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Effect of Tillage, Residue and Nitrogen Management on Soil Water Dynamics and Water Productivity of Wheat in an Inceptisol

Alka Rani, K.K. Bandyopadhyay*, P. Krishnan, A. Sarangi[1] and S.P. Datta[2]
Division of Agricultural Physics, ICAR-Indian Agricultural Research Institute, New Delhi, 110012

A field experiment was conducted during *rabi* season for two consecutive years (2014-15 and 2015-16) on wheat crop in a sandy loam soil (Typic Haplustept) at the research farm of Indian Agricultural Research Institute (IARI), New Delhi with the objective of studying soil water dynamics and water productivity of wheat under different tillage, residue and nitrogen (N) management practices. The treatments comprising of two levels of tillage as main plot *i.e.* conventional tillage (CT) and no tillage (NT), two levels of residue as subplot *i.e.* maize residue @ 5 t ha^{-1} (R_+) and without residue (R_0)), and three levels of N as sub-sub plot *i.e.* 60, 120 and 180 kg N ha^{-1}, representing 50% (N_{60}), 100% (N_{120}) and 150% (N_{180}) of the recommended dose of N for wheat, respectively were evaluated in a split-split plot design with three replications. Results showed that there was increase in the profile moisture storage by 7.7 per cent under crop residue mulch. The evaporative flux was lower by 23.9 per cent but deep percolation flux was higher by 8.3 per cent under mulching than without mulch treatment. The water productivity of wheat was not influenced by tillage but increased significantly with the increase in N levels. During high rainfall year, the effect of crop residue mulch on water productivity was not significant but it increased significantly during low rainfall year.

Key words: Wheat, conservation agriculture, evapotranspiration, water productivity

Wheat (*Triticum aestivum* L.) is the second most important cereal crop after rice in India, which is cultivated with the intensive agricultural practices. Irrigation sector is the largest consumer of fresh water. The growing population poses greater competition for water among the domestic, industrial and irrigation sectors. Therefore, there is greater challenge in the agricultural sector to attain high yield by minimal water use, which is possible by increasing crop water productivity. Excessive and indiscriminate tillage practices under conventional tillage (CT) management practices such as deep moldboard plowing, ridging, *etc*. can cause loss of soil organic carbon (SOC), degradation of soil structure, and extensive wind and water erosion leading to deterioration of soil health and low input use efficiency. Most, if not all, of these impeding factors would likely to be mitigated substantially by replacing CT with conservation tillage, or at least reduced tillage. Conservation agricultural (CA) practices 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). Alvarez and Steinbach (2009) found higher water infiltration rate due to higher aggregate stability under no-tillage (NT) system than under plow tillage system resulting in higher available water content in Argentine Pampas. Bissett and O'Leary (1996) reported that under long-term (8-10 years) conservation tillage (zero and sub-surface tillage with residue retention) infiltration of water was more as compared to CT (frequent plowing plus no residue retention) on a grey cracking clay and a sandy loam soil in south-eastern Australia. No-tillage has higher soil water storage than minimum tillage in wheat crop (Fabrizzi *et al.* 2005). Under stubble cropping, zero tillage and minimum tillage increased soil water in the 0-60 cm soil layer by 9 per cent and in the 0-120 cm soil layer by 6 per cent over CT in heavy clay soil (Lafond *et al.* 1992). According to Fuentes *et al.* (2003), the volumetric water content in the upper 1.5 m of soil was 5-10 per

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*Corresponding author (Email: kk.bandyopadhyay@gmail.com)
Present address
[1]Water Science and Technology, [2]Division of Soil Science and Agricultural Chemistry, ICAR-Indian Agricultural Research Institute, New Delhi, 110 012

cent more in NT as compared to CT due to greater infiltration and water retention, negligible surface runoff, and decreased evaporation because of lower soil temperature. The presence of residues in NT system cause lowering of soil temperature by increasing albedo at soil surface. Bragagnolo and Mielniczuk (1990) observed 10 per cent enhancement in soil moisture content by application of wheat straw at 7.5 t ha^{-1} over control (no residue). With the increase in the amount of crop residues over soil, evaporation rate decreases accordingly (Gill and Jalota 1996; Prihar *et al.* 1996). Alvarez and Steinbach (2009) reported that NT system covered with crop residues had higher infiltration rate, lower evapotranspiration, higher available water content and thus, higher water productivity than tillage system. However, how soil water dynamics is influenced by tillage and residue management under different level of nitrogen (N) has not been studied in detail. This information is useful for scheduling irrigation under CA practice. Therefore, the present study was undertaken to study the impact of different tillage, residue and N management on soil water dynamics and water productivity of wheat in an Inceptisol.

Materials and Methods

The field experiment was conducted on the research farm of ICAR-Indian Agricultural Research Institute, New Delhi with wheat (*Triticum aestivum* L.) as a test crop during the years 2014-15 and 2015-16. 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 physical and chemical characteristics before initiating the experiment are presented in table 1.

The treatments were evaluated in a split-split plot design with three replications. The treatment details are given in the table 2. Wheat crop (cv. HD 2967) was sown on 16th and 28th November in 2014 and 2015, 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^{-1} and harvested on 17th April 2015 and 5th April 2016, 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. In NT treatment, 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^{-1} under R_+ treatment at CRI stage. Nitrogen was supplied as urea in three splits *i.e.* 50% at sowing, 25% at CRI stage and remaining 25% at flowering stage. All the plots received five irrigations at critical growth stages *viz*., CRI, tillering, jointing, flowering and milk stage. Field was kept weed free by employing manual weeding 3-4 times during crop growth stages.

Soil water retention at 0.033 MPa (field capacity) and 1.50 MPa (wilting point) was determined by using pressure plate apparatus (Soil Moisture Equipment Corporation, USA) (Klute 1986). Bulk density (BD) was determined by core method.

Saturated hydraulic conductivity of the soil cores was calculated using Darcy's equation:

$$K_{sat} = (Q/At) \times (L/H) \quad \ldots(1)$$

where, K_{sat} is saturated hydraulic conductivity (cm h^{-1}), A is the cross sectional area (cm^2) of the core, Q

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 (%) Sand	Silt	Clay	Soil texture	Soil moisture constants ($cm^3\ cm^{-3}$) 0.033 MPa	1.5 MPa
0-15	1.58	7.1	0.46	1.01	4.2	64.0	16.8	19.2	SL	0.254	0.101
15-30	1.61	7.2	0.24	0.82	2.2	64.4	10.7	24.9	SCL	0.269	0.112
30-60	1.64	7.5	0.25	0.71	1.6	63.8	10.0	26.2	SCL	0.283	0.129
60-90	1.71	7.5	0.25	0.49	1.2	59.8	10.0	30.2	SCL	0.277	0.110
90-120	1.72	7.7	0.30	0.39	1.1	53.7	13.4	32.9	SCL	0.247	0.097

Table 2. Treatment details

Main plot: Tillage (2)	Sub-plot: Residue (2)	Sub-sub plot: Nitrogen level (3)
CT: Conventional tillage	R_+: With maize residue @ 5 t ha^{-1}	N_{60}: 60 kg N ha^{-1} (50% RDN)
NT: No tillage	R_0: Without residue	N_{120}: 120 kg N ha^{-1} (100% RDN)
		N_{180}: 180 kg N ha^{-1} (150% RDN)

RDN = Recommended dose of nitrogen

Table 3. Matric potential (h) (cm) and hydraulic conductivity (K) (cm day^{-1}) *vs* volumetric moisture content (θ) (cm^3 cm^{-3}) relationship of the study site

Soil depth (cm)	Relationship	R^2
	h *vs* θ	
0-15 cm	$y = 0.005x^{-3.13}$	0.98
15-30 cm	$y = 0.002x^{-3.50}$	0.97
30-60 cm	$y = 0.002x^{-3.43}$	0.99
60-90 cm	$y = 0.003x^{-3.67}$	0.99
90-120 cm	$y = 0.001x^{-4.19}$	0.99
	k *vs* θ	
0-15 cm	$129585.38\ (\theta)^{9.218}$	0.98
15-30 cm	$185540\ (\theta)^{9.949}$	0.97
30-60 cm	$134769\ (\theta)^{9.825}$	0.99
60-90 cm	$82240.52\ (\theta)^{10.30}$	0.99
90-120 cm	$169940.34\ (\theta)^{11.33}$	0.99

is the amount of water passing (cm^3) through the core, t is the time (h), Q/At is the water flux, and L is the length of the core and H is the total hydraulic head and H/L is the hydraulic head gradient. Soil moisture dynamics was studied by determination of soil moisture content gravimetrically in the soil samples collected from 0-15, 15-30, 30-45, 45-60, 60-90 and 90-120 cm soil depth at 15 days intervals during crop growth. Soil water flux was also computed using Darcy's law. Volumetric moisture content was used to find out corresponding matric suction (h) using soil moisture characteristics (h *vs* θ) and unsaturated hydraulic conductivity (k) using k *vs* θ relationship developed for this soil (Table 3) (Pradhan *et al*. 2010).

Evapotranspiration (ET) by wheat crop was computed by water balance method.

$ET = P + I + C_p - D - R - \Delta S$ …(2)

$ET = P + I + C_p - D - (S_f - S_i)$ …(3)

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.

There was no runoff (R) from the field as all the plots were provided with bunds. Soil water flux was computed using Darcy's law.

Soil water flux $q = -k(\theta)\ [\{(h_2-h_1)/(z_2-z_1)\} + 1]$ …(4)

where, h_1 and h_2 are matric potentials determined using h *vs* θ relationship at depths z_1 and z_2, respectively. When q is negative, there is upward flux and when q is positive, flux is downward.

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

Deep percolation loss, $D = [(q_i+q_f)/2] \times t$ …(5)

where, q_i = Initial flux; q_f= Final flux after end of time period 't'.

So, $ET = P + I - D - (S_f - S_i)$ …(6)

Water productivity was computed using the following formulae:

$WP = GY/ET$ …(7)

where, WP = Water productivity (kg ha^{-1} mm^{-1}), GY = Grain yield (kg ha^{-1}) and ET = Evapotranspiration (mm)

Results and Discussion

Weather

The monthly average maximum temperature, minimum temperature, maximum relative humidity, minimum relative humidity, bright sunshine hours, rainfall and evaporation during the growth period of wheat for the year 2014-15 and 2015-16 are presented in the table 4. It was observed that during the year 2015-16, the crop experienced higher maximum temperature during the months of December, January, March and April by 9.7, 22.4, 13.2 and 14.2 per cent, respectively than that of the year 2014-15. During the year 2014-15, the crop received total rainfall of 315.8 mm, whereas during the year 2015-16, the crop received only 2.8 mm of rainfall. The month of March was the wettest month for the year 2014-15 with the

Table 4. Monthly weather condition during wheat growth (2014-15 and 2015-16)

Month	Max. Temp. (°C)		Min. Temp. (°C)		Max. R.H. (%)		Min. R.H. (%)		Sunshine hours		Rainfall (mm)		Evaporation (mm)	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
November	28.3	28.1	10.6	11.9	84.3	90.3	37.6	47.4	5.7	2.4	0	2.2	3.1	3.4
December	20.6	22.6	6.7	6.1	93.8	93.9	59.0	49.7	4.4	3.5	26.4	0.0	2.1	2.8
January	16.9	20.7	6.8	6.5	96.0	95.9	68.8	59	2.3	2.4	35.8	0.0	1.9	2.5
February	24.6	24.6	10.6	8.1	91.9	88.7	48.0	53	5.1	5.7	0	0.0	2.6	3.0
March	27.2	30.8	13.1	13.7	90.8	88.2	51.0	54	6.9	6.8	201.8	0.6	3.7	5.1
April	33.9	38.7	19.2	19.1	76.6	67.7	43.4	45	7.2	7.8	51.8	0.0	6.8	8.2

rainfall of 201.8 mm. The average bright sunshine hours during the month of November and December in 2015-16 were less than that of 2014-15.

Soil water dynamics

The temporal variation in the soil profile moisture storage at 0-120 cm soil depth during wheat growth as influenced by tillage, residue mulch and N levels for the year 2014-15 and 2015-16 are depicted in fig. 1 and 2, respectively. The profile moisture storage during the year 2014-15 was above the 50% available water capacity (AWC) during the entire growth period except at 160 days after sowing (DAS) (Fig. 1). So, the crop was not under water stress for the entire growth period due to higher rainfall received during this year. However, during the year 2015-16, the profile moisture storage at 112 and 130 DAS was below the 50% AWC (Fig. 2). Further, at 17 and 60 DAS, soil moisture storage without crop residue mulch treatment was below 50% AWC. The evaporation loss during the year 2015-16 was higher than that of the year 2014-15 by 23.7 per cent. Thus, wheat crop during the year 2015-16 experienced moisture stress as compared to the year 2014-15. Profile moisture storage during the year 2014-15 was higher than that of 2015-16. This was due to higher

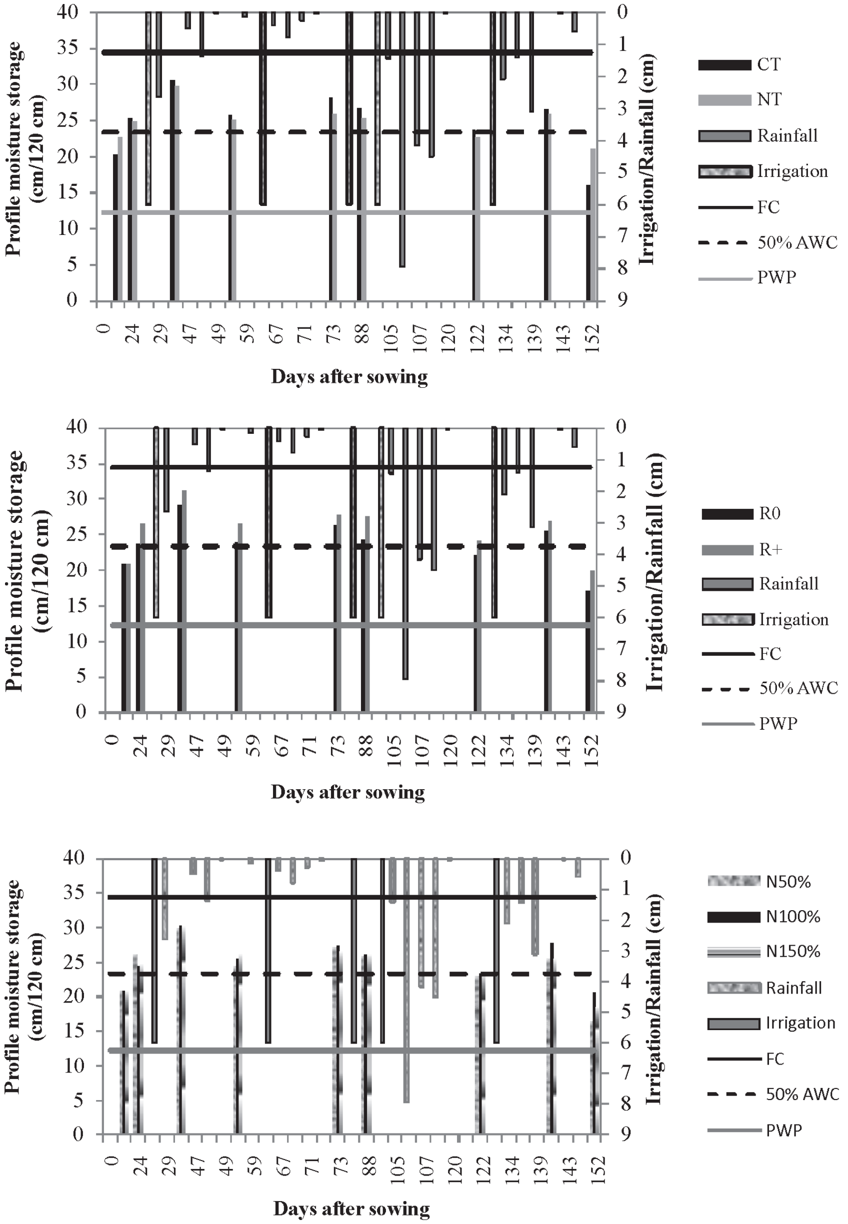

Fig. 1. Profile moisture storage during wheat (2014-15) as influenced by (a) tillage, (b) residue and (c) nitrogen levels

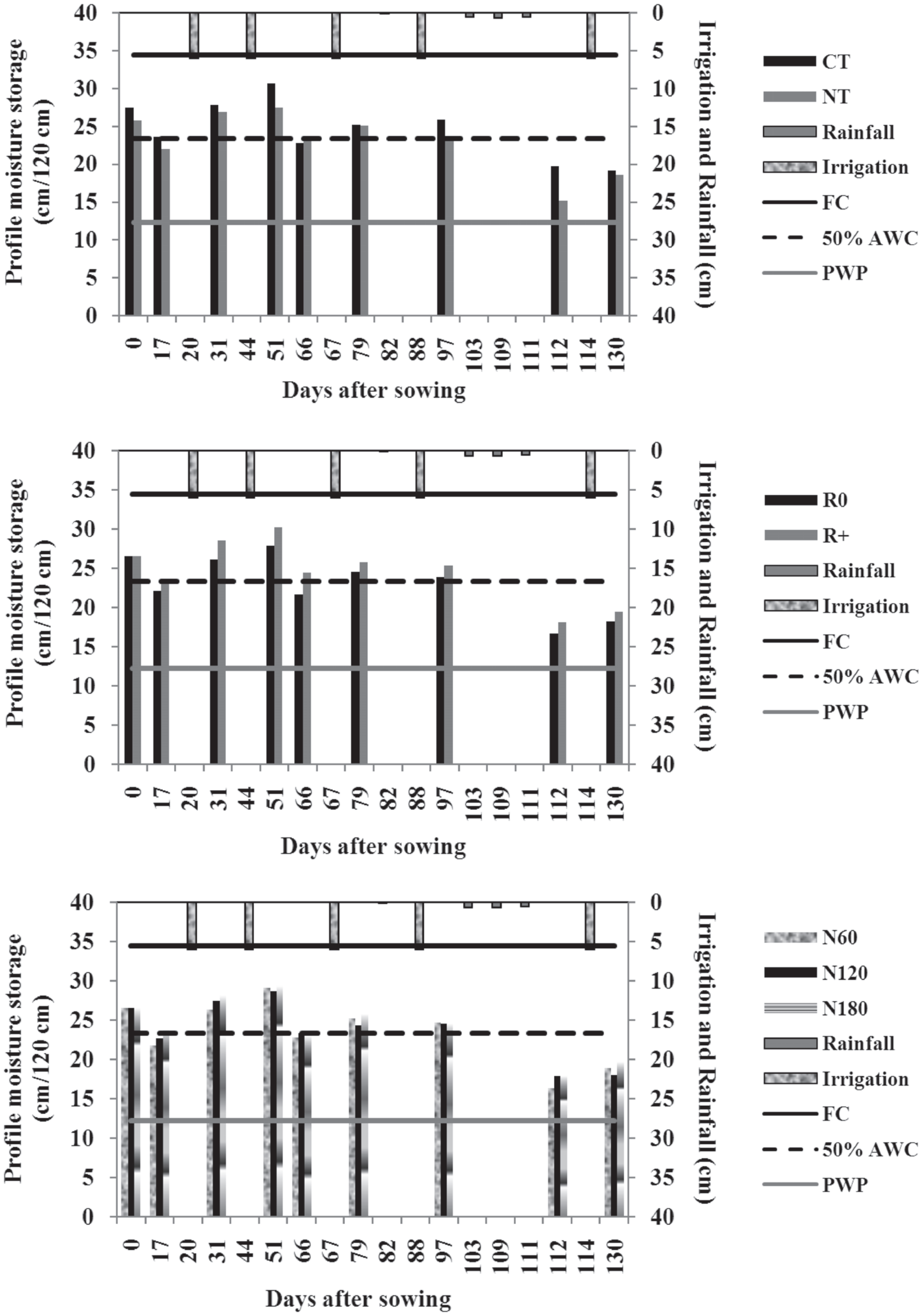

Fig. 2. Profile moisture storage during wheat (2015-16) as influenced by (a) tillage, (b) residue and (c) nitrogen levels

rainfall received in the year 2014-15 as compared to the year 2015-16. The difference in the profile moisture storage due to CT and NT was not statistically significant throughout the crop growth period in both the years of study. However, Fabrizzi *et al.* (2005) reported higher moisture storage under NT than that of minimum tillage in wheat crop. Fuentes *et al.* (2003) also reported that the volumetric water content in the top 1.5 m of soil was 5-10 per cent more in NT as compared to CT due to greater infiltration and water retention, negligible surface runoff, and decreased evaporation because of lower soil temperature. Similar soil moisture storage under CT and NT may be attributed to the fact that the

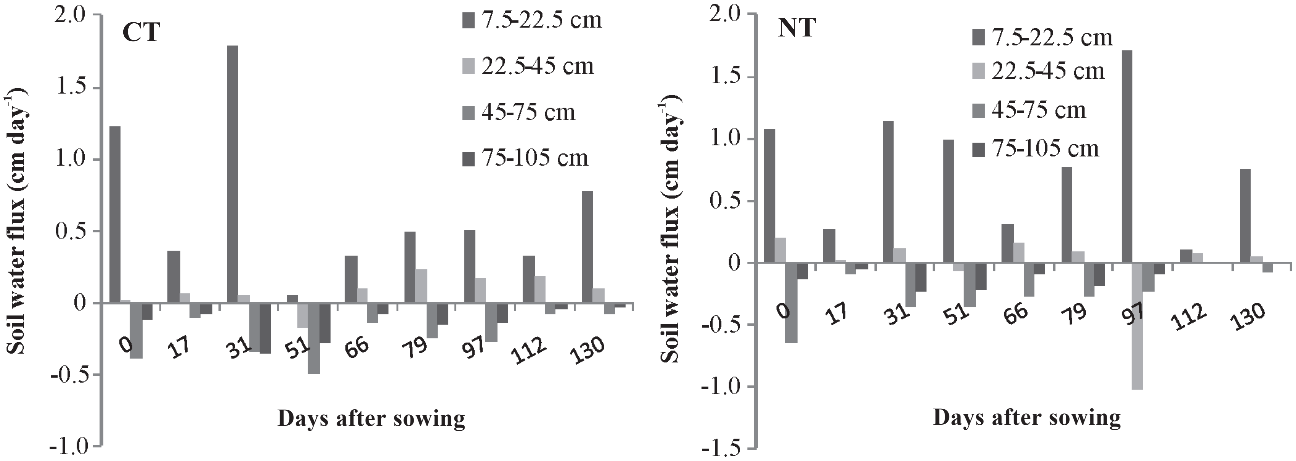

Fig. 3. Temporal variation in soil water fluxes at 7.5-22.5, 22.5-45, 45-75 and 75-105 cm soil depth as influenced by tillage in wheat (2015-16)

present experiment is only two years old. Profile moisture storage due to crop residue mulch was significantly higher than that of without crop residue mulch treatment by 8.5 and 7.0 per cent for the year 2014-15 and 2015-16, respectively. This finding is in agreement with Acharya *et al.* (2005), who reported that crop residue mulching has beneficial impact on the soil moisture regime as it controls evaporation loss from soil surface, increases infiltration and soil moisture retention and facilitates condensation of water near soil surface at night due to temperature reversals. Similar findings have also been reported by Unger (1984), Sharma *et al.* (1998), Kitchen *et al.* (1998) and Verma and Acharya (2004). Nitrogen levels did not show any particular trend with respect to profile moisture storage during both the years of study.

Soil water fluxes

Temporal variation in soil water fluxes at 7.5-22.5, 22.5-45, 45-75 and 75-105 cm soil depths as influenced by tillage, crop residue mulch and N management are depicted in fig. 3, 4 and 5, respectively. The positive values of flux indicate upward flux and the negative value indicate downward flux. Invariably, the soil water flux at 7.5-22.5 cm soil depth was positive indicating evaporation loss whereas soil water flux at 75-105 cm soil depth was negative indicating deep percolation loss. The mean evaporative flux at 7.5-22.5 cm soil depth under NT (0.79 cm day^{-1}) was higher than that of CT (0.65 cm day^{-1}) (Fig. 3). At 22.5-45 cm soil depth, the mean soil water flux under CT (0.08 cm day^{-1}) was positive indicating downward flux whereas under NT the mean soil water flux (-0.05 cm day^{-1}) was negative indicating upward flux. At 45-75 cm soil depth, though the soil water flux was downward both under CT and NT, the mean soil water flux under CT (-0.24 cm day^{-1}) was less than that of NT (-0.26 cm day^{-1}). At 75-105 cm soil depth, the soil water flux was downward both under CT and NT and the mean soil water flux under CT (-0.14 cm day^{-1}) was more than that under NT (-0.11 cm day^{-1}). So the mean deep percolation flux beyond the root zone under CT was higher than that of NT.

Similarly, at 7.5-22.5 cm soil depth, the soil water flux under no-mulch treatment (0.74 cm day^{-1}) was more than under mulching (0.56 cm day^{-1}) (Fig. 4). This is because application of mulch retards intensity of radiation and wind velocity on the surface which in turn decreases evaporation loss (Acharya *et al.* 2005). This finding is in agreement with Gill and Jalota (1996) and Prihar *et al.* (1996) as they reported that with increase in amount of crop residues, evaporation rate decreases. At 22.5-45 cm soil depth, the soil water flux under no-mulch treatment (0.07 cm day^{-1}) was less than that under mulching (0.08 cm day^{-1}). At 45-75 cm soil depth, the soil water flux both under mulching and without crop residue mulch treatment was downward and it was less under no-mulch treatment (-0.22 cm day^{-1}) than mulching (-0.27 cm day^{-1}). At 75-105 cm soil depth, the mean soil water flux under no-mulch treatment (-0.12 cm day^{-1}) was less than that under mulching (-0.13 cm day^{-1}). So the mean deep percolation loss beyond the root zone under mulching was more than that of no-mulch treatment. The reduction in initial evaporation promotes the process of internal drainage and, thereby, allows more water to move downward into the deeper parts of the profile. The deep percolation loss under

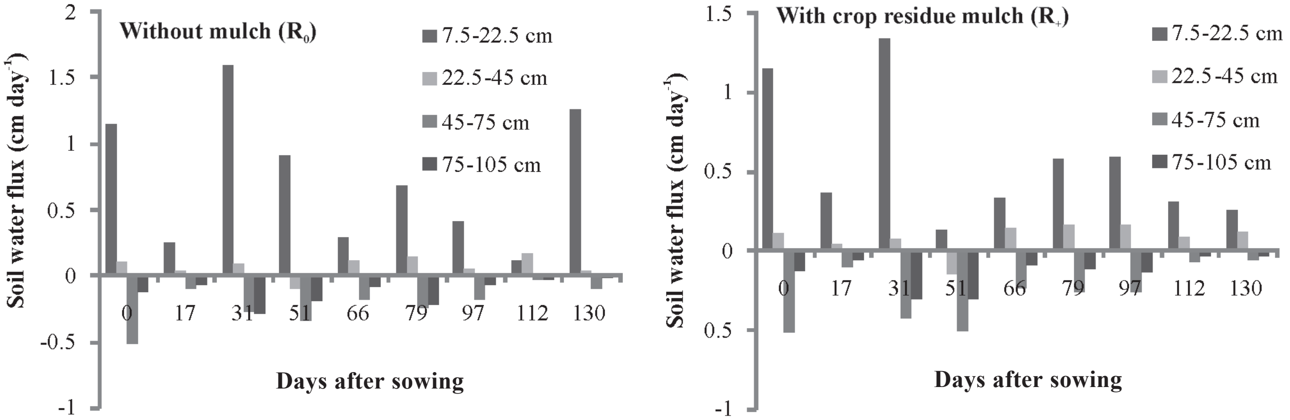

Fig. 4. Temporal variation in soil water fluxes as influenced by crop residue mulch at 7.5-22.5, 22.5-45, 45-75 and 75-105 cm soil depth in wheat (2015-16)

mulch treatment (17.7 cm) was more than that of without mulch (13.3 cm) treatment.

The mean soil water fluxes at 7.5-22.5 cm soil depth were 0.72, 0.57 and 0.59 cm day^{-1} due to application of 60, 120 and 180 kg N ha^{-1}, respectively (Fig. 5). So the mean evaporative flux at 7.5-22.5 cm soil depth decreased at higher N level. This was attributed to lower canopy coverage and shading at lower N levels. At 22.5-45 cm soil depth, the mean soil water fluxes were 0.03, 0.07 and 0.12 cm day^{-1}, due to application of 60, 120 and 180 kg N ha^{-1}, respectively. At 45-75 cm soil depth, the mean soil water fluxes due to application of 60, 120 and 180 kg N ha^{-1} were -0.26, -0.26 and -0.21 cm day^{-1},

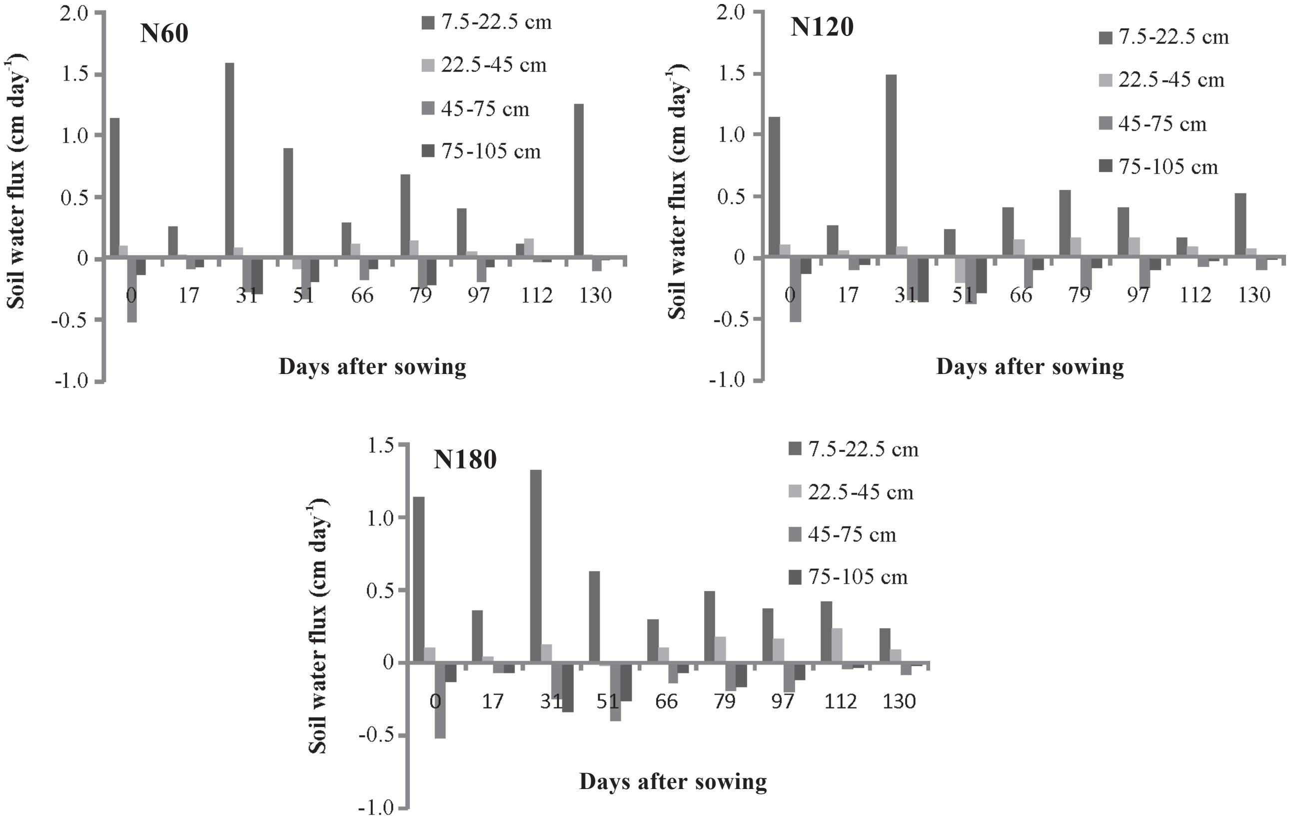

Fig. 5. Temporal variation in soil water fluxes as influenced by nitrogen levels at 7.5-22.5, 22.5-45, 45-75 and 75-105 cm soil depth in wheat (2015-16)

Table 5. Seasonal evapotranspiration and water productivity of wheat as influenced by tillage, residue and nitrogen management

Treatment	Seasonal evapotranspiration (mm)		Water productivity (kg ha^{-1}-mm)	
	2014-15	2015-16	2014-15	2015-16
Effect of tillage				
CT	386^{A}	221^{A}	11.6^{A}	14.4^{A}
NT	357^{A}	218^{A}	12.2^{A}	15.5^{A}
Effect of residues				
R$_0$	326^{A}	263^{A}	13.4^{A}	11.9^{B}
R$_+$	417^{A}	176^{A}	10.3^{A}	18.0^{A}
Effect of nitrogen				
N$_{60}$	388^{A}	208^{A}	9.78^{B}	13.1^{B}
N$_{120}$	357^{A}	222^{A}	12.8^{A}	15.3^{A}
N$_{180}$	370^{A}	229^{A}	13.0^{A}	16.4^{A}
Effect of tillage × residue × nitrogen				
CTR$_0$N$_{60}$	359^{a}	247^{a}	11.2^{bc}	11.5^{a}
CTR$_0$N$_{120}$	352^{a}	269^{a}	12.5^{b}	11.9^{a}
CTR$_0$N$_{180}$	379^{a}	276^{a}	12.3^{bc}	13.0^{a}
CTR$_+$N$_{60}$	444^{a}	173^{a}	9.08^{de}	13.9^{a}
CTR$_+$N$_{120}$	367^{a}	180^{a}	12.7^{b}	17.8^{a}
CTR$_+$N$_{180}$	414^{a}	183^{a}	11.7^{bcd}	18.2^{a}
NTR$_0$N$_{60}$	304^{a}	247^{a}	10.8^{bcde}	10.5^{a}
NTR$_0$N$_{120}$	282^{a}	265^{a}	16.5^{a}	11.4^{a}
NTR$_0$N$_{180}$	281^{a}	275^{a}	17.4^{a}	13.2^{a}
NTR$_+$N$_{60}$	443^{a}	164^{a}	8.06^{e}	16.5^{a}
NTR$_+$N$_{120}$	427^{a}	175^{a}	9.38^{cde}	20.2^{a}
NTR$_+$N$_{180}$	404^{a}	180^{a}	10.8^{bcde}	21.3^{a}
LSD (T)	NS	NS	NS	NS
LSD (R)	NS	NS	NS	2.4
LSD (N)	NS	NS	1.23*	1.8
LSD (T×R×N)	NS	NS	2.47*	NS

$^{\#}$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 $p<0.05$

respectively. At 75-105 cm soil depth, soil water fluxes were -0.10, -0.13 and -0.13 cm day^{-1}, respectively. Thus, with the increase in N dose, there was an increase in deep percolation loss but the difference was not significant.

Soil water balance components

Soil water balance components and evapotranspiration as influenced by tillage, crop residue mulch and N management for the year 2014-15 and 2015-16 are depicted in fig. 6. During the year 2014-15, rainfall (31.6 cm) was the major contributor to evapotranspiration followed by irrigation (30 cm) and soil moisture storage change (-4.1 cm in CTR$_+$N$_{120}$ to 7.4 cm in CTR$_0$N$_{120}$ with mean value of 1.5 cm). The deep percolation loss ranged from 20.6 cm (CTR$_0$N$_{180}$) to 31.5 cm (NTR$_+$N$_{60}$) with a mean value of 26.0 cm. There was no significant difference in deep percolation loss due to CT and NT. However, deep percolation loss under no-mulch treatment (20.7 cm) was less than mulch treatment (31.2 cm). Deep percolation loss due to 60, 120 and 180 kg N ha^{-1} were 26.1, 25.9 and 25.9 cm, respectively.

During the year 2015-16, irrigation (30 cm) was the major contributor followed by profile moisture change (7.24 cm) and rainfall (0.2 cm). The profile moisture contribution ranged from 4.0 cm (NTR$_+$N$_{60}$) to 10.5 cm (NTR$_0$N$_{120}$) with a mean value of 7.24 cm. Averaged over crop residue mulch and N management, profile moisture contribution to soil water balance were 7.4 and 7.1 cm under CT and NT, respectively. Averaged over tillage and N management, profile moisture contribution to soil water balance were 9.4 and 5.1 cm under without crop residue mulch and mulch treatment, respectively. Averaged over tillage and crop residue mulch management, profile moisture contribution to soil water balance due to 60, 120 and 180 kg N ha^{-1} were 4.0, 10.5 and 7.24 cm, respectively. Deep percolation loss ranged from 13.12 (CTR$_0$N$_{180}$) to 17.83 cm (CTR$_+$N$_{60}$) with a mean value of 15.5 cm. There was no significant difference in deep percolation loss (15.5 cm) due to CT and NT. Averaged over tillage and N levels, deep percolation loss under mulch treatment (17.7 cm) was higher than that of without crop residue mulch treatment (13.3 cm). Averaged over tillage and residue management, deep percolation loss due to application of 60, 120 and 180 kg N ha^{-1} were 15.7, 15.4 and 15.4 cm, respectively.

Seasonal Evapotranspiration and Water Productivity

Seasonal evapotranspiration and water productivity during the year 2014-15 and 2015-16 is presented in table 5. During the year 2014-15, seasonal evapotranspiration ranged from 281 mm (NTR$_0$N$_{180}$) to 444 mm (CTR$_+$N$_{60}$) with a mean value of 372 mm. The seasonal evapotranspiration during the year 2014-15 was higher than that of the year 2015-16 by 76.9 per cent. This was mainly attributed to higher rainfall received during the year 2014-15 than the year 2015-16. Averaged over crop residue mulch and N management, evapotranspiration under CT (386 mm) was higher than NT (357.0 mm) by 8.2 per cent. However, Alvarez and Steinbach (2009) reported that NT system covered with crop residues had higher infiltration rate, lower evapotranspiration, higher available water content and, thus, higher water use efficiency than CT system. Averaged over tillage

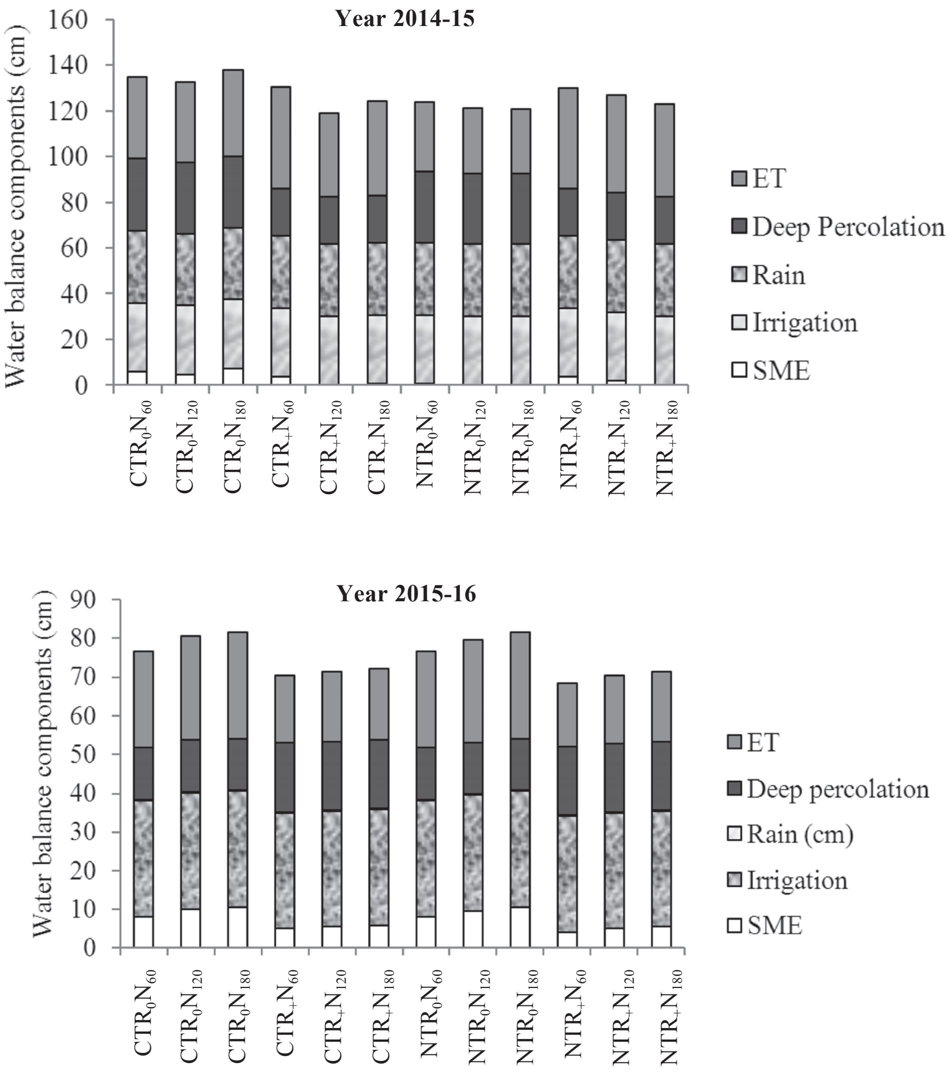

Fig. 6. Soil water balance components as influenced by tillage, residue and nitrogen management in wheat during 2014-15 and 2015-16

and N levels, evapotranspiration under crop residue mulch (417 mm) was higher than without crop residue mulch (326 mm) by 27.7 per cent. Averaged over tillage and residue management, evapotranspiration due to application of 60, 120 and 180 kg N ha^{-1} were 388, 357 and 370 mm, respectively. During the year 2015-16, seasonal evapotranspiration ranged from 164 mm (NTR$_+$N$_{60}$) to 276 mm (CTR$_0$N$_{180}$) with a mean value of 219.5 mm. Averaged over crop residue mulch and N management, cumulative evapotranspiration were 221 and 218 mm under CT and NT, respectively. Averaged over tillage and N management, evapotranspiration under crop residue mulch (176 mm) was at par with that of without crop residue mulch (263 mm). Averaged over tillage and residue management, evapotranspiration due to application of 60, 120 and 180 kg N ha^{-1} were 208, 222 and 229 cm, respectively.

During the year 2014-15, water productivity of wheat ranged from 8.06 kg ha^{-1} mm^{-1} (NTR$_+$N$_{60}$) to 17.4 kg ha^{-1} mm^{-1} (NTR$_0$N$_{180}$) with an average value of 11.9 kg ha^{-1} mm^{-1}. During the year 2015-16, water productivity of wheat ranged from 10.5 kg ha^{-1} mm^{-1} (NT R$_0$N$_{60}$) to 21.3 kg ha^{-1} mm^{-1} (NT R$_+$N$_{180}$) with an average value of 15.0 kg ha^{-1} mm^{-1}. During both the years, effect of tillage on water productivity was not statistically significant. However, Alvarez and Steinbach (2009) reported higher water productivity under NT than that of CT. During the year 2014-15, effect of crop residue on water productivity was not significant whereas during the year 2015-16, application of crop residue mulch significantly improved the water productivity of wheat by 51.1 per cent. Low rainfall received during the year 2015-16 than that of 2014-15 may be responsible for this difference. With increase in N levels, water productivity increased significantly in both the years. This shows synergistic interaction between water and N with respect to water productivity of wheat. This finding is in agreement with Oweis *et al.* (2000) and Pandey *et al.* (2001). Application of 180 kg N ha^{-1} significantly increased water productivity of wheat than that of 60 kg N ha^{-1} by 33.4 and 25.3 per cent during the year 2014-15 and 2015-16, respectively. Application of 120 kg N ha^{-1} significantly increased water productivity than that of 60 kg N ha^{-1} by 30.4 and 17.1 per cent during the year 2014-15 and 2015-16, respectively. During both the years of study, there was no significant difference due to 120 and 180 kg N ha^{-1} with respect to water productivity. During the year 2014-15, interaction between tillage and crop residue mulch, and interaction between tillage, crop residue mulch and N levels significantly influenced water productivity of wheat. The NT with crop residue mulch (19.3 kg ha^{-1} mm^{-1}) registered higher water productivity than NT without crop residue mulch (11.7 kg ha^{-1} mm^{-1}). During the year 2015-16, interaction between tillage, crop residue mulch and N levels was not significant on water productivity of wheat.

Conclusions

The study showed that there was increase in the profile moisture recharge under crop residue mulching. The evaporative flux was lower but deep percolation flux was higher under crop residue mulching. In low rainfall years water productivity increased significantly due to crop residue mulching. However, in high rainfall years the effect of crop residue mulch on water productivity was not significant. With the increase in the N dose, water productivity increased significantly in both the years but there was no significant difference between 120 and 180 kg N ha^{-1}. Conventional tillage and no tillage practices were statistically at par with respect to water productivity of wheat. Therefore, it is recommended that no tillage with crop residue mulching and 120 kg N ha^{-1} may be practiced to achieve higher water productivity in wheat in the Indo-Gangetic Plain region.

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