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Effect of land management practices on soil moisture storage characteristics

Karittika Chawala and Meharban Singh Kahlon*

Department of Soil Science, Punjab Agricultural University, Ludhiana- 141004 (Punjab), INDIA
*Corresponding author. E-mail: dr.mskahlon@rediffmail.com

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Abstract: A field study was conducted to evaluate moisture storage in soil profile under four tillage-residue management practices namely conventional tillage, no-tillage without residue, no-tillage with residue and deep tillage along with three irrigation regime based on IW/PAN-E ratio 1.2, 0.9 and 0.6 in maize with three replications in split plot design. Significant differences were observed in steady state infiltration rate and cumulative infiltration among different land management practices with maximum value in deep tillage (4.9 cm hr^{-1} and 33.1 cm) followed by no tillage with residue (4.1cm hr^{-1} and 28.6 cm), no tillage without residue (4.0 cm hr^{-1} and 23.0 cm) and conventional tillage (2.8 cm hr^{-1} and 19.4 cm), respectively. The highest mean weight diameter and water stable aggregates were found under no tillage with residue (0.64 mm and 49.7%) and lowest under deep tillage (0.3 mm and 21.8%), respectively. Higher volumetric soil water content and soil profile moisture storage were recorded under no tillage with residue at different days after sowing. Among different tillage-residue management practices, maximum leaf area index and relative leaf water content were observed in no-tillage with residue. Under moisture stress conditions, no-tillage with residue retention was suitable land management option for reducing evaporation losses and enhancing moisture storage in the soil profile.

Keywords: Aggregation, Irrigation regimes, Soil moisture storage, Tillage, Water transmission

INTRODUCTION

Under water stress situation, soil profile moisture storage plays an important role in crop growth and productivity. However, this storage varied with land management and residue retention practices. Soil physical properties, directly and indirectly, influence the availability of water, air and nutrients to the plants. Tillage and crop residue management can play a significant role in improving soil quality, crop productivity and preventing environmental pollution (Iqbal *et al.,* 2005). Under conservation tillage practice the disturbance of the soil is minimum, and 30 % of crop residue is maintained on the soil surface, which contributes to the improvement of soil physical properties particularly soil aggregation and water transmission characteristics (Costa *et al.,* 2003, Bertol *et al.,*2004 and Kahlon *et al.,*2013). Conservation tillage improves economic performance and energy efficiency and reduces production risks (Zentner *et al.,* 2002). It decreases disturbance of soil, improves soil organic carbon (SOC) content, maintains and benefits soil quality (Zentner *et al.,*2004). The conventional tillage (CT) practices, on the other hand, lead to the breakdown of soil structure which subsequently affects pore continuity and water transmission characteristics of the soil. The depletion of soil organic matter content (SOM), microbial activity and crop productivity is also affected by CT (Ramos *et al.,*2011). Tillage systems which enhance water infiltration, increase soil moisture storage and improve hydro-physical properties are important to sustain agricultural practices (Brady and Weil, 1999). He *et al.* (2009) reported higher soil water contents in 30-40 cm soil layer under NT than CT. The NT system conserved more moisture probably because of the retention of crop residue on the soil surface, reduction of runoff, interception of rainfall and an increase of available water capacity as compared to conventional tillage (Kahlon *et al.,*2012 and Dao, 1993). Larney and Lindwall (1995) also reported increased water storage capacity in NT as compared to CT.

Zhao *et al.* (2014) observed that straw mulch significantly improved the soil water content during the growing season of sunflower. Straw mulch treatment stored more soil moisture under low evaporative rainy conditions (Jalota *et al.,* 2001). Balwinder-Singh *et al.* (2011) reported that the application of rice straw mulch is significant in wheat as it increased soil moisture content in 0-40 cm layer and beyond that effect was non significant. Shen *et al.* (2012) studied the effects of straw mulch on soil moisture in maize and reported that straw mulch significantly improved soil moisture content at a depth of 20-80 cm below the ground surface during the anthesis-silking stage. The combination of mulching with tillage in conserving soil moisture has been recognized by many researchers (Greevers*et al.,* 1986, Van Ouwerkerk 1986 and Bhagat and Acharya 1988).Hussain *et al.* (1998) stated that as then

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the intensity of soil disturbance and tillage frequency increases volumetric soil moisture content decreased. Lafond *et al.* (1992) reported that NT increase the water storage capacity of the soil and increase the available water for crop growth. Maintenance of stubble on the surface enhanced the capacity to store soil water reserves significantly under NT but not under CT. Thus, tillage accompanied by crop residue management is important for recharging the soil profile. Similar observations were also reported by Bhattacharyya *et al.* (2008), Juan *et al.* (2008) and Aikins and Afuakwa (2012).

Gathala *et al.* (2011) reported highest water stable aggregate (WSA) in NTR (63%) followed by NT (57 %) and least under CT (52 %).The reduction in macro aggregates and mean weight diameter (MWD) with CT may be due to mechanical disruption of macro aggregates from frequent tillage operations and thus reduced aggregate stability. Tillage increases the effect of drying-rewetting and freezing-thawing, which increase physical disruption of macro aggregate (Mikha and Rice, 2004). The soil aggregation was found to be improved to the higher proportion of WSA and MWD were observed in NT than CT by the various researcher (Jat *et al.,* 2006, Arshad *et al.,* 1999 and Zibilske and Bradford, 2007). Choudhury *et al.* (2014) reported that application of NT with residue resulted in 46.5 % higher WSA in the surface as compared to CT. They also suggested that NT promotes macro aggregation as compared to CT. The decline in the size of macro aggregates in CT could be due to the disruption of macroaggregates, which may have exposed, previously protected SOM against oxidation. SOC increased with increase in irrigation levels, as it increases organic matter decomposition (Oriola, 2004). Singh and Sharma (2005) evaluated that NT and ST enhance MWD of aggregates by 49% and 20%, respectively, over CT. Maurya (1986) stated that the initial infiltration rate (IR) for the first 5 minutes was 18% higher in plots with residue (36.0 cm hr^{-1}) than in plots without residue (30.5 cm hr^{-1}). Since soil profile moisture storage under different land management practices has not been evaluated. Therefore, a study was conducted with four tillage systems to test the hypothesis that tillage practices with residue management may improve the soil moisture storage which will help in maize survival during water stress period.

MATERIALS AND METHODS

The field experiment was conducted at the Research farm, Department of Soil Science, Punjab Agricultural University, Ludhiana representing the Indo-Gangetic alluvial plains situated at 30° 56' N latitude and 75° 52' E longitudes with an altitude of 247 meters above the mean sea level. The area is characterized by the sub-tropical and semi-arid type of climate with hot and dry summer from April to June followed by a hot and humid period from July to September and cold winters from November to January. The mean maximum and minimum temperatures show considerable fluctuations during different parts of the year. Summer temperature however around 38°C and touches 45°C with dry summer spells. Winter experiences frequent frosty spells especially in December and January, and the minimum temperature dips up to 0.5°C. The average rainfall of the area is 600-700 mm, of which about 80 percent is received during July to September (Kingra *et al.,* 1996). The tillage treatments included: conventional tillage (CT) with two disk, two cultivator followed by one planking operation, no-tillage without residue (NT), no-tillage with residue (NTR) having residue retention and sowing by happy seeder machine in standing wheat stubbles after combine harvesting, deep tillage (DT) performed by chisel plough upto 45 cm soil depth followed by CT. Three irrigation levels were maintained based on IW/PAN-E ratio 1.2, 0.9 and 0.6. The experiment was conducted in split plot design with three replications. Various methods used for analysis of soil physical properties and maize plant characteristics are mentioned below:

Soil aggregation: Surface soil (0-15 cm) samples were collected for aggregate size. Aggregate status of soil was determined by wet sieving method (Yoder 1936). The air-dried soil peds were passed through 8-mm sieve and were retained on 4-mm sieve. Yoder's wet sieving apparatus, comprising of 4 sieve sets, each having nest of 5 sieves of 12.7 cm diameter and 5 cm height and with hole sizes of 2.0, 1.0, 0.5, 0.25 and 0.1 mm (with mesh numbers of 8, 16, 32, 64 and 150 respectively), were used for this purpose. The samples were evenly distributed over the top sieve of the set and pre-wetted by capillarity for 10 minutes. The nest of sieves was then allowed to move up and down for 30 minutes. Following this, the sieves were drawn out of the water, and the oven-dried weight of aggregates retained on each sieve was recorded after drying these in an oven at 105 °C till the constant weight achieved. The data were analyzed to compute mean weigh diameter (MWD) and water stable aggregates (WSA) of different size (Kemper and Rosenau 1986). The MWD and WSA were calculated using the formula:

$$\text{MWD} = \sum_{i=1}^{n} d_i \times w_i \quad \text{(Eq. 1)}$$

$$\text{WSA} > 0.25\ \text{mm}\ (\%) = \frac{\sum_{i=1}^{n} w_i}{\text{weight of sample}} \times 100 \quad \text{(Eq. 2)}$$

Where, n is a number of size fractions (the finest fraction that passes through the finest sieve inclusive), d_i is the mean diameter of each size range, w_i is the weight of aggregates in that size range as a fraction of the total dry weight of the sample analysed.

***In-situ* determination of infiltration rate (IR) and cumulative infiltration (CI):** Infiltration was measured *in-situ* by double ring infiltrometer method according to Reynolds *et al.*(2002). Water was filled in

Table 1. Effect of tillage –residue management practices and irrigation regimes on leaf area index and relative leaf water content.

Irrigation regimes (IW/ PAN-E =)	Leaf area index				Mean	Relative leaf water content				Mean
	Tillage practices					Tillage practices				
	CT	NT	NTR	DT		CT	NT	NTR	DT	
1.2	2.49	3.44	4.55	5.32	3.95	81.76	78.33	81.83	80.33	80.56
0.9	3.98	5.16	4.64	4.64	4.60	75.90	78.30	77.27	76.66	77.03
0.6	3.38	3.27	3.89	3.70	3.56	70.73	75.20	74.50	74.46	73.72
Mean	3.28	3.96	4.36	4.55		76.13	77.27	77.86	77.15	
LSD (<0.05)	Tillage =0.54; Irrigation=0.38; Interaction=0.77					Tillage =NS; Irrigation=5.16; Interaction=NS				

DT: deep tillage; NT: no-tillage without residue; NTR: no-tillage with residue and CT: conventional tillage

both the outer and inner rings, and the fall of water levels in the inner ring was recorded at different time intervals till the water intake rate becomes constant.

Soil profile moisture storage: The soil samples were taken at 0-15, 15-30, 30-45, 45-60, 60-90, 90-120 cm with screw auger at different days after sowing (DAS) and harvesting of thecrop. Fresh weight of these samples was recorded. The samples were oven dried at 105 °C for 24 hours. Volumetric soil moisture content was determined by multiplying the mass water content to the soil ρ_b(Blake and Hartge, 1986) and soil moisture storage in thedifferent layer was computed by adding the volumetric water content of different layers in thesoil profile.

Relative leaf water content (RLWC) and leaf area index (LAI): The RLWC was determined according to the method described by Barrs and Weatherley (1962) and later modified by Esparza-Rivera *et al.,*(2006). Three plants were randomly sampled from each plot to determine RLWC. The RLWC determination was accomplished by excising discs from the uppermost, medium and lower leaves with two discs from each leaf, thus making a total of six discs per plant and eighteen discs per plot. These disks were collected in plastic vials and weighed immediately, providing a measure of fresh weight (FW). After weighing, the disks were soaked in de-ionized water for 4 hours and then weighed again to obtain a fully turgid weight (TW). Finally, the leaf discs were dried at 60 °C till the constant weight achieved to obtain the dry weight (DW).

$$\text{RLWC (\%)} = \frac{FW-DW}{TW-DW} \times 100 \qquad \text{(Eq. 3)}$$

The LAI was measured at 50 and 75 DAS using leaf area meter at three randomly selected plants within the plot.

$$\text{Leaf area index} = \frac{\text{Leaf area}}{\text{Ground area}}$$

The data collected on various aspects of the investigations were statistically analyzed as prescribed by Cochran and Cox (1967) and adapted by Cheema and Singh (1991) in statistical package CPCS-I. The treatment comparisons were made at 5 per cent level of significance.

RESULTS AND DISCUSSION

Water transmission and soil aggregation: The water transmission characteristics were observed to be significantly affected by tillage-residue management practices (Fig. 1). The final infiltration rate (IR) (cm hr^{-1}) was observed to be maximum under DT (4.9) followed by NTR (4.1), NT (4.0) and least under CT (2.8). Moroke *et al.,* (2009) also observed higher IR in DT than CT due to ample amount of macropores which led to the fast entry of water into the soil profile. The effect of tillage-residue management practices on cumulative infiltration (CI) is presented in Fig 2. After 300 minutes, maximum CI (cm) was observed under DT (33.1) followed by NTR (28.5), NT (23.0) and least under CT (19.3). The CT system showed less CI which

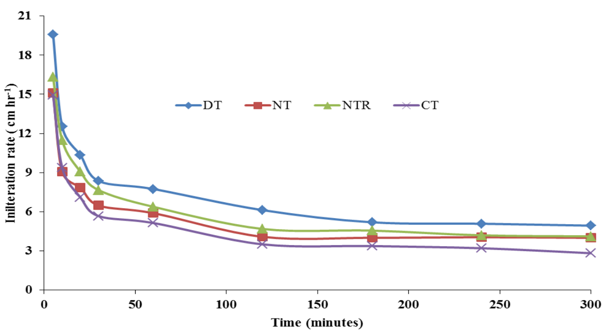

Fig. 1. *Infiltration rate as affected by different tillage-residue management practices (DT: deep tillage; NT: no-tillage without residue; NTR: no-tillage with residue and CT: conventional tillage)*

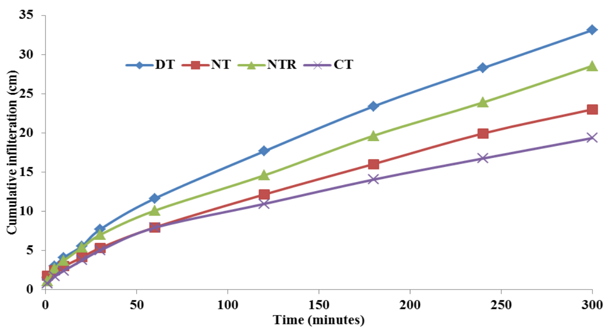

Fig. 2. *Cumulative infiltration as affected by different tillage-residue management practices(DT: deep tillage; NT: no-tillage without residue; NTR: no-tillage with residue and CT: conventional tillage)*

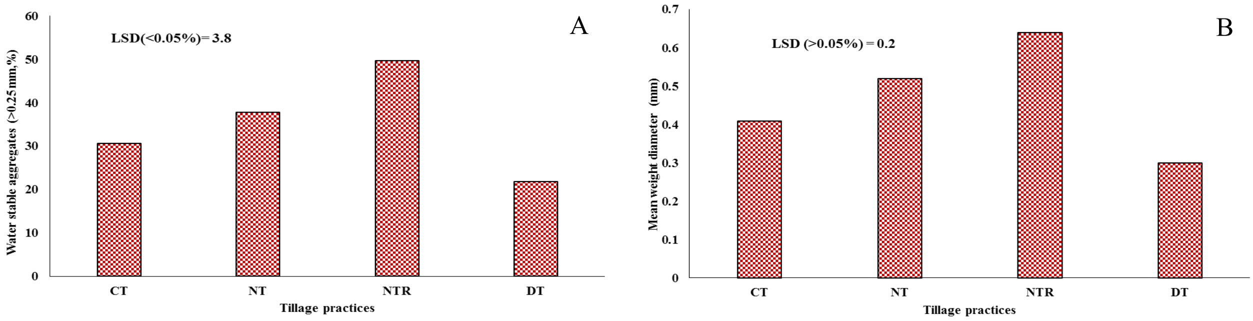

Fig. 3. *Effect of tillage-residue management practices on water stable aggregates (A) and mean weigh diameter (B) (DT: deep tillage; NT: no-tillage without residue; NTR: no-tillage with residue and CT: conventional tillage).*

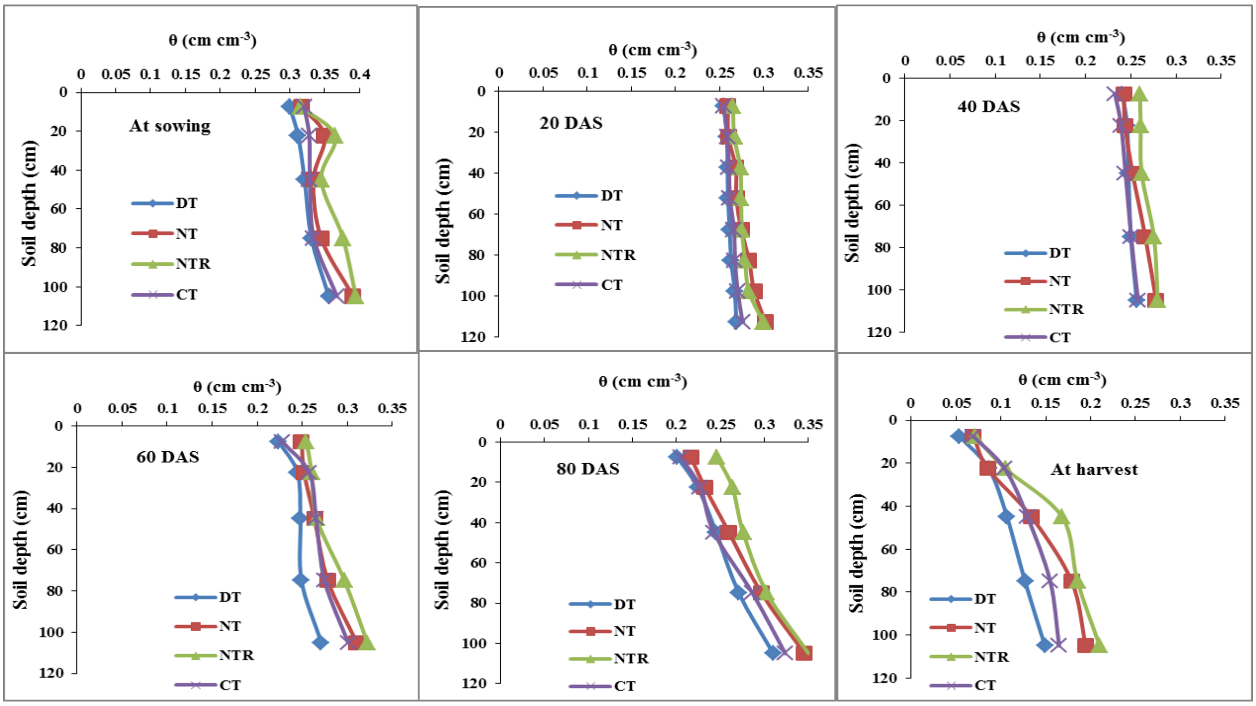

Fig.4. *Volumetric soil water (θ) content under different tillage-residue management practices at different days after sowing (DAS) of maize (DT: deep tillage; NT: no-tillage without residue; NTR: no-tillage with residue and CT: conventional tillage).*

might be due to relatively smaller pore heterogeneity and discontinuity of pores (Sauwa *et al.,*. 2013). Martin *et al.,* 2004 observed that NT plots infiltrated 2.2 inches more water than CT. Kahlon *et al.* (2012) also observed higher CI (8.1 cm) under NT than CT (5.8 cm) after 270 minutes. More CI under NT might be due to a minimal disturbance that maintained continuity and connectivity of water conducting pores. Similarly, soil aggregation {(WSA >0.25mm (%) and MWD (mm)} was also observed to be significantly affected by tillage- residue management practices (Fig 3 A and B). Mean maximum WSA (%) was observed in NTR (49.7) followed by NT (37.8), CT (30.6) and least under DT (21.8). Similarly, mean maximum MWD (mm) was observed in NTR (0.64), followed by NT (0.52), CT (0.41) and least under DT (0.30).Chen *et al.* (2007) stated that frequent tillage operation caused mechanical disruption of macroaggregates and therefore reduced aggregate stability. Jat *et al.* (2006) found ahigher proportion of WSA and MWD in NT than CT. Choudhary *et al.* (2014) reported that application of NT with residue resulted in 46.5 per cent higher WSA in thesurface as compared to CT. The binding of residues and soil particulates into macro aggregates in higher proportion in surface than sub-surface soil layer. Tillage increased the effect of drying-rewetting and freezing-thawing, which increased the susceptibility of macro aggregate to physical disruption thus decreasing MWD and WSA. Six *et al.* (2000) reported that NT increased the amount of carbon-rich macro aggregates and decreased the amount of carbon-depleted micro aggregates. NTR increases the macro aggregates as compared to other tillage and residue management practices which might be due to residue retention and enhanced organic matter decomposition.

Volumetric water content (θ) and soil profile moisture storage: The effect of different tillage-residue management practices on volumetric soil water content

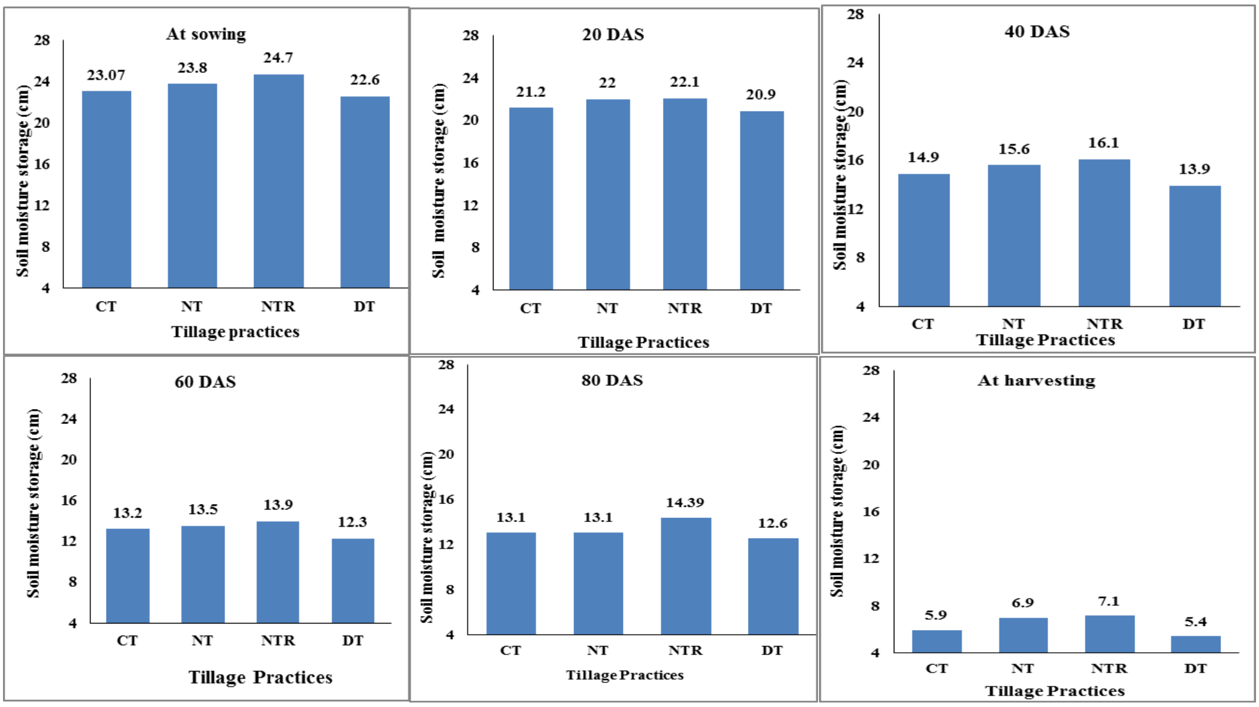

Fig. 5. *Effect of tillage-residue management practices on soil profile moisture storage at different days after sowing (DAS) of maize (DT: deep tillage; NT: no-tillage without residue; NTR: no-tillage with residue and CT: conventional tillage).*

under different soil depth at different days after sowing is presented in Fig. 4. At the time of sowing the θ (cm cm^{-3}) ranged from 0.29-0.39 and at the time of harvesting, θranged from 0.06-0.21 among different tillage-residue management practices. As the soil depth increased, the soil water content increased. Kebede and Bekelle (2008) also reported an increase in θ with increasing soil depth. NT had more θ due to lower evaporation rate than other tillage. Wang *et al.* (2009) stated that surface mulch favorably influenced the soil moisture regime by controlling evaporation from the soil surface. Tillage induced disturbance and the pulverizing effect of CT produced a finer and loose soil structure which had lower retention pores than NT (Rashidi and Keshavarzpour, 2007). The NT system conserved more moisture probably because of the retention of crop residues on the soil surface, interception of rainfall, reduction of runoff, and an increase of available water capacity as compared to CT. Hussain *et al.*(1998) stated that as the soil disturbance and tillage frequency increased, θ decreased. There are several practices (i.e. cover crop, mulch, residue incorporation) which reduce losses and increase moisture storage in the root zone, and NT is especially effective in enhancing soil moisture storage (Yuecun *et al.,* `2008). The data pertaining to soil profile storage under different tillage residue management practices at different DAS is presented in Fig.5. At sowing, moisture storage (cm) was maximum under NTR (24.7), followed by NT (23.8), CT (23.07) and least under DT (22.6). Tillage system affects number, shape, continuity and size distribution of the pore network, which controls the ability of soil to store and transmit water and enhance soil moisture under NT. Adoption of conservation tillage can improve available water capacity, which enhances the edaphic environment and use efficiency of inputs (Khan *et al.,* 2001). More water was conserved in the soil profile during the early growth period with straw mulch than without it. Several studies reported improved water infiltration and storage in NT due to higher organic matter contents (Franzluebbers 2002), crop residue (Nielsen and Miller 2005), or mulch cover (Ramakrishna *et al.,*2006).

Leaf area index (LAI) and Relative leaf water content (RLWC) and root mass density (RMD): Maximum LAI of maize (Table 1) was observed in DT (4.55) followed by NTR (4.36), NT (3.96) and least under CT (3.28). Irrespective of tillage and residue management practices, maximum LAI was observed under I2 (4.60) followed by I1 (3.95) and least under I3 (3.70). Qamar *et al.*(2013) also observed maximum LAI of wheat under DT followed by NTR and minimum under CT. The data related to the effect of tillage -residue practices and irrigation regimes on relative leaf water content (RLWC) is presented in Table 1.Effect of tillage-residue management practices was found to be non significant whereas irrigation effect on RLWC was significant. Maximum RLWC was observed under I1 (80.56) followed by I2 (77.03) and least under I3 (73.72). With theincrease in irrigation, the RLWC increased. Jayasankar and Ramakrishnyya (1993) and Kumar (2005) also reported higher uptake of water under more applied irrigation thus showing higher RLWC.

Conclusion

From the results, it could thus be concluded that where the water stress is a major problem the no-tillage with residue management is a suitable land management option for enhancing moisture storage in the soil profile and achieving a higher water content of plant leaves for maintaining turgidity under water stress situation.

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