}	9278^{A}	6822^{A}
		Effect of residues		
R0	3229^{A}	2623^{A}	8786^{A}	6794^{A}
R+	3390^{A}	2732^{A}	9472^{A}	6806^{A}
		Effect of Nitrogen		
N60	2763^{C}	2220^{C}	7553^{C}	5675^{C}
N120	3403^{B}	2805^{B}	9415^{B}	7017^{B}
N180	3763^{A}	3008^{A}	10419^{A}	7708^{A}
LSD (T)	NS	NS	NS	NS
LSD (R)	NS	NS	NS	NS
LSD (N)	311.6*	714.2	115.3	419.9

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; * Significant at $p<0.05$

of January, February and March of 2017-18 as compared to the year 2016-17.

Water use efficiency of wheat

The water use efficiency (WUE) of wheat ranged between 5.6 to 10.7 kg/ha-mm (mean=8.7 kg/ha-mm) during the year 2016-17 and between 6.8 to 9.9 kg/ha-mm (mean = 8.7 kg/ha-mm) during the year 2017-18 (Table 2). This was attributed to higher yield recorded in the year 2017-18 than that of the year 2016-17. The effect of tillage treatments on WUE of wheat was not significant in both the years. Though WUE of wheat increased due to crop residue mulch in both the years, this effect was statistically significant only during the low rainfall year 2017-18. This finding is in agreement with Das *et al*. (2016) and Kumar *et al.* (2016). With the increase in the N dose, WUE of wheat increased significantly in both the years. This shows synergistic interaction between water and N with respect to water productivity of wheat. This was attributed to significant increase in the grain yield of wheat with the increase in N level. Increase in WUE with increase in nitrogen fertilization was also reported by Zhang *et al.* (2017), Oweis *et al.* (2000) and Pandey *et al*. (2001). Tillage × residue × nitrogen interaction effect was not significant on WUE of wheat during the year 2016-17, but this effect was significant during the year 2017-18. The treatment conven-tional tillage with residue and 180 kg N/ha (CTR+N180) registered highest WUE during this year which is statistically at par with NTR+N180, NTR0N180 and CTR+N120.

Partial factor productivity of nitrogen of wheat

Partial factor productivity of nitrogen (PFPN) of wheat ranged between 19.0 to 51.8 kg grain/kg N (mean=31.8 kg grain/kg N) during the year 2016-17 and between 16.0 to 41.0 kg grain/kg N (mean=25.7 kg grain/kg N) during the year 2017-18 (Table 2). In both the years, effect of tillage, residue and tillage×residue×nitrogen interaction was not significant on PFPN of wheat. However, PFPN of wheat decreased significantly with the increase in N level in both the years. This is mainly attributed to the losses of nitrogen at higher level of N application and also due to the fact that yield of wheat did not increase linearly with the increase in nitrogen doses. Similar results have been reported by many workers (Bandyopadhyay *et al*., 2010; Chakrabarty *et al*.,

Table 2. Water use efficiency and Partial Factor Productivity of wheat as influenced by tillage, residue and nitrogen management

Treatment	Water use efficiency (kg/ha-mm)		Partial Factor Productivity of N (kg grain/kg N applied)	
	2016-17	2017-18	2016-17	2017-18
Effect of tillage				
CT	8.94[A#]	8.87[A]	32.91[A]	26.66[A]
NT	8.49[A]	8.47[A]	30.64[A]	24.76[A]
Effect of residues				
R0	8.34[A]	8.43[A]	30.84[A]	25.04[A]
R+	9.10[A]	8.91[B]	32.71[A]	26.37[A]
Effect of Nitrogen				
N60	7.43[C]	7.50[C]	46.07[A]	37.02[A]
N120	8.77[B]	8.90[B]	28.36[B]	23.38[B]
N180	9.97[A]	9.60[A]	20.90[C]	16.73[C]
LSD (T)	NS	NS	NS	NS
LSD(R)	NS	0.42*	NS	NS
LSD(N)	0.79	0.37	3.91	1.27

#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; *Significant at p<0.05

2010; Pradhan *et al*., 2013; Pradhan *et al*., 2014a,b; Vukovic *et al.,* 2008).

Conclusion

Thus, from this study it may be concluded that grain and biomass yield of wheat under no tillage were similar to that under conventional tillage practice, while it saved energy and time by reducing the frequency of tillage operations. The grain yield of wheat increased significantly with the increase in N level up to 150% of the recommended dose of nitrogen. Due to the retention of crop residues and minimum disturbance of the surface soil, mean weight diameter of the soil improved under NT compared to the conventional tillage system. Water use efficiency increased significantly whereas partial factor productivity of N decreased significantly with the increase in N level. Our findings suggests that no tillage to wheat with maize residue mulch at 5t/ha and150% recommended dose of nitrogen can be a viable alternative to conventional tillage for improving productivity and water use efficiency of wheat with concomitant improvement of physical properties in Inceptisols of IGP region.

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