EFFECT OF LAND MANAGEMENT PRACTICES ON PHYSICAL PROPERTIES OF SOIL AND WATER PRODUCTIVITY IN WHEAT-MAIZE SYSTEM OF NORTHWEST INDIA

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Abstract. Decline in soil physical health and crop productivity are the major concerns in wheat-maize cropping system of northwest India. Depending on objective, conservation and deep tillage are the potential solutions. Therefore, a field study was conducted to investigate the interactive effects of land management practices and irrigation regimes on soil properties and wheat-maize productivity. The tillage treatments comprised of no-tillage, strip tillage, conventional tillage and deep tillage, while the irrigation regimes included three levels based on irrigation water over pan evaporation (IW/PAN-E) ratios i.e. $I_{0.6}$, $I_{0.9}$ and $I_{1.2}$ for both wheat and maize crops. By shattering soil up to 45 cm depth, the deep tillage helped in improving infiltration rate by 31 % over conventional tillage. However, the no-tillage improved soil aggregation by 38 % than deep tillage. At subsurface depth (15-30 cm) the soil bulk density and penetration resistance were found to be significantly lower under deep tillage (1.52 Mg m^{-3} and 1.9 MPa) than conventional tillage (1.68 Mg m^{-3} and 2.8 MPa), respectively. The deep tillage enhanced root proliferation by increasing root length density by 44 % and 34 % than conventional tillage in maize and wheat, respectively. The grain yields (Mg ha^{-1}) of maize and wheat were 14 % and 12 % more under deep tillage than conventional tillage, respectively. The water productivity varied significantly under different irrigation regimes and was found to be highest at $I_{0.9}$ in maize and $I_{1.2}$ in wheat.
Keywords: *soil compaction, mechanical resistance, water transmission, root proliferation, crop productivity*

Introduction

Alternate tillage practices and excessive use of machinery leads to soil compaction and hard pan formation in subsurface soil layer (Kukal and Aggarwal, 2003; Singh et al., 2009) this may affect the growth of wheat and maize due to reduced water transmission and root proliferation (Gajri et al., 1994). The deep tillage (DT) enhances rooting system by lowering soil strength which helps in better uptake of water and nutrients from the deeper layers (Gajri et al., 1994). On the other hand, conservation tillage i.e. no-tillage with residue retention (NT) provide favorable soil environment by improving soil water transmission, moisture storage, aggregation, carbon sequestration and crop productivity (Tessier et al., 1990). This practice also improves economic performance, energy use efficiency and reduces production risks (Zentner et al., 2002; Lal, 2003). The area under NT has been substantially increased in South Asia and particularly Indo-Gangetic plains (Derpsch et al., 2010). Continuous use of NT can cause measurable changes in soil hydrological, mechanical, physical, chemical and biological properties (Lal and Elder, 2008). The other conservation tillage practice i.e. strip till (ST) disturbs the soil minimally and it also manages to keep the previous crop residue in between the rows. However, the conventional tillage (CT) practices lead to breakdown of soil structure which subsequently affects soil water transmission characteristics, soil organic matter depletion, microbial activity and crop productivity

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(Ramos et al., 2011). The CT, including intensive soil cultivation and crop residue removal and burning, have exacerbated soil erosion and degradation, thus contributing to the development of soils with low organic matter contents and a fragile physical structure. There is thus an urgent need to identify land management practice which would help in sustaining soil physical health as well as crop productivity. Since, it is difficult to sow wheat and maize directly in the standing stubbles and the loose residue of previous crops, the farmers, mostly, burn them for seed bed preparation. The crop residue burning or removal can cause huge loss to soil fertility, physical health and environmental issues such as aerosols (Sidhu et al., 2007). However, with the help of NT practices, residue management problem can be solved to a great extent (Afzalinia and Zabihi, 2014). Water stress (both due to excessive and deficient soil moisture conditions) at any growth stage of wheat and maize can reduce crop and water productivity (Paudyal et al., 2001). Thus, optimum irrigation is a solution to this problem. The knowledge of wheat and maize performance at various irrigation regimes is of utmost importance in a semi-arid environment to improve water productivity. Water scarcity and uneven distribution are considered to be the primary limiting factors affecting wheat and maize production in the semiarid region (Kang et al., 2002; Wang et al., 2009). There are few reports on the interactive effects of straw mulching and DT in relation to irrigation regimes on crop yield. There is thus, dire need to find out a suitable land management practice along with optimum irrigation to resolve soil physical constraints and improve crop productivity. This study examined the combined effects of tillage and irrigation on soil water transmission characteristics, yield and water productivity of wheat and maize in a semi-arid sub-tropical environment of Punjab in northwest India.

Materials and methods

A field study was conducted at research farm of Department of Soil Science, Punjab Agricultural University, Ludhiana (30° 56’ N, 75° 52’ E, 247 m above the mean sea level), Punjab, India. The area is characterized by sub-tropical and semi-arid type of climate with hot and dry summer from April to June followed by hot and humid period during July to September and cold winters from November to January. The average rainfall of the area is 600-700 mm, of which about 80 percent is received during July to September. The soil was non calcareous, non-saline, neutral with medium organic carbon content.

The treatments includes four tillage practices i.e. no-tillage with residue (NT), strip tillage (ST), conventional tillage (CT) and deep tillage (DT). In NT practice, the surface residue was retained and sowing of both wheat and maize was done directly in standing stubbles and loose straw of previous crop, however, in ST, the seedbed is tilled in strips leaving the residue in between undisturbed. The conventional tillage (CT) involved five field operations i.e. two disks, two cultivator followed by one planking operation, whereas in DT the deep ploughing of soil was done up to 45 cm followed by CT. The irrigation treatments include three irrigation water over pan evaporation (IW/PAN-E) ratios, 1.2, 0.9 and 0.6. The experiment was conducted in split plot design with three replications. The tillage treatments were kept in main plots and irrigation in sub plots. The recommended dose of fertilizers as per Punjab Agricultural University package of practices were applied at the rate of 125 kg N ha^{-1} in the form of urea, 62.5 kg P_2O_5 ha^{-1} in the form of single superphosphate and 30 kg K_2O ha^{-1} in the form of muriate of

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potash to both the crops. The wheat and maize crops were sown with the recommended seed rate of 100 and 20 kg ha^{-1}, respectively. Weeds were kept under check with use of recommended herbicides and hand weeding. The manual harvesting of wheat was performed in mid April, while decobbing of harvested maize crop was done mechanically after sun drying and the seed yield was recorded from each plot.

Infiltration was measured, *in-situ* at the end of cropping cycle by double ring infiltrometer method according to 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 saturated hydraulic conductivity (K_s) was determined using constant head method (Reynolds et al., 2002). Undisturbed soil cores (8 cm diameter and 7.5 cm length) were collected from 0-7.5 and 7.5-15 cm depths. Samples were saturated in the laboratory by placing on cloth covered perforated disks in 25 cm deep tray containing 5 cm of water. Saturated soil sample along with core was connected with another core and to avoid the water leakage grease was applied in the jointing place on the top of previous core. A thin layer of water was slowly poured on top of the sample by using siphons connected to a constant head device (Mariotte apparatus). The volume of water that percolates through the sample was measured at definite intervals of time. The K_s was calculated using the following equation:

$$K_s = (Q/At) \times \{L/(H+L)\} \quad \text{(Eq.1)}$$

where,
Ks = saturated hydraulic conductivity (cm h^{-1}),
Q = volume of percolate collected (cm^3),
L = length of soil column (cm),
A = cross sectional area of soil column (cm^2),
t = time (h),
H = depth of water above soil (cm).

For determining soil bulk density (ρ_b) the undisturbed soil cores were taken at the end of cropping cycle upto 30 cm depth (0-7.5, 7.5-15, 15-22.5 and 22.5-30 cm) with the help of cylindrical core (7.5 cm height and 8.0 cm diameter) and dried in an oven at 105 °C till the weight of the soil becomes constant. The ratio of dry soil mass (M_s) and internal volume (V_t) of the cylindrical ring is expressed as bulk density (ρ_b) of soil (Mg m^{-3}) (Blake and Hartge, 1986).

$$\text{Bulk density } (\rho_b) = M_s/V_t \quad \text{(Eq.2)}$$

The penetration resistance (PR) was measured by a hand-held digital cone penetrometer (CP40II; Rimik electronics, RFM Australia) at three randomly selected locations within a plot. The soil PR readings were recorded up to 60 cm depth. The measurements were made at the end of the cropping cycle along with simultaneous measurements of soil moisture content.

Soil moisture samples were taken for entire soil profile (0-120 cm soil depth with 15 cm increments) with screw auger. Moisture storage in different layer was computed by multiplying the mass water content depth of a particular layer and bulk density. It was summed up for all the layers to get profile moisture storage in cm. Surface soil (0-15 cm) samples were collected for aggregate size analysis Aggregate status of soil was

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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 sieve sets 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 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. Mean weight diameter (MWD) and water stable aggregates (WSA) were calculated using the formula:

$$\text{MWD} = \sum_{i=1}^{n} d_i \times w_i \qquad \text{(Eq.3)}$$

$$\text{WSA} > 0.25\ \text{mm}(\%) = \frac{\sum_{i=1}^{n} w_i}{\text{weight of sample}} \times 100 \qquad \text{(Eq.4)}$$

where, n is 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. Oxidizable soil organic carbon was estimated using (Walkley and Black, 1934) rapid titration method, using a diphenyl amine indicator.

The plant height of ten randomly selected plants in each plot was measured with the help of meter scale from ground surface to apex of the plant at 70 days after sowing (DAS) in maize and 100 DAS in wheat. The root distribution was measured at 70 DAS in maize and 100 DAS in wheat. The root samples were collected from 0-15, 15-30, 30-45 and 45-60 cm soil layers. For root sampling, the soil cores were taken with the help of core sampler of 5 cm diameter. Samples were taken in between the plant rows. The root-soil cores were then collected and washed in plastic nets. Roots were carefully separated from the soil by washing the nets under water. The washed roots were further cleaned to remove any leftover weed roots, seed and other organic debris. The root length density (RLD) (cm cm^{-3}) was calculated from the total length of roots measured by scanner to the volume of the core. A representative sample of one thousand grains of maize from each plot was counted manually and weighed on a precision balance and expressed in grams. However, a representative sample of one thousand grains of wheat from each plot was counted with the help of automatic seed counter (SLY-C Automatic Seed Counter, Shailron Technology Pvt. Ltd.) and weighed on a precision balance and expressed in grams.

The crop biomass determination was made by taking all the above ground plant parts at time of harvesting. The samples were allowed to dried and then weighed to express in Mg ha^{-1}. The harvested crop produced from each plot was thrashed in case of wheat and decobbed in maize. Grain yields of both the crops were recorded in kg from 24 m^2 area in each plot and finally expressed in Mg ha^{-1}. The water productivity was calculated by dividing the grain yield of corresponding treatments of both the crops with the total water use (irrigation water + rainfall + profile water use) in particular treatment. The data

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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

Bulk density (ρ_b) and penetration resistance (PR)

Soil mechanical characteristics including ρ_b and PR affect other soil properties as well as the crop productivity. The data presented in *Figure 1* showed that at subsurface soil depth (15-30 cm), where the chances of occurrence of hard pan were prominent yielded highest ρ_b (Mg cm^{-3}) under CT (1.68) and minimum under in DT (1.52). Similar observations were recorded for other soil depths. The other two tillage systems recorded in between values. The use of heavy machinery and intensive tillage in CT for performing five field operations (twice disc, twice cultivators and one planking operation) can increase soil ρ_b at the ploughing depth (15 to 30 cm). Whereas, in case of DT the soils was shattered up to 45 cm depth, which break down the compaction and reduces ρ_b of soil. The DT experienced an all-time low ρ_b. However, the lower ρ_b in NT plots may be associated with greater soil biological activates, especially earthworms (Lal, 1976; Kahlon et al., 2012a). Jin et al. (2011) also reported that the mean ρ_b at 0-10 and 10-20 cm soil layers under NT practice was 2.1 per cent and 4.7 per cent significantly ($P< 0.05$) lower than under CT. In general with increase in depth there was an increase in ρ_b. The PR determines the soil strength which effect root proliferation. The PR measurements of soil can be used to assess the need for tillage operations, which will help in maintaining effective plant rooting and facilitate good water and nutrient uptake. In general, root tips are unable to penetrate pores narrower than their diameter. They can exert a vertical pressure ranging from 0.7 to 2.5 MPa, depending on crop species. Likewise soil ρ_b, the PR also showed maximum value in CT (2.8 MPa) and minimum in DT (1.9 MPa) at subsurface soil depth (15-30 cm) (*Figure 1*). This indicates the formation of hard pan, which restricts the downward movement of water and root penetration. Since the PR linked with the soil moisture content, its value decreased at lower soil depths. Maximum difference in PR values were observed between DT and CT at subsurface soil depth i.e. 15-30 cm. Kahlon et al. (2012b) reported higher soil PR in CT than NT. Penetrometer values greater than 2 MPa are generally reported to reduce root growth significantly (Atwell, 1993). In well-structured soils or those in which biochannels are preserved (as in non-tilled soils); roots continue to extend at greater penetrometer readings because they can grow in integrated space.

Water transmission characteristics

Soil management practices affect water transmission characteristics to such an extent that they may cause considerable loss to crop and water productivity. Significant differences ($P< 0.05$) in K_s were observed among tillage practices for 0-7.5 and 7.5-15 cm depths (*Figure 2*). The highest K_s (cm h^{-1}) were observed in DT (4.9 and 3.7) and the least under CT (3.8 and 2.2) at 0-7.5 and 7.5-15 cm depths, respectively. The higher K_s under DT may be due to more macro porosity. However, the NT plots showed more K_s than CT and ST. The presence of abundant roots and biochannels are responsible for rapid conduit of water through the soil under NT. The pore continuity maintained due to better aggregate stability and pore geometry also leads to higher K_s under NT. The

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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 (Singh et al., 1995; Bhattacharyya et al., 2006; Kahlon et al., 2012b). In general, K_s decreased with increase in depth in all tillage practices. Due to more soil disturbance and trafficking the macro pores reduced under CT which leads to lowest K_s.

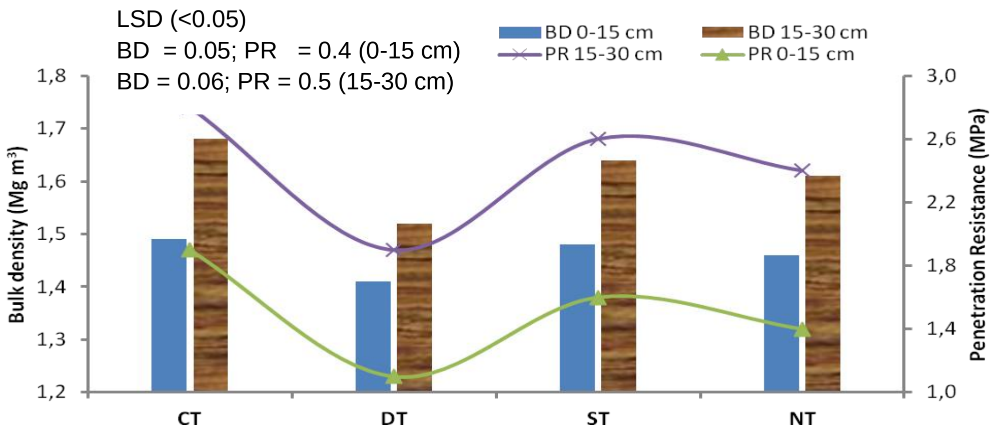

Figure 1. *Effect of tillage practices on soil bulk density and penetration resistance recorded at the end of wheat-maize cropping system (DT = deep tillage; CT = conventional tillage; ST = strip tillage; NT = no-tillage)*

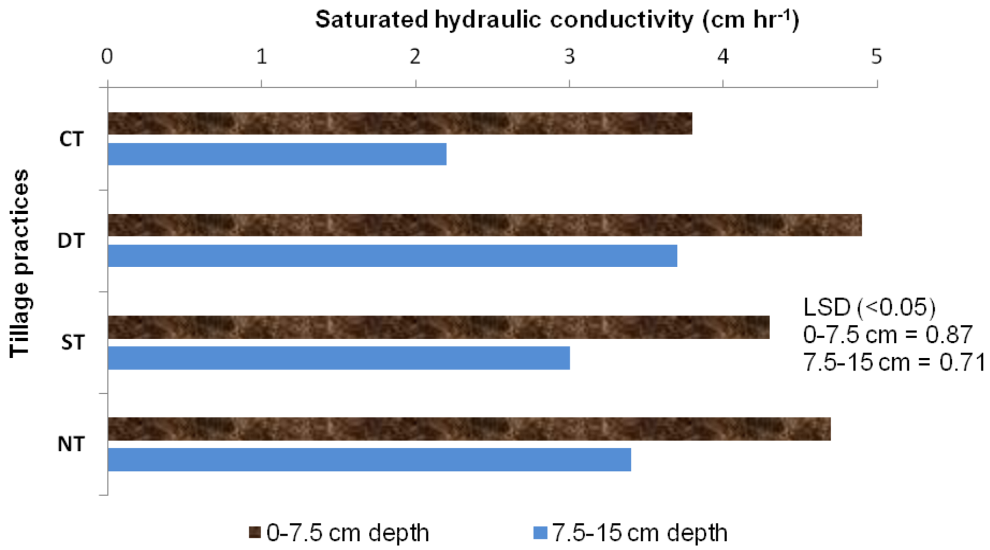

Figure 2. *Saturated hydraulic conductivity as affected by tillage practices at 0-7.5 and 7.5-15 cm soil depth measured in wheat-maize cropping system (DT = deep tillage; CT = conventional tillage; ST = strip tillage; NT = no-tillage)*

Final infiltration rate (IR) was also found to be significantly affected by tillage practices (*Table 1*). Mean highest IR (cm h^{-1}) was observed under DT (3.9), followed by NT (3.5), ST (3.1) and CT (2.7). The higher infiltration recorded under DT attributes to more macro porosity which leads to fast entry of water into the soil profile. The NT still

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recorded more IR than CT and ST. The reason cited for higher IR under NT than CT may be due to higher SOC content, continuity of water conducting pores, biochannels and MWD which led to a better pore size distribution (Azooz et al., 1996; Jabro et al., 2008). In pattern of IR the maximum cumulative infiltration (CI) was observed under DT (30.6 cm) followed by NT (24.3 cm), ST (21.7 cm) and CT (18.2 cm) (*Table 1*). The higher IR observed under DT reflect the breakdown of hard pan which restricts downward entry of water into the soil. As concluded by Shaver et al. (2002), more number of macropore channels in DT aided in better water transmission characteristics as compared to other tillage treatments. This may also be due to less stable aggregates in the CT practice which upon intense rainfall event clogs the soil pores through slaking of aggregates leading to decrease in water transmission through the soil as also reported by Mbagwu and Auerswald (1999). Further, less soil disturbance in the NT also kept pore structure continuous which aids greater water transmission through the soil. Another reason cited by the researchers to support conservation tillage is that the crop residues left on the soil surface limit evaporation, soil sealing and crusting and thereby increase soil infiltration (Gangwar et al., 2006). Water transmission through the soil profile also depends on the antecedent water content, aggregation and the presence of macropore channels. Least value was observed under CT might be due to relatively smaller pore heterogeneity, discontinuity of pores and less stable aggregates. Maximum water holding capacity (%) and soil moisture storage (cm) was observed in NT (41.8 and 9.6), respectively. Whereas, the minimum values of both were recorded under CT (*Table 1*).

Table 1. *Soil physical characteristics under different tillage practices in wheat- maize system*

Tillage practices	MWD (mm)	WSA (>0.25 mm, %)	IR (cm h^{-1})	CI (cm)	WHC (%)	SMS (cm)
CT	0.39	28.9	2.7	18.2	39.8	8.7
ST	0.48	36.1	3.1	21.7	41.4	9.3
NT	0.58	41.6	3.5	24.3	41.8	9.6
DT	0.36	27.4	3.9	30.6	40.3	8.8
Mean	0.45	33.5	3.3	23.7	40.8	9.1
LSD (<0.05)	0.19	2.8	0.5	4.2	1.6	0.6

CT: conventional tillage; ST: strip tillage; NT: no-tillage; DT: deep tillage; MWD: mean weight diameter; WSA: water stable aggregates; IR: infiltration rate; CI; cumulative infiltration; WHC: water holding capacity; SMS: soil moisture storage

Mean weight diameter (MWD), water stable aggregates (WSA > 0.25 mm) and soil organic carbon

Tillage practices experienced a significant effect on soil aggregation as observed from the data for both the indicators i.e. MWD and WSA (>0.25 mm) (*Table 1*). Among tillage practices, the mean highest MWD (mm) of 0.58 was found under NT followed by ST (0.48), CT (0.39) and least under DT (0.36). Mathematical representation foretells that the mean highest WSA (> 0.25 mm, %) of 41.6 was observed in NT followed by ST (36.1), CT (28.9) and DT (27.4). The DT showed significantly lower values of MWD and WSA in comparison to other treatments. The higher soil aggregation observed in NT attributes to the non disturbed soil conditions and retention of crop residue on soil surface, which helps the aggregates to break from direct raindrop

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impacts as well as with addition of organic matter in the soil. Different aggregate size fractions (per cent) as affected by tillage practices are presented in *Figure 3*. The data on aggregate size distribution indicate that greater proportion of smaller particles with size < 0.25 mm was found in DT as compared with other tillage treatments. However, the proportion of larger size aggregates (> 1.0 mm) follows the order NT > ST > CT > DT (*Figure 3*). It is well established fact that soil aggregation correlated significantly with the organic carbon content of soil. The same was reported in present study, where, the SOC content was more i.e. under NT practice the bigger size aggregates were also recorded in that treatment. The NT recorded 28 % more SOC than DT (*Figure 4*).

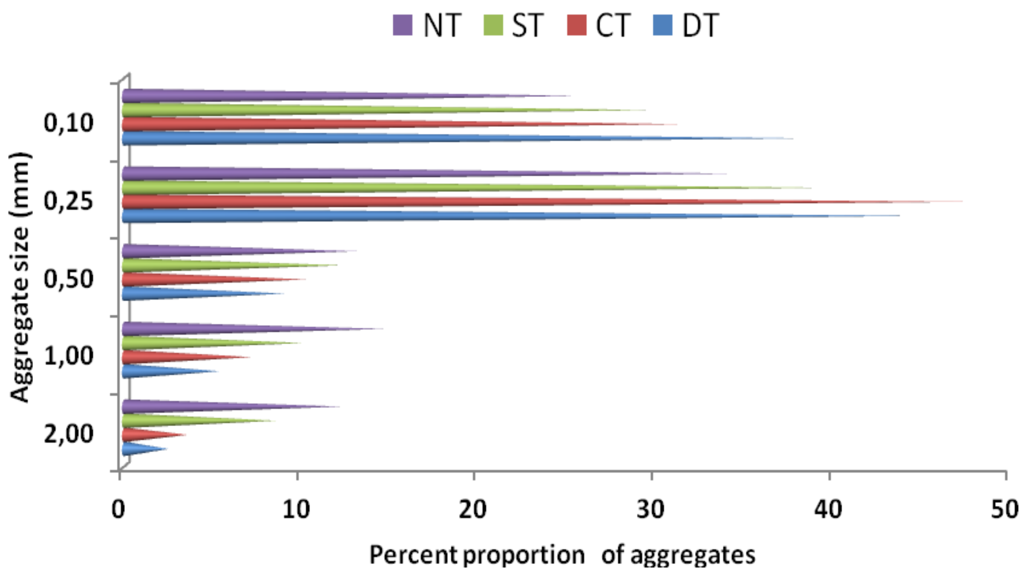

Figure 3. *Percent proportion of aggregate size fractions under different tillage practices in wheat-maize cropping system (DT = deep tillage; CT = conventional tillage; ST = strip tillage; NT = no-tillage)*

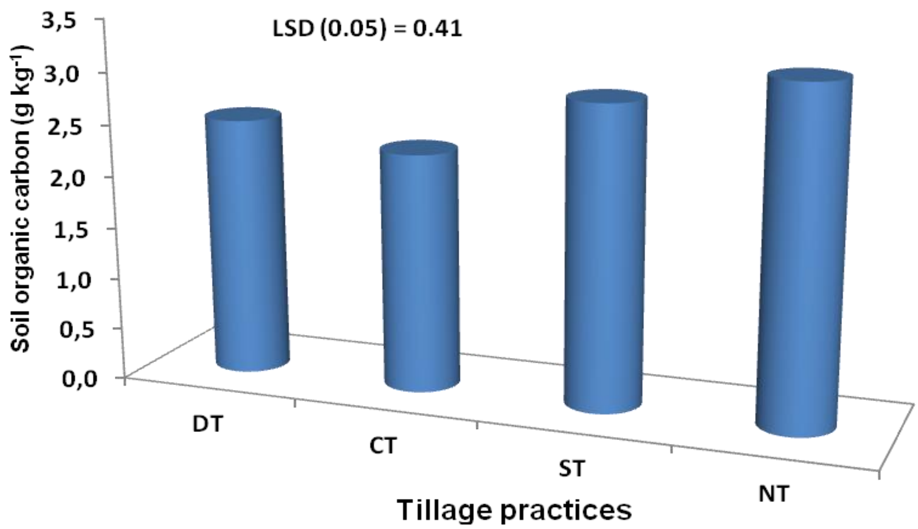

Figure 4. *Soil organic carbon under different tillage practices in wheat-maize system (DT = deep tillage; CT = conventional tillage; ST = strip tillage; NT = no-tillage)*

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Root length density (RLD)

In general, the increase in subsoil compaction resulted in reduced rooting system. According to the data presented in *Table 2*, it was observed that due to high soil ρ_b and PR in subsurface soil layer (15-30 cm), CT recorded the least RLD while its maximum value was recorded in DT. However, due to more availability of soil moisture and nutrients in surface layer (0-15 cm) the NT had more RLD than CT and ST. Alternatively, the main reason for higher RLD in DT is the removal of compact hard pan below surface soil layer which otherwise restrict the root proliferation to lower soil depths. Similar observations were recorded for the wheat crop (*Table 2*). The higher root concentration observed in NT attributes to formation of bio channels. However, under CT the presence of plow pan does not allow easy root penetration. Arora et al. (1991) reported that increased tillage reduces soil strength in tilled zone which results in better growth of maize as strength is negatively correlated with root growth. Kumar (2005) studied the effect of tillage on root development of maize and reported that depth of roots at harvest was maximum under DT as compared to CT.

Table 2. *Root length density (cm cm^{-3}) under different tillage practices in wheat- maize system at different soil depths*

Tillage practices	Wheat				Maize			
	Soil depth (cm)							
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
CT	0.83	0.48	0.22	0.16	1.14	0.62	0.41	0.18
ST	0.78	0.56	0.27	0.21	1.05	0.74	0.47	0.22
NT	1.04	0.59	0.38	0.23	1.23	0.97	0.51	0.25
DT	1.12	0.73	0.42	0.27	1.66	1.11	0.65	0.35
Mean	0.94	0.59	0.32	0.22	1.27	0.86	0.51	0.25
LSD (<0.05)	0.11	0.09	0.06	0.05	0.32	0.18	0.16	0.07

CT: conventional tillage; ST: strip tillage; NT: no-tillage; DT: deep tillage

Plant parameters and productivity of maize and wheat

The data pertaining to tillage effects on plant parameters and productivity of maize and wheat is presented in *Table 3*. It depicts that DT outperformed the other tillage treatments with respect to plant height, thousand grain weight and crop biomass for both the crops. The highest maize grain yield (Mg ha^{-1}) was recorded in DT (6.4) followed by NT (6.3), ST (5.9) and CT (5.5). The same yield pattern was observed for wheat crop. The water productivity (kg ha^{-1} mm^{-1}) was also observed to be maximum in DT (8.8) and least in CT (7.2) for maize crop. The WP of wheat followed the similar trend. The irrigation regimes also significantly affect the plant parameters and crop productivity of both the crops (*Table 4*). Maximum maize grain yield (Mg ha^{-1}) was recorded at irrigation regime $I_{0.9}$ (6.5) followed by $I_{1.2}$ (6.2) and least under $I_{0.6}$ (6.1). Irrigation regimes also showed significant effect on water productivity (WP). The mean highest water productivity (kg ha^{-1} mm^{-1}) was found under $I_{0.9}$ (8.7) and the lowest under $I_{0.6}$ (7.8) for maize. The water productivity decreased with increase in IW/PAN-E ratio (0.6 to 1.2). Memon et al. 2013 also reported higher maize grain yield in DT than NT and CT treatments. The increase in yield with increase in number of irrigations is because of

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more availability of water for plant physiological processes. Mojid et al. (2009) also reported decrease in water productivity with increase in irrigation level.

Table 3. *Plant height, thousand grain weight, crop biomass, crop yield and water productivity of wheat and maize under different tillage practices*

Tillage practices	Plant height (cm)		Thousand grain weight (g)		Crop biomass (Mg ha^{-1})		Crop yield (Mg ha^{-1})		Water productivity (kg ha^{-1} mm^{-1})	
	Wheat	Maize	Wheat	Maize	Wheat	Maize	Wheat	Maize	Wheat	Maize
CT	0.84	2.21	35.8	253.7	12.8	14.9	3.8	5.5	18.7	7.2
ST	0.92	2.42	37.6	267.6	13.2	15.2	4.0	5.9	19.4	7.6
NT	0.88	2.57	39.5	287.5	14.1	16.3	4.1	6.3	20.6	8.1
DT	1.12	2.62	42.3	301.4	14.6	17.6	4.3	6.4	22.2	8.8
Mean	0.94	2.46	38.8	277.6	13.7	16.0	4.0	6.0	20.2	7.9
LSD (<0.05)	0.08	0.18	3.6	16.2	0.8	1.4	0.3	0.51	1.7	0.8

CT: conventional tillage; ST: strip tillage; NT: no-tillage; DT: deep tillage

Table 4. *Plant height, thousand grain weight, crop biomass, crop yield and water productivity of wheat and maize under different irrigation regimes*

Irrigation regimes	Plant height (cm)		Thousand grain weight (g)		Crop biomass (Mg ha^{-1})		Crop yield (Mg ha^{-1})		Water productivity (kg ha^{-1} mm^{-1})	
	Wheat	Maize	Wheat	Maize	Wheat	Maize	Wheat	Maize	Wheat	Maize
I1	1.02	2.49	41.5	280.6	14.4	16.2	4.3	6.2	21.3	8.2
I2	0.95	2.58	37.6	282.6	13.5	16.6	4.0	6.5	20.2	8.7
I3	0.89	2.30	35.9	269.3	13.1	15.7	3.8	6.1	19.4	7.8
Mean	0.95	2.46	38.3	277.5	13.7	16.1	4.0	6.3	20.3	8.2
LSD (<0.05)	0.09	0.21	2.2	7.4	0.7	0.6	0.3	0.3	0.9	0.4

I1: IW/ PAN-E ratio 1.2; I2: IW/ PAN-E ratio 0.9; I3: IW/ PAN-E ratio 0.6 (for both wheat and maize)

It is concluded that under compaction or hard pan formation at subsurface soil layer the deep tillage (DT) is most appropriate practice while under water stress situation the no-tillage with residue retention (NT) is viable option for achieving higher crop and water productivity in maize-wheat system in northwest India.

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