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Soil Porosity as Affected by Land Management Practices in Sandy Loam and Loamy Sand Soils

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Abstract Land management practices significantly affect soil porosity and related characteristics including soil moisture characteristics, soil consistency and water holding capacity. Hence, a field study was conducted with 3 land management practices in main plots including conventional tillage (CT), no-tillage with residue (NTR) and deep tillage (DT) under 2 textured soils i.e. sandy loam and loamy sand with 3 replications. Soil porosity (%) was found to be significantly higher under DT (0.494 and 0.416) followed by CT (0.478 and 0.399) and least in NTR (0.458 and 0.383) in sandy loam and loamy sand soils, respectively. However, the effect of tillage and residue management practices on soil consistency limits i.e. liquid limit and plastic limits were neither significant nor uniform. The highest liquid limit was found in NTR (45.9) in sandy loam while, the same was highest in DT (39.7) in loamy sand soil. The liquid limits were found to be 36.7 and 44.8 in CT in loamy sand and sandy loam soils, respectively. The plastic limit followed the similar trend with maximum value was observed in NTR (19.7 and 22.8) followed by CT (18.8 and 22.2) and least in DT (18.3 and 21.7) in loamy sand and sandy loam soils, respectively. The soil organic carbon content (g kg^{-1}) was found to be highest under NTR (4.2 and 4.7) followed by CT (3.8 and 4.1) and least in DT (3.6 and 3.9) in loamy sand and sandy loam soils, respectively. Maximum water holding capacity (%) was observed in NTR (48.2 and 41.3) followed by DT (45.4 and 38.7) and minimum in CT (43.5 and 34.5) in sandy loam and loamy sand soils, respectively. At field capacity (0.3 bar suction) the maximum soil moisture content was observed in NTR (24.3 and 18.1), followed by DT (23.8 and 17.6) and least in CT (22.7 and 17.3) in sandy loam and loamy sand soils, respectively. Mean maximum GMD (mm) was observed in NTR (1.5 and 1.2) followed by CT (1.3 and 1.1) and least under DT (1.2 and 0.9) in sandy loam and loamy sand soils, respectively.

Keywords Soil porosity, Soil consistency limits, Organic carbon, Geometric mean diameter, Water holding capacity.

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Introduction

Soil tillage is one of the basic agricultural operations which significantly influence soil physical characteristics. Soil structure is largely influenced by tillage and the implements used for tillage (Acharya and Sharma 1994, Pagliai et al. 1995). The intensity of tillage effect porosity, soil consistency, soil moisture characteristics. However, the effect of not disturbing the soil i.e. conservation tillage on soil physical properties depend upon soil type and soil water-storage capacity (Hemmat and Eskandari 2004). According to Lampurlanés et al. (2001), conservation tillage increases stored soil water by increasing infiltration and reducing evaporation, but depending on the soil type and climatic conditions, this leads to higher, equal or even lower yields than conventional tillage systems. For example, McMaster et al. (2002) reported that grain yields were always equal or higher in no-tillage than on moldboard plowed plots, while Unger (1994) found that tillage system had no effect on yield in long-term trials. The aim of this investigation was to determine the influence of 3 tillage systems on soil physical properties in sandy loam and loamy sand soils. 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 the 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 decrease disturbance of soil, improve soil organic carbon (SOC) content, maintain 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). Studies in Punjab (Kukal and Aggarwal 2003 and Singh et al. 2009) have shown the presence of high p_b layer at 15-25 cm soil depth, which may affect the growth of maize due to reduced root proliferation (Gajri et al. 1994). Soil porosity is the best guide to soil structural condition (Greenland 1981). Shipitalo and Protz (1987) observed no significant difference in mean pore number among treatments. However, mean porosity in samples from tilled plots was almost twice that of samples from no-till plots. Because porosity was greater in samples from tilled plots than in samples from no-till plots and no significant differences in pore numbers were detected it follows that mean pore size must be larger in samples from tilled plots. Mean pore area and maximum diameter represent 2 measures of pore size that were performed. Mean pore area for tilled samples was more than twice that of no-till samples. However, mean pore maximum diameter for tilled samples was only 20% greater than that for no-till samples. Pores in tilled samples had more irregular boundaries than did pores in no-till samples. The plots indicated that at any given equivalent circular diameter, a greater proportion of pores were smaller than the indicated in no-till samples than in tilled samples. Differences between the 2 tillage treatments were greatest at the smallest pore size and diminished as pore size increased. This suggested that suspension of tillage operations in no-till plots did not result in the elimination of pores in a particular size range but that loss of macroporosity was accompanied by an overall reduction in equivalent circular diameter. Pores are of different size, shape and continuity and these characteristics influence the infiltration, storage and drainage of water, the movement and distribution of gases and the ease of penetration of soil by growing roots (Kay and VandenBygaart 2002). Physical and mechanical properties of cohesive (fine-grained) soils greatly depend on the water content. Soil consistency indicates the soil's resistance to deformation when exposed to mechanical forces. These limits and indices are helpful for classifying soils in relation with compaction and tillage practices (Soane et al. 1972,Campbell et al. 2001), optimum water content for tillage (Campbell et al. 2001, Dexter and Bird 2001, Keller et al. 2007 and in soil-machine interactions (Campbell et al. 2001). This, a study was conducted to evaluate the effect of different tillage practices on soil porosity, geometric mean diameter, soil moisture characteristics and soil consistency in sandy loam and loamy sand soils.

Materials and Methods

The field experiments were 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 meter above the mean sea level. 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 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 minimum temperature dips up to 0.5°C. The average rainfall of the area is 600-700 mm, of which about 80% is received during July to September. The mean maximum and minimum air temperatures show considerable fluctuations during different parts of the year. The meteorological data were collected from the meteorological observatory of the Punjab Agricultural University, Ludhiana located at a distance of 2 km from the experimental field during the crop growing season (May to September).

Tillage and residue management treatments include conventional tillage (CT) where, 2 disk, 2 cultivator operations were followed by 1 planking operation, no-tillage with residue (NTR) retention where, residue retention and sowing by happy seeder machine in standing wheat stubbles after combine harvesting and deep tillage (DT) where, chisel plough upto 45 cm soil depth followed by CT.

Total porosity and soil organic carbon

The total porosity of soil was calculated from the values of dry bulk density and an assumed particle density of 2.65 Mg m^{-3} using the following equation (Chancellor 1994, Fig.1). The result was multiplied 100 :

$$\text{Total porosity} = \left(1 - \frac{pb}{pp} \right) * 100$$

Where , pb is the dry bulk dessity (Mg m^{-3}) and pp is the particle density of soil (Mg m^{-3}). The oxidizable

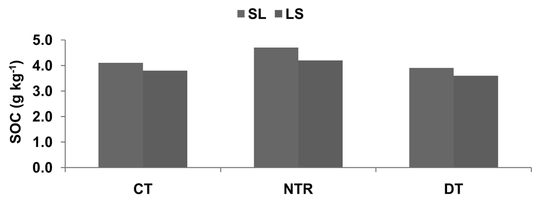

Fig. 1. Soil organic carbon in different tillage in loamy sand (LS) and sandy loam (SL) soils.

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

Water holding capacity

The water holding capacity of soil is the amount of water held in the soil at zero tension. It is expressed in terms of percentage. It depends on the pore space particularly macropores, which again depends on the amount and type of colloidal matter present in the soil and dominant cation associated with it. Water holding capacity and bulk density are determined by Keen Raczkowski box technique. A filter paper was placed at the bottom of the Keen Raczkowski box. The soil was packed by taping the box 20 times on a wooden bench. Small portion of the soil was further added to the box and tapped as before. Finally the top of the box was leveled by striking of the surplus soil with the straight edge of spatula. The box was then placed in a petridish containing water and was left for over night. The box containing the saturated soil was removed from the petridish, weight was taken, finally dried in an oven at 105° C and weight was recorded.

Soil consistency limits

Liquid limit : The liquid limit of a soil is the water content at which the soil behaves practically like a liquid, but has small shear strength. It flows to close the groove in just 25 blows in Casagrande's liquid limit device. The test was conducted for 3 times and the number of blows (N) required in each test was determined. To prepare uniform paste distilled water was added to 250 g of air-dried soil. Placed a portion of the paste in the cup of *Liquid Limit device* and spread it with a few strokes of spatula. Using the grooving tool, cut a groove along the center line of soil pat in the cup, so that clean sharp groove of proper dimension (11 mm wide at top, 2 mm at bottom and 8 mm deep) is formed. The cup was then lifted and dropped by turning crank at the rate of 2 revolutions per second until the 2 halves of soil cake come in contact with each other and recorded the number of blows. A representative portion of soil sample from the cup was taken for moisture content determination. The test was repeated 3 times.

Plastic limit : The plastic limit of a soil is the moisture content at which soil begins to behave as a plastic material. At this water content (plastic limit), the soil will crumble when rolled into threads of 3.2 mm (1/8in) in diameter. Water was added to the soil sample and mixed with spatula. Formed a ball from the watered soil sample using palms. Then form a uniform thread from the obtained soil ball by rolling it on a glass plate using palms and fingers. In this step care was taken to provide enough pressure by exerting 90 strokes per minutes–means forward and backward movement of hand from the starting position. The thread was rolled until it achieves 3 mm or 1/8 inches of diameter. Then the thread was broken into pieces and repeated the same procedures of above 2 steps for those broken pieces. The procedure was repeated until the rolling thread crumbles. Then measure the weight of the crumbled soil. Finally the moisture content was determined.

Geometric mean diameter (GMD)

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 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 water and the oven-dried weight of aggregates

Table 1. Effect of tillage practices on soil porosity (%) at different soil depths in sandy loam and loamy sand soils.

Tillage practices	Soil depth (cm) 0-7.5	7.5-15	15-22.5	22.5-30	Mean
		Sandy loam			
CT	0.547	0.494	0.448	0.425	0.478
NTR	0.521	0.476	0.432	0.404	0.458
DT	0.554	0.511	0.477	0.432	0.494
Mean	0.541	0.494	0.452	0.421	
LSD (<0.05%)	0.023	0.027	0.031	0.022	
		Loamy sand			
CT	0.460	0.415	0.366	0.355	0.399
NTR	0.457	0.389	0.347	0.340	0.383
DT	0.468	0.426	0.392	0.377	0.416
Mean	0.457	0.401	0.362	0.350	
LSD(<0.05%)	NS	0.027	0.020	0.026	

retained on each sieve was recorded after drying these in an oven at 105° C till the constant weight achieved. The data was analyzed to compute geometric mean diameter (GMD).

$$GMD = \exp\left(\sum W_i \log X_i / \sum w_i\right)$$

Results and Discussion

Effect of tillage and residue management practices on soil porosity

The data pertaining to effect of tillage-residue management practices on soil porosity are presented in Table 1. Maximum mean soil porosity (0-30 cm depth) was recorded in DT (0.494 and 0.416) followed by CT (0.478 and 0.399) and least in NTR (0.458 and 0.383) in sandy loam and loamy sand soils, respectively. Similar results were also observed by Alam et al. (2014). Pagliali et al. (1995) reported higher porosity in samples from tilled plots than in samples from no tilled plots. Shipitalo and Protz (1987) observed no significant difference in mean pore number among tillage treatments. However, mean porosity in samples from tilled plots was almost twice that of samples from no-till plots. Mean pore area for tilled samples was more than twice that of no-till samples. However, mean pore maximum diameter for tilled samples was

Table 2. Effect of tillage practices on liquid and plastic limits (%) under different textured soils.

Tillage practices	Loamy sand 0-15	Loamy sand 15-30	Sandy loam 0-15	Sandy loam 15-30
		Liquid limit		
CT	36.7	38.2	44.8	47.1
NTR	38.1	39.3	45.9	47.7
DT	39.7	39.8	45.6	45.5
Mean	38.2	39.1	45.4	46.7
LSD (<0.05%)	1.4	NS	NS	NS
		Plastic limit		
CT	18.8	20.9	22.2	23.8
NTR	19.7	21.4	22.8	24.3
DT	18.3	20.6	21.7	23.4
Mean	18.9	21.0	22.2	23.8
LSD (0.05%)	1.2	NS	NS	NS

Table 3. Effect of tillage practices on soil moisture characteristics at different suctions.

Tillage practices	Suction 0.3	0.5	1.0	5.0	10.0	15.0
			Loamy sand			
CT	17.3	16.1	14.3	12.1	7.4	6.8
NTR	18.1	17.3	16.6	14.4	9.2	7.6
DT	17.6	16.5	14.8	13.1	8.1	7.1
Mean	17.7	16.6	15.2	13.2	8.2	7.1
LSD (<0.05%)	NS	NS	NS	1.2	NS	NS
			Sandy loam			
CT	22.7	18.3	17.4	15.1	10.4	9.9
NTR	24.3	19.7	19.2	17.4	13.5	11.4
DT	23.8	19.3	18.1	16.4	11.8	10.3
Mean	23.6	19.1	18.2	16.3	11.2	10.5
LSD (0.05%)	NS	NS	NS	NS	0.6	NS

only 20% greater than that for no-till samples.

Soil consistency limits

Liquid limit and plastic limits

Tillage and residue management practices also affect soil consistency limits i.e. liquid limit was found to be higher in NTR (45.9), followed by DT (45.6) and minimum in CT (44.8) in sandy loam soil, while the same was observed to be highest in DT (39.7) followed by NTR (38.1) and minimum in CT (36.7) in loamy sand soil, respectively (Table2). The plastic limit followed almost similar trend with maximum value was observed in NTR (19.7 and 22.8) followed by CT (18.8 and 22.2) and least in Dt (18.3 and 21.7) in loamy sand and sandy loam soils, respectively. Zolfaghari et al. (2015) reported that the liquid limit (LL) and plasticity index (PI) showed significant differences among the land uses; the highest values belonged to the irrigated farming due to high biomass production and plant residues returned to the soils. Furthermore, slope position significantly affected the Atterberg limits and consistency indices. The highest values of LL and PI were observed in the toe slope position probably because of higher OM and CEC/clay due to greater amount of expandable phyllosilicate clays. Overall, soils on the toe slope under irrigated farming with high LL and SI and low values of FI need careful tillage management to avoid soil compaction. Manyiwa and Dikinya (2014) reported significant difference between PL and LL ($p<0.05$) in all tillage treatmnts. High compaction in zero tillage (2.28 MPa) is attributed to relatively higher percent of clay (16%) . The finer clay particles cause the particles to easily bind together. This is supported by Sekwakwa and Dikinya (2012) who stated that cohesive soils are susceptible to compaction. Soils with high clay content normally have high liquid limit and plastic limit because of the binding potential of clay particles with instant retardation of detachment. While sand particles are easily merged together (because of no binding) hence they easily come together and lead to low plastic and liquid limit (Manyiwa and Dikinya 2013). According to Hamza and Anderson (2005), there is positive correlation between PR and PL and LL. Conventional tillage with relatively low LL and PL compared to deep-ripping tillage.

Soil moisture characteristics

The Table 3 represents the soil moisture characteristic curve i.e. relationship between soil water content at different suction value. At field capacity (0.3 bar suction), maximum soil moisture content was observed in NTR (24.3 and 18.1), followed by DT (23.8 and 17.6) and least in CT (22.7 and 17.3) in sandy loam and loamy sand soils. Similarly at permanent wilting point (15 bar suction) highest soil water content was

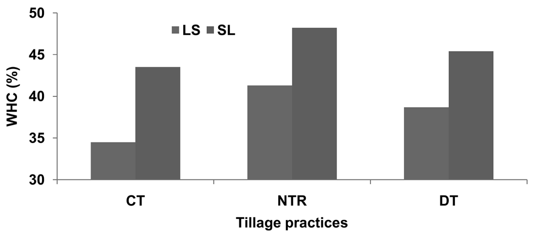

Fig. 2. Effect of tillage-on water holding capacity (%) in loamy sand (LS) and sandy loam (SL) soils.

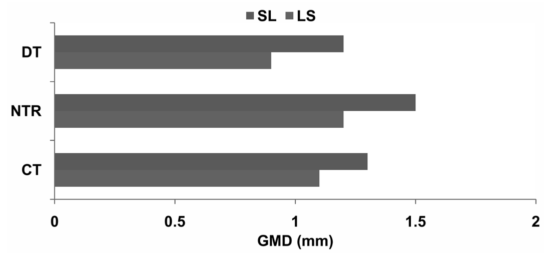

Fig. 3. Effect of tillage practices on geometric mean diameter (mm) in SL and LS soils.

recorded in NTR (11.4 and 7.6) followed by DT (10.3 and 7.1) and minimum in CT (9.9 and 6.8) in sandy loam and loamy sand soils, respectively. Noelmeyyer et al. (2013) reported higher water content under NTR than CT at field capacity and permanent wilting point.

Water holding capacity (%)

The Fig. 2 depicts the significant effect of tillage-residue management practices on water holding capacity (%). Maximum water holding capacity (%) was observed in NTR (48.2 and 41.3), DT (45.4 and 38.7) and CT (43.5 and 34.5) in sandy loam and loamy sand soils, respectively. It was observed that tillage treatments (moldboard plowing, chisel plowing and disk plowing) may effect soil water holding capacity and soil physical properties. Soil water holding capacity was investigated by plotting soil water characteristic curves for different tillage treatments. These curves were constructed by measuring soil moisture potential and moisture content. Potential was measured using watermark sensor and moisture content was measured by gravimetric method. Significant differences were reported for the 10% probability level. Dry bulk density from 0 to 20 cm was affected by tillage treatments and from 20 to 40 cm by axle load. Tillage systems generally affected the ability of the soils to hold moisture and the available water capacity. Earlier experiment was conducted to study the effects of no-tillage on the spatio temporal dynamics of soil water content and related soil physical properties in spring corn fields in Beijing region during growth season. In study period, the water storage in 0-100 cm soil layer in tillage and no-tillage treatments had the same variation trend with time and precipitation, but the water storage at different time periods and under different precipitations was 2.7%—30.3% higher in no-tillage treatment than in tillage treatment. When the precipitation was relatively abundant, the increment of soil water storage was somewhat increased, but no-tillage was still worth to be popularized in the regions relatively deficit in precipitation. Under no-tillage, the average water storage in 0-100 cm soil layer during the 3 growth seasons in 2006-2008 was 3.4%-12.8% higher than that under conventional tillage and the increment of the water storage in 0-20 cm and 80-100 cm soil layers under no-tillage was higher than that in intermediate layer, with the highest increment reached 22.2%. No-tillage improved soil water -holding capacity and water use efficiency via decreasing soil bulk density, Increasing soil porosity and promoting the formation of soil water-stable aggregates and thereby, promoted crop yielding. After 3 years no-tillage, the soil water use efficiency and spring corn yield were increased by 13.3% and 16.4%, respectively, compared with those under conventional tillage.

Geometric mean diameter (GMD)

The Fig. 3 represents the significant effect of tillage residue management practices on GMD (mm). Mean maximum GMD (mm) was observed in NTR (1.5 and 1.2) followed by CT (1.3 and 1.1) and least under DT (1.2 and 0.9) in sandy loam and loamy sand soils. It was found that frequent tillage operation caused mechanical disruption of macro aggregates and therefore reduced aggregate stability. Choudhury et al. (2014) reported that application of NT with residue resulted in 46.5% higher WSA in surface as compared to CT. Benbi and Senapati (2010) reported binding of residues and soil particulates into macro aggregates in higher proportion in surface than sub-surface soil layer. Mikha and Rice (2004) reported that tillage increased the effect of drying-rewetting and freezing-thawing, which increased 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.

Soil organic carbon (SOC)

The data regarding effect of tillage-residue management practices on SOC is presented in Fig.1. Tillage-residue management practices significantly affect the SOC. Among different tillage-residue management practices maximum SOC (g kg^{-1}) was found in NTR (4.7 and 4.2) followed by CT (4.1 and 3.8) and least under DT (3.9 and 3.6) in sandy loam and loamy sand soils. Saha et al. (2010) also observed more SOC in NTR (6.7 g kg^{-1}) than CT (5.7 g kg^{-1}). Hazarika et al. (2009) reported 14-17% higher SOC in surface soil under NTR than CT practices. Wang et al. (2008) reported that continuous long-term conservation tillage practice (NTR) significantly increased SOM in the surface soil (0 to 10 cm) layer . Many studies have reported lower SOC in CT when compared to NTR (Mishra et al. 2010). Kutcher and Malhi (2007) stated that retaining crop residues along with NT improved SOC, N and aggregation, while burning in combination with CT resulted in the deterioration of these soil properties.

Conclusion

Soil porosity which played important role in water transmission and aeration characteristics of soil was found to be significantly affected by tillage practices. Due to deep loosing of soil up to 45 cm soil depth, the soil porosity was found to be higher under deep tillage as compared to undisturbed no-tillage practice. However, the soil consistency limit i.e. plastic limit was observed to be more under no-tillage practices. The geometric mean diameter and soil organic carbon was also found to be more under no-tillage than conventional and deep tillage. At all the soil suction levels the moisture content was found to be significantly more under no tillage than conventional and deep tillage and so more in sandy loam than loamy sand soil.

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