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Water Transmission Characteristics of Soil as Affected by Tillage- Residue Management Practices and Irrigation Levels

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ABSTRACT: *Tillage along with residue management practices affects water transmission characteristics of soil. However, these changes are site specific. Therefore, a field study was conducted in split plot design by keeping tillage along with residue management practices in main plots and irrigation levels in sub plots. Two separate but treatment-wise similar experiments were conducted in two prominent soil textural group of the region i.e., sandy loam (SL) and loamy sand (LS). The treatments includes four tillage and residue management practices i.e., happy seeder (HS), no-tillage (NT), roto-tillage (RT) and conventional tillage (CT) and three irrigation levels based upon IW/PAN-E ratios 1.2 (I_1), 0.9 (I_2) and 0.6 (I_3). The data indicate significant differences in tillage along with residue management practices on water transmission characteristics of soil. Mean highest infiltration rate (IR, cm hr^{-1}) for SL and LS (1.14 and 2.90) was observed under HS followed by NT (0.89 and 2.71), RT (0.73 and 2.24) and least under CT (0.60 and 2.22), respectively. Mean highest cumulative infiltration (CI, cm) for SL and LS soil was found under HS (4.88 and 7.67) followed by NT (4.39 and 6.67), RT (4.17 and 6.41) and least under CT (4.10 and 6.43), respectively. The highest saturated hydraulic conductivity (K_s, cm hr^{-1}) were observed in HS (1.82 and 1.36) and the least under CT (1.12 and 0.78) at 0-7.5 and 7.5-15 cm depths, respectively in SL soil. Irrespective of tillage and residue management practices, K_s (cm hr^{-1}) increased significantly with increase in irrigation levels, being highest under I_1 (1.85 and 3.24) followed by I_2 (1.49 and 2.30) and I_3 (0.85 and 1.52) respectively, for SL and LS soils. The highest mean profile soil moisture storage (cm) of 12.6 was recorded under HS with I_1 and lowest of 7.4 under CT with I_3 for SL soil. Same trend of change in soil profile moisture storage under different tillage and residue management practices was observed for LS soil. It can be concluded that conservation tillage along with residue management practices like HS improves water transmission characteristics of soil.*

Keywords: *Tillage, irrigation, residue management, infiltration characteristics, saturated hydraulic conductivity.*

INTRODUCTION

Tillage along with residue management practices play significant role in improving soil quality (with respect to physical, chemical and biological aspects) and crop productivity (Iqbal *et al.*, 2005). However, excessive tillage without proper residue management decreases soil organic carbon (SOC) concentration (Ahmad *et al.*, 1996). Conservation tillage on the other hand retains at least 30% of the crop residue on soil surface. The area under NT has substantially increased in South Asia and particularly the Indo-Gangetic plains (Derpsch *et al.*, 2010). Diffusion of no-tillage technology increased in Northwest India, particularly during last two decades. The aggregate area in India under NT amounted to 1.76 M ha (Erenstein, 2009). Large quantity of crop residue is produced every year in Punjab, a northwest Indian state (Sidhu and Beri, 2008). Due to lack of appropriate technology/ machinery most of the crop residue particularly the rice residue (18.8 M ton) is burnt in the fields to make the cultivation operations easy and timely sowing of subsequent wheat crop (Singh *et al.*, 2005). The crop residue burning and removal cause great loss to soil fertility, soil physical health and environment problems (Sidhu *et al.*, 2007). There is thus, need to manage crop residue properly either by retaining it on soil surface or by incorporating it into the soil using different machinery. Agriculturally, the best way is to retain it on the soil surface, which serves dual purpose of reducing evaporation at the soil surface by creating mulch and secondly it adds organic matter to the soil. During the past few years, research efforts have been focused on managing the crop residue, reducing the cost of cultivation, improving soil health for sustainable crop production. The technologies

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developed, tested and validated are Happy Seeder (HS), no-tillage (NT), conventional tillage (CT) and roto-tillage (RT). The HS drilling offers the apparent advantage of managing large quantity of crop residue, timely planting, reducing cost of fuel and labor and improving the soils health as well as crop productivity. The HS enables to sow the succeeding crop directly in loose straw and standing stubbles of previous crop. The HS machines differ from NT machine in respect of managing large straw loads. In other words, the HS is improved technology than NT machine, where, sowing is possible keeping both loose straw and standing stubbles in field. The other machine used for managing crop residue is the roto-tillage (RT). In this type of tillage the residue of previous crop is incorporated into the soil rather than keeping it on soil surface. Until now, the most commonly used tillage practice for seed bed preparation is conventional practice in which land cultivated by discs followed by tillers and planking operations. Thus, 4 to 5 operations are required for sowing of crop by conventional mean. However, these operations can easily be reduced to single operation using HS machine. It is reported in literature that, different tillage along with residue management practices affects soil physical characteristics significantly, particularly, water transmission characteristics, which subsequently affect crop yield (Strudley *et al.*, 2008). The NT practice disturbance the soil to minimum possible extent, it adds organic matter to soil through addition of crop residues, which further improve soil structure, soil moisture storage and microbial activities (Zentner *et al.*, 2004). Whereas, CT disturbs the natural condition of soil, it damages the pore continuity and aggregate stability resulting in sediment mobilization, erosion and surface hardening. Shallow (0-5 cm) or NT has the positive effect on soil health such as aggregate stability, infiltration capacity, K_s and aeration (Riley *et al.*, 2008; Vakali *et al.*, 2011). Infiltration characteristics of the soil depend on the size distribution, geometry, continuity and the stability of the pores (Shaver *et al.*, 2002). NT system reduces the runoff from the soil surface, retains moisture in the soil and increase the stability of soil aggregates (Hamza and Anderson, 2005; Sauwa *et al.*, 2013). Jin *et al.*, (2009) observed higher IR under NT than CT plots because of maintenance of pore continuity and macro porosity. Similar observations were also reported by Sharma *et al.*, (2011). The use of CT can affect soil K_s in two contradicting ways: it can increase K_s by reducing bulk density (ρ_b) and increasing total porosity or can reduce K_s by increasing compaction of the plough depth and crusting of the surface layer (Heard, 1988). Kahlon *et al.*, (2013) found that the K_s significantly affected by tillage methods and mulch rates. The K_s ($\times 10^{-2}$ cm hr^{-1}) increased from 1.78 to 3.37, 1.57 to 2.95 and 1.37 to 2.28 under NT, RT and PT, respectively with the increase in mulch rate from 0 to 16 Mg ha^{-1}. Bhattacharyya *et al.*, (2006) observed that K_s was in order NT> MT> CT. Greater amount of WSA in NT system probably also contributed to its higher K_s. Sauwa *et al.*, (2013) reported that NT and reduced-tillage treatments had higher K_s value at both surface and sub-surface soil depths compared to CT treatment. McGarry *et al.*, (2000) observed higher values of K_s under NT relative to CT due to a greater number of macropores. The conservation tillage enhances soil moisture storage by reducing evaporation and drainage losses; however, information is scanty with respect to quantification of soil profile moisture storage under conservation tillage, particularly under recently introduced HS and RT practices at different irrigation levels. Therefore, a study was conducted to investigate the effects of tillage along with residue management practices and irrigation levels on soil profile moisture storage and water transmission characteristics of SL and LS soils of Northwest Indian region.

MATERIALS AND METHODS

The study was conducted on an already going on experiment initiated in 2009 on tillage-residue management practices at the research farm of Department of Soil Science, Punjab Agricultural University, Ludhiana (30° 56′ N latitude and 75° 52′ E longitude) in two different experiments in sandy loam (SL) and loamy sand (LS) soils. The experiment involved four tillage and residue management practices {HS (surface rice residue retention and sowing of wheat by HS machine), NT (residue removal and sowing by no-till machine), RT (rice residue incorporation into the soil by rotavator operations and sowing by ordinary drill) and CT (disking followed by cultivator and one planking operation)} and three irrigation levels based upon IW/PAN-E ratios (i.e., 1.2, 0.9 and 0.6). The experiment was conducted in split plot design by keeping tillage along with residue management treatments in main plots and irrigations levels in sub plots with three replications. The plot size was 33 m^2. The mean maximum and minimum temperature of the study site showed considerable fluctuations during different parts of the year. Summer temperature reaches up to 45°C with dry summer spells. Winter experiences frequent frosty spells especially in December and January and minimum temperature dips up to 0.5°C. The average annual rainfall of studied location was 733 mm (Kingra *et al.*, 1996) and the major portion of which (75%) is received during July to September. Undisturbed soil samples were collected after wheat harvesting for analyzing various soil physical characteristics.

The infiltration rate (IR) of soil was determined *in-situ*, using double ring infiltrometer method (Reynolds *et al.*, 2002). Water was filled in 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. The undisturbed soil samples were collected in cores (8 cm diameter and 7.5 cm length) for K_s determination from 0-7.5 and 7.5-15 cm depths. Samples were saturated in the laboratory by placing on cloth covered perforated disks in trays containing water. The K_s was determined using constant head method (Reynolds *et al.*, 2002). Soil moisture samples were taken for entire soil profile (0-105 cm soil depth with 15 cm increments) with screw auger. Periodic measurement of gravimetric soil moisture content determinations was made throughout crop growing season.

The data collected on various soil physical characteristics was statistically analyzed as described 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

Infiltration Characteristics

The infiltration rate (IR) of SL and LS soils was significantly affected by both tillage and residue management practices (Table 1). Mean highest IR (cm hr^{-1}) for SL and LS (1.14 and 2.90) was observed under HS followed by NT (0.89 and 2.71), RT (0.73 and 2.24) and least under CT (0.60 and 2.22), respectively. The higher IR observed under HS plots may be attributed to higher SOC content and better MWD which led to better pore size distribution and thus higher infiltration rates (Bhattacharyya *et al.*, 2008). The higher IR in the plots under HS was probably also due to minimum disturbance that maintained the continuity of water conducting pores (Acharya and Sood, 1992) and bio-channels (Azooz *et al.*, 1996). Water transmission through soil profile depends on antecedent water content, aggregation and macropore channels (Shaver *et al.*, 2002).

Cumulative infiltration (CI) as a function of time was significantly affected by tillage and residue management practices. The HS recorded highest CI as compared to the NT, RT and CT systems for both SL and LS soils (Figs. 1 and 2). The CT system showed less CI which might be due to relatively smaller pore heterogeneity, discontinuity of pores and less stable aggregates (Sauwa *et al.*, 2013) as compared to the NT plots (Singh *et al.*, 1995). The excavation of profiles displayed abundant roots and biochannels in the NT systems which served as important conduits for movement of water through the soils (Kladivko *et al.*, 1986; Singh *et al.*, 1995) despite greater ρ_b of these systems relative to the CT system. Highest CI (cm) for SL and LS soil was found under HS (11.2 and 20.4) followed by NT (10.0 and 18.3), RT (9.3 and 17.4) and least under CT (8.4 and 16.7) respectively. Further, less soil disturbance in the HS and NT systems, also kept pore structure continuous which aids greater water transmission through the soil (Singh *et al.*, 1995; Azooz and Arshad, 1996; Jabro *et al.*, 2008). Conversely, less stable aggregates in the CT practice upon intense rainfall event clog soil pores through slaking of aggregates leading to decrease in water transmission through the soil (Pikul and Aase 1995; Mbagwu and Auerswald, 1999). Gangwar *et al.*, (2006) reported that the crop residues left on the soil surface limit evaporation, soil sealing and crusting and thereby increase soil infiltration. Water transmission through the soil profile also depends on the antecedent water content, aggregation and the presence of macropore channels (Shaver *et al.*, 2002). Irrespective of tillage practices, the mean IR decreased with decrease in IW/PAN-E ratio for both textured soils. These results were in agreement with the findings of Bhattacharyya *et al.*, (2008).

Saturated Hydraulic Conductivity (K_s)

Significant differences ($P < 0.05$) in K_s were observed among tillage and residue management practices for 0-7.5 and 7.5-15 cm depths under SL soil (Table 2). The highest K_s (cm hr^{-1}) were observed in HS (1.82 and 1.36) and the least under CT (1.12 and 0.78) at 0-7.5 and 7.5-15 cm depths, respectively. In general, K_s decreased with increase in depth in all practices, in accord with increase in ρ_b (Kahlon *et al.*, 2012). Similarly, in LS soil (Table 3) the K_s varied significantly among tillage and residue management practices.

CT recorded the lowest K_s values due to more soil disturbance, compaction as well as lesser organic

Table 1
Effect of tillage along with residue management practices and irrigation levels on final infiltration rate ($cm\ hr^{-1}$) in sandy loam (SL) and loamy sand (LS) soils

Tillage-residue management practices	*Soil texture*							
	SL IW/PAN-E=				*LS IW/PAN-E=*			
	1.2	*0.9*	*0.6*	*Mean*	*1.2*	*0.9*	*0.6*	*Mean*
HS	1.27	1.15	1.00	1.14	2.97	3.07	2.68	2.90
NT	1.05	0.86	0.75	0.89	2.90	2.65	2.57	2.71
RT	0.97	0.66	0.57	0.73	2.50	2.33	1.90	2.24
CT	0.75	0.61	0.45	0.60	2.63	2.23	1.80	2.22
Mean	1.01	0.82	0.69		2.75	2.57	2.24	
LSD (P<0.05)	Tillage =		0.26		Tillage =		0.34	
	Irrigation =		0.22		Irrigation =		0.36	
	Interaction =		NS		Interaction =		NS	

HS: happy seeder; NT: no-tillage; RT: roto-tillage; CT: conventional tillage

Table 2
Effect of tillage along with residue management practices and irrigation levels on saturated hydraulic conductivity ($cm\ hr^{-1}$) in sandy loam soil

Tillage-residue management practices	*Soil depth (cm)*							
	0-7.5 IW/PAN-E=				*7.5-15 IW/PAN-E=*			
	1.2	*0.9*	*0.6*	*Mean*	*1.2*	*0.9*	*0.6*	*Mean*
HS	2.14	1.93	1.39	1.82	1.62	1.60	0.87	1.36
NT	1.88	1.29	0.92	1.36	1.33	1.11	0.60	1.01
RT	1.79	1.40	0.66	1.28	1.23	1.07	0.53	0.94
CT	1.58	1.35	0.44	1.12	1.20	0.68	0.46	0.78
Mean	1.85	1.49	0.85		1.35	1.11	0.61	
LSD (P<0.05)	Tillage =		0.18		Tillage =		0.15	
	Irrigation =		0.14		Irrigation =		0.12	
	Interaction =		NS		Interaction =		NS	

HS: happy seeder; NT: no-tillage; RT: roto-tillage; CT: conventional tillage

Table 3
Effect of tillage along with residue management practices and irrigation levels on saturated hydraulic conductivity ($cm\ hr^{-1}$) in loamy sand soil

Tillage-residue management practices	*Soil depth (cm)*							
	0-7.5 IW/PAN-E=				*0-7.5 IW/PAN-E=*			
	1.2	*0.9*	*0.6*	*Mean*	*1.2*	*0.9*	*0.6*	*Mean*
HS	3.94	2.91	2.06	2.97	3.73	2.81	1.97	2.84
NT	3.46	2.41	1.83	2.56	3.12	2.39	1.80	2.44
RT	2.74	1.94	1.15	1.94	2.90	1.74	1.09	1.91
CT	2.81	1.95	1.05	1.93	2.67	1.76	1.12	1.85
Mean	3.24	2.30	1.52		3.10	2.18	1.49	
LSD (P<0.05)	Tillage =		0.12		Tillage =		0.08	
	Irrigation =		0.32		Irrigation =		0.14	
	Interaction =		NS		Interaction =		NS	

HS: happy seeder; NT: no-tillage; RT: roto-tillage; CT: conventional tillage

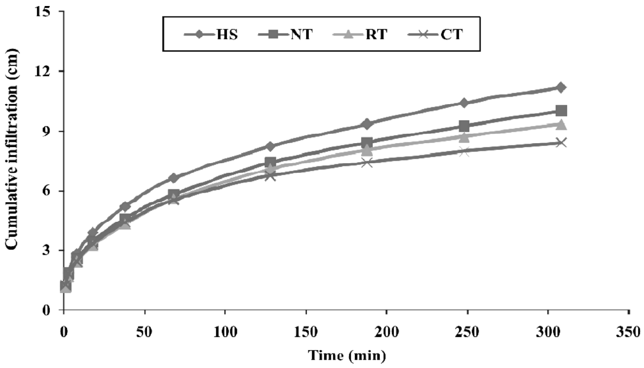

Figure 1: Effect of tillage and residue management practices on cumulative infiltration under SL soil

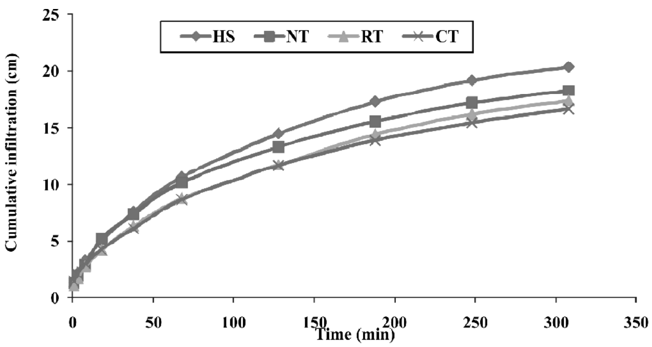

Figure 2: Effect of tillage and residue management practices on cumulative infiltration under LS soil

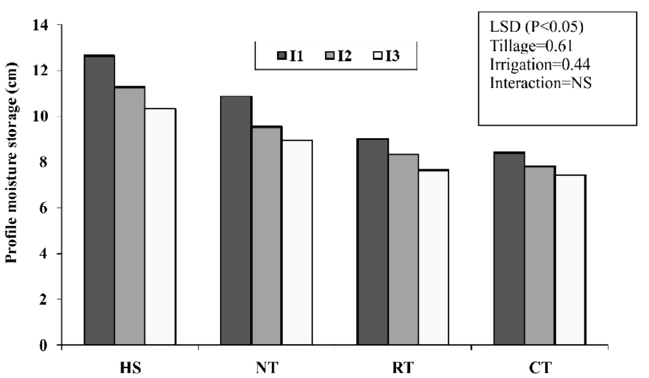

Figure 3: **Effect of tillage- residue management practices and irrigation levels on soil profile moisture storage in sandy loam (SL) soil**

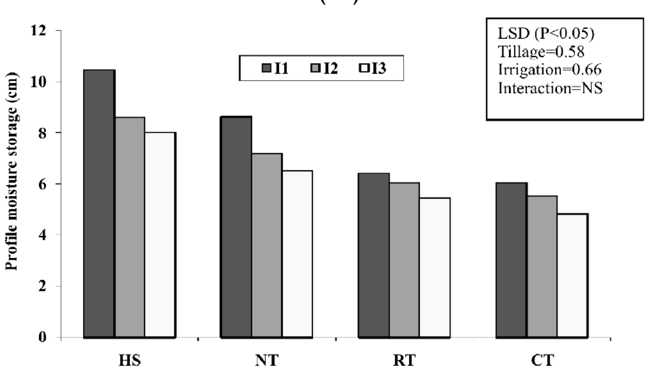

Figure 4: Effect of tillage - residue management practices and irrigation levels on soil profile moisture storage in loamy sand (LS) soil

carbon concentration. Whereas, in HS plots the pore continuity was probably maintained due to better aggregate stability and pore geometry (Bhattacharyya *et al.*, 2006). Here, activity and population of soil organisms may also have played an important role in increasing pore continuity. The pores were more continuous under NT plots, probably because of more soil fauna and preceding crop root channels (Zachamann *et al.*, 1987). Irrespective of tillage and residue management practices, there was significant increase in K_s (cm hr^{-1}) with increase in irrigation levels. The highest K_s (cm hr^{-1}) was observed under I1 (1.85 and 3.24) followed by I2 (1.49 and 2.30) and I3 (0.85 and 1.52) in SL and LS soils, respectively, at 0-7.5 cm depth. The K_s at 7.5-15 cm were lower as compared to 0-7.5 cm which might be due to increase in ρ_b at this depth (Kahlon *et al.*, 2012). Bhattacharyya *et al.*, (2008) reported that the application of irrigation water not only increased the total porosity, but also increased pore continuity which resulted in more K_s under plots receiving more irrigation as compared to plots receiving less irrigation.

Profile Moisture Storage

Data on soil profile moisture storage as affected by tillage along with residue management practices and irrigation levels under SL and LS soil is presented in Figs. 3 and 4. The mean highest soil profile moisture storage (cm) of 12.6 was recorded under HS with I_1 and lowest of 7.4 under CT with I_3 for SL soil. Same trend of change in soil profile moisture storage was observed for LS soil. Greater soil water storage was observed under NT than CT (He *et al.*, 2006 and Bhattacharyya *et al.*, 2008). Among tillage and residue management practices HS recorded highest soil profile moisture storage followed by NT, RT and CT for both SL and LS soils. Lafond *et al.*, (1992) and Larney and Lindwall, (1995) reported that NT increased the profile moisture storage as compared to CT. Maintenance of stubble on the surface enhanced the capacity to store soil water reserves under NT. Greater infiltration and lower surface evaporation are the advantages associated with the soil structure created by NT (Larney and Lindwall, 1995). However, among irrigation levels the highest profile moisture storage values were observed under I_1 followed by I_2 and least under I_3 in both SL and LS soils.

CONCLUSION

Conservation tillage along with residue management practices improves water transmission characteristics of soils, like HS which enhances infiltration rate, cumulative infiltration and saturated hydraulic conductivity of both sandy loam and loamy sand soils. Higher soil profile moisture storage was observed under HS than CT. Infiltration rate and saturated hydraulic conductivity increases with increase in irrigation level from IW/PAN-E 0.6 to 1.2.

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