Vol. 19, No. 1, pp. 46-57 (2019)
Journal of Agricultural Physics
ISSN 0973-032X
http://www.agrophysics.in

Research Article

Effect of Tillage, Residue and Nitrogen Management on Soil Water Dynamics, Grain Yield and Water Productivity of Wheat

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ABSTRACT

Field experiments were conducted in a sandy-loam soilin the research farm of the Indian Agricultural Research Institute, New Delhi during the years 2017-18 and 2018-19 to evaluate the effect of conventional tillage (CT) and no tillage (NT) both in the absence and presence of maize residue mulch @ 5 t ha^{-1} at three different levels of nitrogen fertilizer (60, 120 and 180 kg N ha^{-1}) on soilwater dynamics, soil water balance, grain yield and water productivity (WP) in a sandy-loam soil under wheat crop. It was found that the average profile moisture storage due to crop residue mulching (CRM) was higher than no mulch treatments during both the years under study. Under crop residue mulch deep percolation loss increased. Grain yield of wheat was not influenced by tillage and residue management but water productivity of wheat increased significantly due to crop residue mulching during both the years of study.The WP of wheat under CT in a dry year (2017-18) was significantly higher than that of NT. However,during the wet year (2018-19), the effect tillage on WP was not significant. Both grain yield and water productivity of wheat increased significantly with the increase in N dose.

Key words: Conventional tillage, No tillage, Soil water dynamics, Evapotranspiration, Water productivity

Introduction

Soil tillage practices are aimed to provide better soil physical environment to plants for growth and production. The potential adverse effects of conventional tillage (CT) systems in arable cropping systems, such as the loss of soil organic matter and degradation of soil structure, can be countered by using conservation tillage practices (Lal, 2008; He *et al*., 2009). No tillage has higher soil water storage than minimum tillage or conventional tillage practices (Fabrizzi *et al*., 2005; Wang *et al*., 2012; He *et al*., 2011; Rani *et al.,* 2017; Seeraj *et al.,* 2018). Crop residue mulching has beneficial impact on the soil moisture regime as it checks evaporation, improves infiltration capacity, soil moisture retention and facilitates condensation of water at night by decreasing soil temperature (Acharya *et al.,* 2005). It can also check the weed growth (Erenstein, 2002). Straw mulching on the other hand is also very effective in conserving soil moisture (Granovsky *et al*., 1994; Verma and Acharya, 2004). High residue application saves more water than low residue application (Unger, 1984; Sharma *et al*., 1998).In semi-arid regions with the shortage of water for agriculture due to competition from other sectors is the major issue for agricultural production. So efficient use of precipitation and irrigation water is essential to

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sustain agricultural production. Water loss through evaporation is also a serious constraint in these areas. From a wheat crop, soil evaporation can contribute to almost 30 to 60% water loss of total evapotranspiration (ET) (Cooper *et al*., 1983). During the early growth stage evaporation is the major pathway for soil water movement to the atmosphere (Yunusa *et al*., 1993). Therefore, it is important to enhance water productivity (WP), the amount of economic/biological yield produced per unit of water evapotranspired. Conservation tillage practices involving retention of residues reduces evaporation loss and encourages infiltration and hence improves water productivity. The beneficial effects of crop residue mulch in conserving water is mainly due to suppression of soil evaporation (Bond and Willis 1969), and it may be attributed to the reductions in wind speed and interception of solar radiation close to the ground. It can also check soil evaporation to a greater extent thus can be very effective under dry semi-arid conditions (Kitchen *et al.,* 1998), which ultimately improve the irrigation efficiency by reducing its frequency and amount. Conservation tillage or no tillage practices in combination with crop residue mulching improves the water use efficiency compared to conventional tillage practices (Alvarez and Steinbach, 2009; Kern *et al*., 1993; Su *et al*., 2007). The evapotranspiration under these systems was also lower than conventional tillage system (Alvarez and Steinbach, 2009). This effect was more pronounced in NT and under low rainfall years (De Vita *et al.,* 2007). From an experiment conducted in Punjab on the effect of rice straw mulching on ET of irrigated wheat, it was observed that the seasonal evaporation was reduced by 30-40% as a proportion of total ET in residue mulched treatments during the preanthesis periods of the crop and the transpiration of crops with these treatments was also on the higher side compared to the non-mulch treatments (Eberbach *et al*., 2011). Nitrogen application facilitates crop growth and hence influences the crop water use and water productivity. Though the effect of tillage, residue mulch and nitrogen management on soil water dynamics and water productivity has been studied in isolation, there is very limited study on the interactive effect of these factors on soil water dynamics and water productivity of wheat. In this back drop, the present study was conducted to optimizethe interaction of tillage, residue and nitrogen management for improving grain yield and water productivity of wheat.

Materials and Methods

The field experiment was conducted during *rabi* season of 2017-18 and 2018-19 at ICAR-IARI Research Farm (MB 4C), New Delhi (between 28°37' and 28°39' N latitude and 77°90' and 77°11' E longitude and at an altitude of 228.7 m above mean sea level). New Delhi has 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°C and19.9°C, respectively. The corresponding temperature in May (the hottest month) ranged between 24.4 and 38.6°C, respectively. The average annual rainfall is 651 mm, out of which, 75% is received through southwest monsoon from July to September.

The soil of the experimental site was sandy loam (Typic Haplustept) of Gangetic alluvial origin, very deep (>2 m), flat and well drained. Detailed soil physico-chemical characteristics were determined before initiating the experiment and the data are presented in table 1. It showed that the soil was slightly alkaline, non-saline, low in organic C and available N, and medium in available P and K content. The surface soil (0–15 cm) has saturated hydraulic conductivity 1.01 cm h^{-1}, saturated water content (0.41 m^3 m^{-3}), EC (1:2.5 soil/water suspension) 0.36 dS m^{-1}; organic C 4.2 g kg^{-1}; total N 0.032%; available (Olsen) P 7.1 kg ha^{-1}; available K 281.0 kg ha^{-1}; sand, silt and clay, 64.0, 16.8 and 19.2%, respectively. The bulk density varied from 1.58 Mg m^{-3} in the 0-15 cm layer to 1.72 Mg m^{-3} in the 90-120 cm layer. Available soil moisture content ranged from 24.6-28.3% (0.033 MPa) to 9.7-12.9% (1.50 MPa) in different layers of 0-120 cm soil depth.

Crop culture and treatment structure

Wheat crop (cv HD 2967) was sown on 24th November in both the years (2017 and 2018), at

Table 1. Soil properties of the experimental site

Depth (cm)	Bulk density (Mg m^{-3})	pH	EC (dS m^{-1})	Saturated hydraulic conductivity (cm h^{-1})	SOC (g kg^{-1})	Particle size distribution			Soil texture	Soil moisture constants (cm^3/cm^3)	
						Sand (%)	Silt (%)	Clay (%)		0.033 MPa	1.5 MPa
0-15	1.58	7.1	0.46	1.01	4.2	64.00	16.80	19.20	SL	0.254	0.101
15-30	1.61	7.2	0.24	0.82	2.2	64.40	10.72	24.88	SCL	0.269	0.112
30-60	1.64	7.5	0.25	0.71	1.6	63.84	10.00	26.16	SCL	0.283	0.129
60-90	1.71	7.5	0.25	0.49	1.2	59.84	10.00	30.16	SCL	0.277	0.110
90-120	1.72	7.7	0.30	0.39	1.1	53.68	13.44	32.88	SCL	0.247	0.097

4-5 cm soil depth at a row spacing of 22.5 cm by a tractor drawn no-till seed drill with a seed rate of 100 kg/ha. The crop was harvested on 16th April in both the years. The treatments comprising of two levels of tillage as main plot factor (CT and NT), two levels of residue as subplot factor (maize residue @ 5 t ha^{-1} (R+) and without residue (R0)), and three levels of Nitrogen as sub-sub plot factors (60, 120 and 180 kg ha^{-1}, representing 50% (N60), 100% (N120) and 150% (N180) of the recommended dose of nitrogen for wheat, respectively) were evaluated in a split-split plot design with three replications.The size of sub-sub plot was 4.5 m × 5 m.

The plots under Conventional tillage treatment was ploughed one time with disc plough and then once with duck-foot tine cultivator followed by land levelling and finally the seeds were sown by seed drill. Under No tillage treatments, the seed was sown directly using an inverted T type no-till seed drill. A spray of Glyphosate @ 10 mL/L was used to check the growth of weeds before sowing of wheat. In the Residue treatments (R+), the maize residue was applied manually at CRI stage at the rate of 5 t/ha which corresponds to 52% of field cover. Nitrogen was supplied as urea in three splits *i.e.*, 50%, 25% and 25% at sowing, CRI and flowering stage, respectively. Phosphorus and potassium was applied uniformly as basal application during sowing in all the plots as single super phosphate @ 60 kg P_2O_5/ha and as muriate of potash @ 60 kg K_2O/ha. Four irrigation of 6 cm depth water was applied in all the plots during critical growth stages of the crop *viz*., CRI, Tillering, Jointing, and Flowering. Weeding was done 3-4 times in all the plots to ensure weed free situations during crop growth stages.

Soil water content

Soil moisture dynamics was studied by determination of soil moisture content in the soil samples collected from 0-15, 15-30, 30-45, and 45-60, 60-90 and 90-120 cm soil depth at 15 days intervals during crop growth using thermo-gravimetric method.

Soil water flux calculation

Darcy's Equation was used for computing soil water flux. The relationship between volumetric moisture content and corresponding matric suction, (h *vs* θ) and volumetric moisture content and hydraulic conductivity (k *vs* θ) relationship already developed for the soil (Pradhan *et al*. 2010), was used for this purpose. The volumetric moisture content data was used to find out corresponding matric suction and unsaturated hydraulic conductivity from these relationships.

Soil water flux (q) was computed using Darcy-Buckingham relationship:

$$q = -k(\theta)\left(\frac{h_2 - h_1}{z_2 - z_1} + 1\right) \qquad \ldots(1)$$

Where k(θ) is the mean unsaturated hydraulic conductivity; h_1 and h_2 represent the matric suctions at depths z_1 and z_2.

Deep percolation loss was computed using soil water flux beyond 90 cm soil depth (75-105 cm).

Deep percolation loss (D) was computed as follows.

$$D = \left(\frac{q_i + q_f}{2} \right) \times t \qquad \ldots(2)$$

Where, q_i = Initial flux; q_f= Final flux after end of time period t.

Estimation of evapo-transpiration and Water Productivity

Evapo-transpiration (ET) by wheat crop was calculated by water balance method.

$$ET = P + I + Cp - D - R - \Delta S \qquad \ldots(3)$$

$$\text{or,} \quad ET = P + I + Cp - D - (S_f - S_i) \qquad \ldots(4)$$

Where P is amount of precipitation, I represents depth of irrigation, Cp is capillary rise from the underground water table, D is deep percolation loss, R is runoff, ΔS represents change in soil moisture storage in the profile, S_i and $S_f$are initial moisture storage during sowing and final moisture storage during harvest, respectively in the profile (0-90 cm).

In the calculation procedure Cp is neglected as the groundwater is very deep (6-8m). Deep percolation loss (D) was calculated by using Darcy equation as mentioned in the equation.

There was no runoff (R) loss from the field because all the plots were provided with bunds. So, the final form of the equation becomes

$$ET = P + I - D - (Sf - Si) \qquad \ldots(5)$$

Water Productivity (WP) was computed as per the following formula

$$WP = GY/ET \qquad \ldots(6)$$

Where WP = Water Productivity (kg m^{-3}), GY = Grain yield (kg ha^{-1}) and ET = Evapotranspiration (m^3 ha^{-1})

Penman and Monteith equation (Allen *et al.,* 1998) is used to calculate the Potential evapotranspiration using daily meteorological data.

Results and Discussion

Weather

Monthly average Maximum temperature, minimum temperature, maximum relative humidity, minimum relative humidity, bright sunshine hours, rainfall and evaporation during crop growth periods of wheat for the years 2017-18 and 2018-19 are presented in table 2. It was observed that the crop experienced a higher maximum temperature during the month 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°C, respectively. During the year 2017-18, the crop received a total rainfall of 26 mm whereas, during the year 2018-19 the crop received a total rain of 144.1 mm. The average sunshine hour during the year 2017-18 (5.93 hr) was higher than that of the year 2018-19 (5.33 hr). The mean RH during the year 2018-19 (74.7%) was higher than that of the year 2017-18 (62.1%).

Soil water dynamics

The storage temporal variation in the soil profile moisture in 0-120 cm soil depth during wheat growth as influenced by tillage, residue and nitrogen management for the years 2017-18 and 2018-19 is depicted in fig. 1 and 2, respectively. During the year 2018-19 the profile moisture storage was above 50% available water holding capacity for most of the time except at 51 and 130 days after sowing. Whereas, during the year 2017-18 the profile moisture storage was less than 50% available water capacity at 66 and 119 days after sowing. During the years 2017-18 under no-mulch treatments the profile moisture storage was less than 50% of available water holding capacity at 66 and 84 DAS whereas, under crop residue mulch it was at 50% available water holding capacity. Thus, due to application of crop residue mulch, there was increase in profile moisture storage than no-mulch treatments in both the years. This finding is in agreement with Acharya

Table 2. Monthly weather condition during wheat growth during the year 2017-18 and 2018-19

Month	Max. Temp.(°c)		Min. Temp.(°c)		Max. RH(%)		Min. 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	2017-18	2018-19
November	26.8	27.4	10.6	11.8	87.7	88.9	49	57.6	2.5	4.7	0.0	4.0	2.3	2.9
December	23.0	21.8	6.8	5.0	87.0	94.7	51	63.8	4.5	4.4	0.0	0.2	2.3	2.0
January	20.6	20.0	4.3	6.4	92.8	90.3	49.3	70.7	6.3	3.8	6.0	52.0	2.4	1.6
February	24.9	21.3	8.4	10.0	80.2	95.0	41.9	74.6	6.4	3.6	0.0	72.2	3.5	1.9
March	31.6	27.0	13.4	12.4	83.0	89.3	31.3	57.5	8.2	7.3	0.0	10.0	5.1	3.1
April	36.5	37.2	19.9	21.1	62.3	71.8	29.8	42.0	7.7	8.2	20.0	5.7	6.0	5.3

et al. (2005), who reported that CRM improves the soil moisture regime as it controls soil evaporation loss from the profile, increases infiltration and soil moisture retention and facilitates condensation of water near soil surface at night due to temperature reversals. Similar findings has also been reported by Granovsky *et al.* (1994); Sharma *et al.* (1998); Kitchen *et al.* (1998); Verma and Acharya (2004). The difference in profile moisture storage due to CT and NT was not significant in both the years of study. The N dose did not show any particular trend in profile moisture storage in both the years of study. The average profile moisture storage due to crop residue mulch was higher than no mulch treatment by 3.0 and 1.9% during the years 2017-18 and 2018-19, respectively.

Soil water balance components and seasonal ET

Soil water balance components and seasonal ET as influenced by tillage, crop residue mulch and nitrogen management for the year 2017-18 and 2018-19 is depicted in Fig. 3 and 4, respectively. During the year 2017-18 rainfall (2.6 cm) contribution to evapotranspiration was less compared to irrigation (24cm) and profile moisture contribution (3.8cm). Deep percolation loss ranged from 4.21cm (NT R0 N180) to 9.36 cm (CT R+ N60) with mean value of 6.6 cm. Seasonal ET ranged from 21.92 cm (CT R+ N60) to 25.28 cm (NT R0 N180) with mean value of 23.55 cm whereas, the potential evapo-transpiration (PET) as per Penman-Monteith method was 43.41cm.

Averaged over the crop residue mulch and N-management, ET under NT (24.13cm) was higher than CT (22.97 cm). Averaged over tillage and nitrogen levels, ET under crop residue mulch (23.25 cm) was similar to that of no-mulch treatments (23.86 cm). Deep percolation loss under CT (8.97 cm) was higher than that of NT (4.55 cm). Under crop residue mulch, deep percolation loss (7.0 cm) was higher than no-mulch treatments (6.52 cm). Averaged over tillage and residue management, ET due to 60, 120 and 180kg N/ha were 22.71, 23.93 and 24.02 cm, respectively and the corresponding deep per-

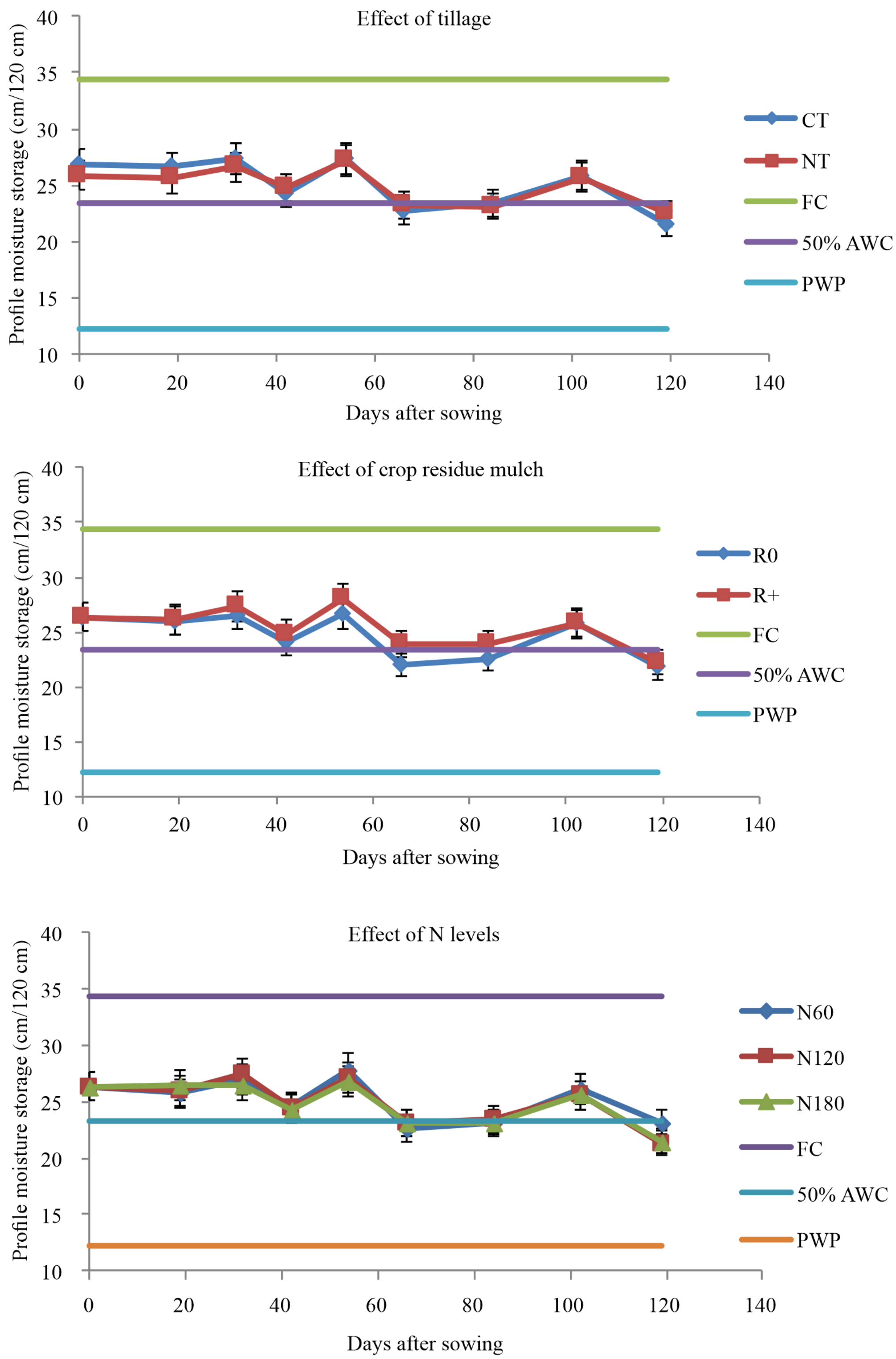

Fig. 1. Profile moisture storage during wheat, 2017-18 as influenced by (a) tillage, (b) residue and (c) nitrogen levels

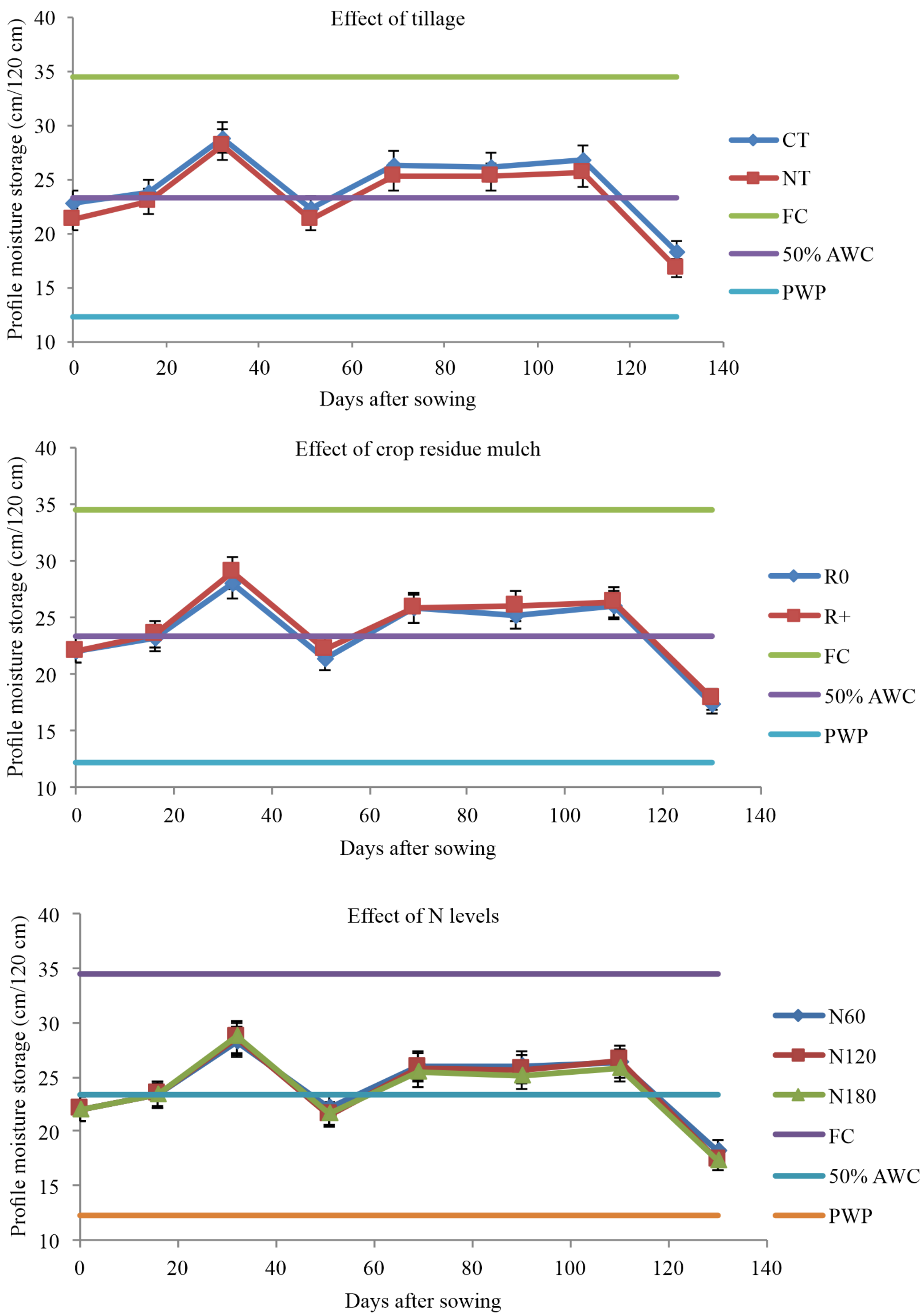

Fig. 2. Profile moisture storage during wheat, 2018-19 as influenced by (a) tillage, (b) residue and (c) nitrogen levels

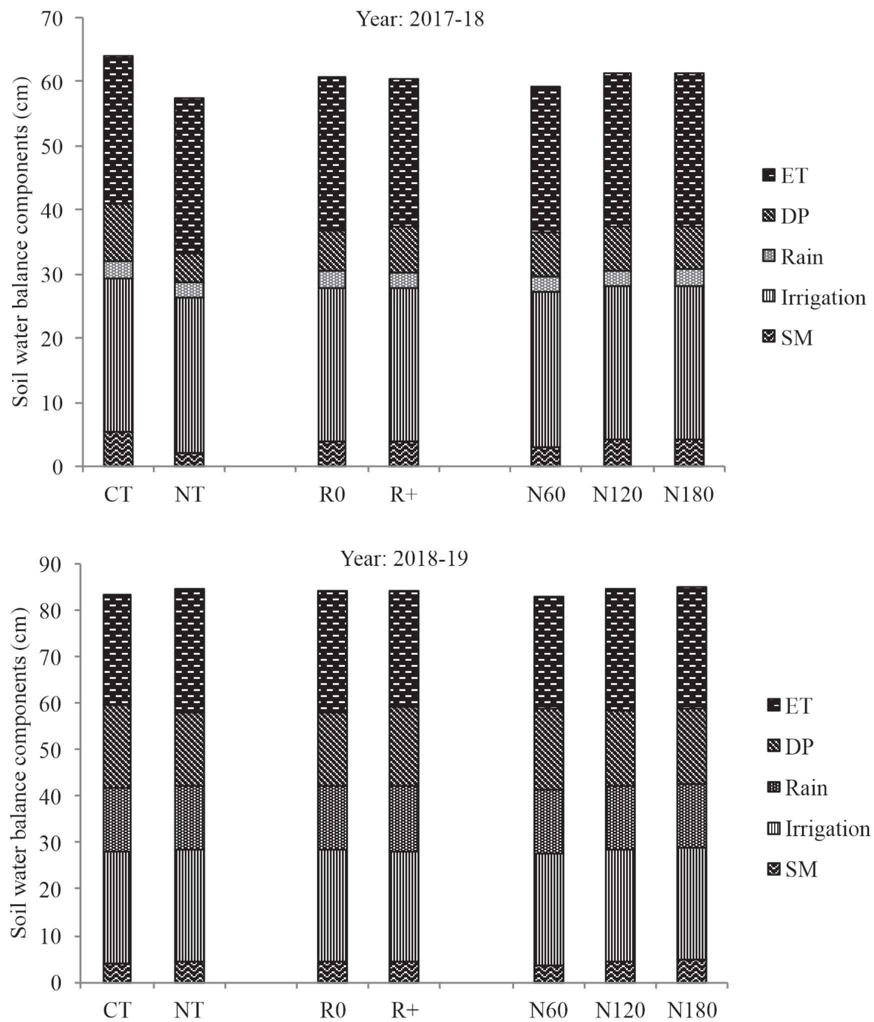

Fig. 3. Soil water balance components as influenced by tillage, residue and nitrogen management in wheat during the year 2017-18 and 2018-19

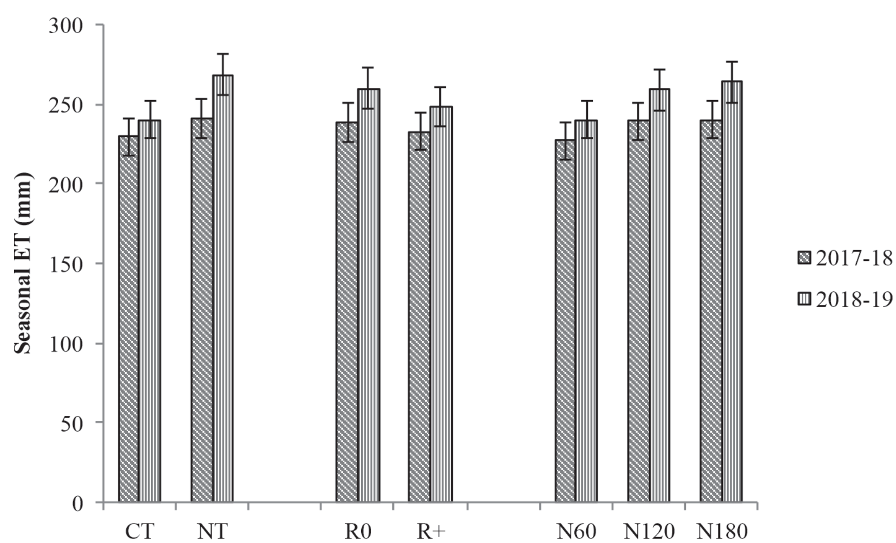

Fig. 4. Seasonal Evapo-transpiration of wheat as influenced by tillage, crop residue mulch and N levels at flowering stage during the year 2017-18 and 2018-19

colation loss were 6.89, 6.71 and 6.68 cm, respectively.

During the year 2018-19, the contribution of rainfall (total rainfall 13.8 cm and effective rainfall 12.52 cm) to ET was more than that of the year 2017-18. The contribution of irrigation and profile moisture depletion to ET were 24 and 4.25 cm, respectively. Deep percolation loss ranged from 15.16 (NT R0 N120) to 17.95 cm (CT R+ N60) with mean value of 16.48cm. The profile moisture contribution ranged from 2.36 cm (CT R0 N60) to 5.72 cm (NT R0 N180) with mean value of 4.25 cm. Seasonal ET ranged from 22.92 cm (CT R0 N60) to 28.36 cm (NT R0 N180) with mean value of 25.57cm whereas, the PET as per Penman-Monteith method was 38.99 cm. Averaged over crop residue mulch and N-management, the profile moisture contribution to soil water balance were 3.96 and 4.54 cm for CT and NT, respectively. Deep percolation loss under CT (17.44cm) was higher than that of NT (15.52 cm). However, ET under NT (26.82 cm) was higher than that of CT (24.32 cm) by 10.3%. Averaged over tillage and N-management, the profile moisture contribution to ET under crop residue mulch treatments (4.21 cm) was similar to that no mulch treatments (4.3 cm) but, deep percolation loss was more in case of crop residue mulch treatments (16.79 cm) than that of no mulch treatments (16.18 cm) by 3.8%. However, the seasonal ET under no mulch treatments (25.92 cm) was similar to that of crop residue mulching (25.22 cm). Averaged over tillage and residue management, the seasonal ET due to 60,120 and 180 kg N/ha were 24.76, 25.80 and 26.15cm, respectively and the corresponding deep percolation losses were 16.64, 16.41 and 16.40 cm, respectively.Seasonal ET during the year 2018-19 was higher than that of the year 2017-18 by 8.6%. Deep percolation loss during the year 2018-19 (16.48 cm) was also higher than that of the year 2017-18 (6.76 cm). This was attributed to higher rainfall received during 2018-19 than that of the year 2017-18. It was observed that seasonal ET under NT was higher than that of CT in both the years. However, Wang *et al.* (2012) reported that change in ET due to tillage treatments were not significant.

Grain yield and Water productivity (WP)

The grain yield of wheat as influenced by tillage, crop residue mulch and N-management for the year 2017-18 and 2018-19 is depicted presented in table 3. During the year 2017-18 grain yield of wheat ranged from 2133 (NTR0N60) to 3201 kg/ ha (CTR+N180) with a mean value of 2680 kg/ha. Whereas, the grain yield of wheat for the year 2018-19 ranged from 2698 (NTR0N60) to 4366 kg/ha (NTR0N180) with a mean value of 3540 kg/ha. So, there was anincrease in wheat grain yield by 32.1% during

Table 3. Grain yield and water productivity of wheat as influenced by tillage, residue and nitrogen management

Treatment	Grain yield (kg/ha)		Water productivity (kg/m^3)	
	2017-18	2018-19	2017-18	2018-19
Effect of tillage				
CT	2778 ^{A}	3444 ^{A}	1.21^A	1.41 ^{A}
NT	2577 ^{A}	3630 ^{A}	1.06^B	1.35 ^{A}
Effect of residues				
R_0	2623 ^{A}	3530 ^{A}	1.10^B	1.36^B
R_+	2732 ^{A}	3545 ^{A}	1.18^A	1.40^A
Effect of Nitrogen				
N_{60}	2220^C	2873^C	1.26^A	1.55^A
N_{120}	2805^B	3684^B	1.18^B	1.43^B
N_{180}	3008^A	4054^A	0.98^C	1.17^C
Effect of Tillage ×Residue × Nitrogen				
CTR_0N_{60}	2133 ^{a}	2783 ^{a}	0.94 ^{a}	1.21 ^{a}
CTR_0N_{120}	2901 ^{a}	3256 ^{a}	1.21 ^{a}	1.28 ^{a}
CTR_0N_{180}	3027 ^{a}	3978 ^{a}	1.30 ^{a}	1.63 ^{a}
CTR_+N_{60}	2457 ^{a}	3015 ^{a}	1.12 ^{a}	1.28 ^{a}
CTR_+N_{120}	2951 ^{a}	3729 ^{a}	1.30 ^{a}	1.50 ^{a}
CTR_+N_{180}	3201 ^{a}	3902 ^{a}	1.39 ^{a}	1.57 ^{a}
NTR_0N_{60}	2118 ^{a}	2698 ^{a}	0.93 ^{a}	0.97 ^{a}
NTR_0N_{120}	2683 ^{a}	4095 ^{a}	1.06 ^{a}	1.54 ^{a}
NTR_0N_{180}	2879 ^{a}	4366 ^{a}	1.15 ^{a}	1.54 ^{a}
NTR_+N_{60}	2171 ^{a}	2996 ^{a}	0.93 ^{a}	1.21 ^{a}
NTR_+N_{120}	2685 ^{a}	3656 ^{a}	1.14 ^{a}	1.39 ^{a}
NTR_+N_{180}	2926 ^{a}	3971 ^{a}	1.18 ^{a}	1.47 ^{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 the 2018-19 than that of the year 2017-18. This may be attributed to higher rainfall received and lower maximum temperature experienced by the crop during 2018-19 than 2017-18. Neither tillage nor CRM significantly influenced the grain yield of wheat during both the year of study. However, N-levels significantly influenced the grain yield of wheat in both the years of study. Application of 180 kg N/ha significantly increased grain yield by 7.2 and 35.5% than that of 120 kg N/ha and 60kg N/ha during the year 2017-18 and by 10.1 and 41.1% than that of 120kg N/ha and 60kg N/ha during the year 2018-19, respectively. Application of 120 kg N/ha significantly increased the grain yield of wheat by 26.3 and 28.2% than that of 60kg N/ha 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 an improvement in wheat yield from the second year onwards under conservation agriculture than CT in a Maize-Wheat systems, whereas, Zang *et al.* (2009) reported that yield increased under conservation agriculture after three years of cropping. On the other hand, Reiger *et al.* (2008) found 3% less wheat yield under NT than minimum and conventional tillage. Effect of tillage, residue and N-interaction was not significant on grain yield of wheat during both the years of study.

The WP of wheat during the year 2017-18 and 2018-19 is presented in table 3. During the year 2017-18, WP of wheat ranged from 0.93 (NTR0N60) to 1.39 kg/m^3 (CTR+N180) with a mean value of 1.14 kg/m^3. Averaged over residue mulch and N-management, WP under CT (1.21 kg/m^3) was significantly higher than that of NT (1.07 kg/m^3) by 13.5%. Similarly, WP under CRM (1.18 kg/m^3) was significantly higher than no mulch treatments (1.10 kg/m^3) by 7.1%. WP of wheat increased significantly with increase in N-doses. Application of 180 kg N/ha increased the WP significantly by 6.9 and 28.3% than that of 120 kg N/ha and 60 kg N/ha, respectively. Similarly, application of 120 kg N/ha significantly increased the WP by 20% than that of 60 kg N/ha. During the year 2018-19 the WP of wheat ranged from 0.97 kg/m^3 (NTR0N60) to 1.63 (CTR0N180) kg/m^3 with a mean value of 1.38 kg/m^3. Unlike the year 2017-18 there was no significant difference between CT and NT with respect to WP. However, WP of wheat due to CRM (1.40 kg/m^3) increased significantly over no-mulch treatment (1.36 kg/m^3) by 3.0%. This was mainly attributed to reduction in evaporation and higher profile moisture under CRM. It was reported that incorporation of residue or residue mulching into soil by tillage significantly improved water use efficiency (Su *et al.*, 2007; Jin *et al.*, 2014).WP of wheat increased significantly with increase in N-doses. Averaged over tillage and residue management, there was significant increase in WP with application of 180 kg N/ha by 8.8 and 32.9% than that of 120 kg N/ha and 60 kg N/ha, respectively. Similarly, application of 120 kg N/ha significantly increased the WP by 22.1% than that of 60 kg N/ha. This was mainly attributed to increase in crop yield with the increase in N dose. In both the years the interaction between tillage, residue and N-levels were not significant on WP of wheat. This shows the synergistic interaction between water and Nitrogen with respect to water use efficiency (WUE) of wheat. This finding is in agreement with Oweis *et al.* (2000); Pandey *et al.* (2001) and Pradhan *et al.* (2014).

Conclusions

Thus from this study it may be concluded that seasonal ET of wheat increased significantly with the increase in nitrogen dose. It was observed that seasonal ET under NT was higher than that of CT in both the years. Deep percolation loss under residue mulch was more than that of no mulch treatments in both the years. Grain yield of wheat was not influenced by tillage and residue management but water productivity of wheat increased significantly due to crop residue mulch during both the years of study. Water productivity of wheat under CT in a dry year (2017-18) was significantly higher than that of NT but during wet year (2018-19) the effect tillage on WP was not significant. Both grain yield and water productivity of wheat increased significantly with the increase in N dose. Therefore, wheat may be grown under no tillage with crop residue mulch to obtain higher water productivity in the Indogangetic plain region.

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Received: April 10, 2019; Accepted: June 13, 2019