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Soil Surface Structure and Hydraulic Properties as Affected by Long-term Organic Matter Management in Cotton-Wheat System.

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Abstract

During the years 1990-1996, the highest grain yield and in 1996, the highest wheat root density resulted from application of farmyard manure. Farmyard manure application increased the soil organic matter content more than wheat straw and green-manure, which was attributed variation in nature and quantity of organic matter in each treatment. Saturated infiltration rate, hydraulic conductivity (K_{fs}), matric potential ($\varnothing m$), and bulk density (ρ_b) changed significantly with the profile depth, while, the treatment effect averaged over the profile was non-significant. The BA horizon (14-27 cm) had greater ρ_b and a lesser saturated infiltration than the horizons above and below. Un-saturated infiltration, K(I), and $\varnothing$(I) decreased as the tension (I) increased from -40 mm to -180 mm of water. Farmyard manure and wheat straw application resulted in greater infiltration rate, K(I), $\varnothing$(I) and greater number of large pores than the control without organic matter and green manure. In the Ap horizon plant available water increased due to wheat straw.

Introduction

Soil organic matter, *inter alia* other factor, plays a major role in improving soil plant available soil water and the structure stability. Approximately 3 g organic matter per 100 g soil is considered necessary for optimum soil physical conditions (Schindler, 1989). In the arid sub-tropics of Pakistan, summer soil temperature is high enough to cause increased oxidation of organic matter and consequently, these soils are inherently low in organic matter content, generally below 0.5 percent. Special agronomic practices are, therefore, needed to attain a level of soil organic matter content so that productivity remains unaffected.

Organic matter addition through application of green manure and animal manure improves water retention capacity, infiltration and hydraulic conductivity (Mbagwu, 1993; Klik and Salokhe., 1994; Obi and Ebo, 1995; Ohu *et al.*, 1994). Darwish *et al.* (1995) reported that long-term field application of animal manure increased water retention but the effect was dependent on soil texture. Green manuring (Sur *et al.*, 1993) and poultry manure (Obi and Ebo, 1995) increased water retention, which resulted in an increased available water content in the soil profile as concluded from long-term studies. Rapid microbial degradation of the manure could also be responsible for the lack of changes in some cases but generally, a high correlation between soil organic matter content and available water capacity exists (Obi and Ebo, 1995).

Organic matter improves soil structure (Kooistra, 1991). An increased total and macro-porosity and decreased bulk density was reported due to green-manuring (Sur *et al.*, 1993; Ohu *et al.*, 1994), application of animal manure (Sen *et al.*, 1994; Zhu and Yao, 1993), and mixed organic sources (McCoy, 1992). An increased wet aggregate stability and decreased dispersible clay for a sandy loam and silt loam soil resulted due to long-term field application of animal manure (Darwish *et al.*, 1995). There is a high correlation between soil organic matter and total porosity (Obi and Ebo, 1995). Organic matter alleviated compaction as indicated by reduced bulk density, resistance to penetration, and shear strength (Ohu *et al.*, 1994). Soil compaction reduces percentage of $>50\mu m$ diameter pores but this damage is limited in a soil with >4.5 percent organic matter (Schindler, 1989).

Organic matter induces improvement in soil surface structure (Sur *et al.*, 1993) and the macropores can be estimated by measuring un-saturated infiltration by tension infiltrometer (White and Sully, 1987; White *et al.*, 1992; Hussen and Warrick, 1993; Logsdon, 1993a,b). Tension infiltrometer provides a rapid and practical method for determining temporal changes to surface hydraulic properties (Somaratne and Smettem, 1993; Messing and Jarvis, 1993; Angulo-Jaramillo *et al.*, 1997). The method offers a hydraulic technique to study the impact of management factors on *in situ* soil structure.

The soil parameters viz. surface soil structure, bulk density, infiltration/hydraulic conductivity, and water retention as affected by long-term organic matter management have not been quantified in Pakistan. Monitoring these parameters would be essential to determine the efficacy of organic matter management practices.

Materials and Methods

The soil occurs in an arid tropical climate with a mean annual rainfall of 150 to 175 mm, mean summer (May, June, July) temperature 31.5 °C (May being the hottest with 42.2 °C), and the mean winter (December, January, February) temperature 17.5 °C (Baig *et al.*, 1970). The site is located at a latitude of 25°25′40″ N and a longitude of 68°32′06″ E. The soil was *shallow over fine* phase of Sultanpur series classified as a Typic Camborthid. It consists of deep, excessively drained, coarse textured, moderately calcareous soils with a Cambic horizon. It has been developed in a mixed calcareous sandy alluvium derived from the Himalayas and deposited during the Recent and Subrecent periods. The series occupies shallowly covered channel infills in the floodplains. The shallow phase has under-lain silty clay to silty clay loam material at depths between 38 to 51 cm (Baig *et al.*, 1970).

The site had light brown, friable, massive, moderately calcareous very fine sandy loam to silt loam 0-14 cm surface soil and brown/dark brown, moderately calcareous, with a weak sub-angular blocky structure B horizon. A buried soil with silty clay loam texture underlies at 43 cm profile depth.

A long-term experiment was established in 1991 at the Latif Experimental Farm, Sindh Agriculture University, Tando Jam. The treatments: (1) no organic matter input (CON), (2) wheat straw @ 4 Mg ha^{-1} (WST), (3) farm yard manure @ 20 Mg ha^{-1}, and (4) green manuring of *sinji* (*melilotus sp*) or *jantar* (*sesbania aegyptica*) (GMN) were applied each year in a continuous cotton-wheat cropping system. The organic amendments were incorporated in surface soil and no soil inversion implement was used.

Soil physical properties were sampled in plot at depths corresponding to the genetic horizons of the soil profile in February, 1996. Soil bulk density was measured using a Gamma probe CPN 501. Water retention characteristics were determined using undisturbed soil samples were taken by a 5 cm dia double core sampler. The intact soil cores were cut into 1 cm thick pies. Water retention was measured at -5, -10, -50, -200, and -1500 kPa matric potentials. Water content (θm, g/g) retained at -10 kPa matric potentials represented *field capacity* and θm at -1500 kPa a *permanent wilting point* (Klute, 1986). The difference between θm at *field capacity* and at *permanent wilting point* was assumed as the *plant available water*. The *plant available* θm was converted to volumetric fraction (θv) by multiplying with bulk density. Volumetric fraction multiplied by depth of horizon yielded depth of water and summation of depths of water of each horizon added up to the total depth of *plant available water* in the profile.

Plant root mass was determined during the second weak of February 1996, which corresponds to the third growth stage of wheat of 1995-96. Galvanized pipe of 18 cm diameter was hammered into the soil, around representative healthy plants to the profile depth of 50 cm. The monolith was extracted by excavating soil around it. Roots were extracted manually by washing the monoliths. Root mass was taken after further washing with distilled water and oven drying at 65 °C.

Saturated infiltration was measured using a constant head well permeameter. From the steady-state rate of water flow out of a cylindrical well with 5 cm water head, infiltration flux, infiltration rate, field saturated hydraulic conductivity (K_{fs}) and matric flux potential ($\oslash m$) were calculated (Reynolds *et al.*, 1983; Reynolds *et al.*, 1985).

Soil surface infiltration properties and surface structure were determined by a disk-type tension infiltrometer (White *et al.*, 1992). Steady state volumetric water intake rate or infiltration flux, Q in mm^3 h^{-1}, was measured at -40, -10
and -180 mm of water tension. Infiltration rate (I
infiltration flux per unit surface area, mm h^{-1}, w
calculated from the Q data. Hydraulic conductivity, K(ıi) an
matric flux potential, $\oslash(\psi i)$, for the ıi pairs: (i) –40/-10
mm, (ii) -100/-180 mm, and (iii) -180/-250 mm. Infiltrati
rate at –250 mm water tension was predicted wi
exponential regression equation developed using the data
-40, -100, and -180 mm of water tension.

Calculations for hydraulic conductivity, K(ı) and matric f
potential, $\oslash$(ı), were done using the Posselious equatio
= $\pi r^2 K + 4 r \oslash$, where K is hydraulic conductivity (m
min^{-1}) and $\oslash$ is matric flux potential (Childs, 196
Infiltration flux (Q) at tension ψ1 and ψ2 yields
following two equations (Ankeny *et al.*, 1991; Anke
1992):

$$Q(\psi_1) = \pi r^2 K(\psi_1) + 4 r \oslash(\psi_1) \ldots\ldots\ldots 1$$

$$Q(\psi_2) = \pi r^2 K(\psi_2) + 4 r \oslash(\psi_2) \ldots\ldots\ldots 2$$

The above two equations have four unknowns, i.e., K(
$\oslash(\psi_1)$, $K(\psi_2)$, and $\oslash(\psi_2)$. A third equation was obtai
assuming a constant $K(\psi)/\oslash(\psi)$ ratio (A) between the ı1
ı2 (Ankeny *et al.*, 1991). The equation 1 and 2 can
rewritten as:

$$Q(\imath_1) = [\pi r^2 + 4 r/A]K(\psi_1) \ldots\ldots\ldots 3$$

$$Q(\imath_2) = [\pi r^2 + 4 r/A]K(\psi_2) \ldots\ldots\ldots 4$$

The equations 3 and 4 have three unknown A, $K(\imath_1)$,
$K(\psi_2)$. As given by Ankeny *et al.* (1991). Following P
(1995), the difference between $\oslash(\psi_1)$ and $\oslash(\psi_2)$
approximately

$$\oslash(\psi_1) - \oslash(\psi_2) = \Delta\imath[K(\psi_1) + K(\psi_2)]/ 2 \ldots\ldots\ldots 5$$

Substituting the value of A [$A = K(\psi) / \oslash(\psi)$] in to
equation 5 and re-arranging equation 5 yields:

$$[K(\psi_1) - K(\psi_2)]/A = \Delta\imath\, [K(\psi_1) - K(\psi_2)]/2 \ldots\ldots\ldots 6$$

Table 1: Soil organic matter determined in 199 as affe
by the lon-term organic matter treatment.

Horizon	Depth	CON	FYM	GMN	W
	(cm)				
AP	0-14	1.00	1.19	1.15	1.
AB	14-27	0.53	0.70	0.66	0.
Bw + 2Bwk	27-66	0.40	0.38	0.32	0.
2BCk	66-90	0.20	0.23	0.16	0.

Length: CON, control without organic matter; F
farmyard manure; GMN, green manure; WST, wheat st

The set of the three equations 3, 4, and 6 have
unknowns ($K(\imath_1)$, $K(\imath_2)$, and A) which can be s
simultaneously for hydraulic conductivities K(ıi) and $\oslash$(ı

pairs of Q taken at tensions $\psi 1$ and $\psi 2$.

As an estimate of soil structure, macroscopic capillary length, λc, was calculated following Ankeny (1992). The method is based on White and Sully (1987) equation:

$$
\begin{aligned}
\lambda c &= [K(\psi_0) - K(\psi_i)]^{-1} \int^{\psi 0}_{\psi i} K(\psi)\, d\imath \text{.......7} \\
&= \phi / \Delta K \\
&= \phi(\psi_0)/[K(\psi_0) - K(\psi i)] \\
&= \phi(\psi_0)/K(\psi_0);\ K(ii) << K(\psi_0)
\end{aligned}
$$

where K(ψi) is the hydraulic conductivity pressure head relation at initial water potential of the un-wetted soil and K(ψo) and $\phi(\psi_0)$ are the hydraulic conductivity and matrix flux potential measure at the known water potential. Assuming $K(\psi i) << K(\psi_0)$ (White *et al.*, 1992)

$$\lambda c = \phi(\psi_0)/K(\psi_0) \text{ ....8}$$

Since λc is a K-weighted mean soil-water potential (equation 7), we can relate λc by the capillarity theory to a characteristics pore dimension, λm,

$$\lambda m = \sigma(\rho g \lambda c) \text{ ....9}$$

where σ, is water surface tension (72.75E-3 N m^{1} or 72.75 kg s^{-2}; ρ, water density (1000 kg m^{-3}); g, acceleration due to gravity (9.80 m s^{-2}); and λc, m. Putting the values will reduced the equation 9 to λm = 7.4 / λc. There is evidence that λm is a representative mean pore radius that control the flow through the soil surface with $\imath_{=} \imath_0$ (White *et al.*, 1991). Therefore, the λm may have utility for quantifying soils structure and change in soil structure (Ankeny, 1992).

Pore radii **associated with each tension can be calculated** using **capillarity equation:** $r = 2\sigma\cos\alpha/\rho g\imath\imath$, where α is contact angle between water and pore wall and $\imath_i$ is water tension level. According to capillary theory, infiltration at $\imath_{40}$, $\imath_{100}$, and $\imath_{180}$ mm water tension will exclude pores of equivalent radius, r, greater than 375 μm, 150 μm, 83 μm, respectively, from the flow process.

Infiltration rate associated with 375 μm pore was calculated as the difference between the infiltration rate at $\imath_{40}$ and $\imath_{100}$, and infiltration rate associated with 150 μm pore was the difference between the infiltration rate at $\imath_{100}$ and $\imath_{180}$. According to Poiseuille's equation (Wilson and Luxmoore, 1988; Watson and Luxmoore, 1986) number of effective pores per area (m^{2}) is

$$N = 8 \mu I / \pi \rho g (r)^4 \text{ ....10}$$

where μ is viscosity of water (kg m^{-1} s^{-1}), I is infiltration rate (m s^{-1}), ρ is density of water (kg m^{-3}), g is acceleration due to gravity, and r is minimum radius (m) for the pore class. Minimum radii (r) class for the tension range $\imath_{40} - \imath_{100}$ was 375 to 150 μm and for the tension range $\imath_{100} - \imath_{180}$ was 150 to 83 μm. Since, infiltration rate below -250 mm tension was not known, all pore < 83 μm were included in the pore class for $\imath_{180} - \imath_{250}$. Total effective (macro)porosity is given by the following equation (the given (Wilson and Luxmoore, 1988; Watson and Luxmoore, 1986):

$$\Phi m = N \pi r^2 \text{ ....11}$$

where N is number of pores per m^2 and r is radius in m. Φm will be a unit less quantity in m^3 pore m^{-3} soil.

Two-way analysis of variance was used to determine the depth wise effect of organic amendments on soil physical properties. However, one way analysis of variance was used to determine whether grain yield, root density, and surface structure varied by organic matter treatment. Comparison of treatment means was made by Duncan's Multiple Range test (SAS Institute, 1992).

Results

Wheat Grain Yield :With differences among the sources, the long-term application of organic matter increased crop yield in all the years. Farmyard manure had significantly greater yield of wheat in 1995-96 than WST and GMN. Grain yield was 3.43 Mg h^{-1} in case of FYM, 2.79 in WST, 2.68 in GMN, and 2.76 in CON. Similar trend was observed in other years (data not presented). Higher grain yield in case of FYM could be attributed to improvement in soil physical conditions and to narrow C:N ratio of FYM compared to other sources. The beneficial effect of FYM was also evident from the visual observation during crop growth.

Wheat Plant Root Density: Wheat root density was determined for the 1995-96 crop as an index of plant growth that usually affected by soil physical condition. Wheat root density ranged from 2.23 to 5.01 g 0.0157 m^{-3}. Wheat root density was the highest in FYM followed by WST, CON, and GMN. The values were 3.90, 3.76, 3.03, and 2.96 g 0.0157 m^{-3}, respectively. Apparently, the effect of FYM and WST was similar to each other and exceeded to that of CON and GMN. The greater root density in FYM and WST than GMN and CON suggested significant improvement in soil physical properties and plant root environment as a result of 5-year application of the organic amendments to the soils.

Soil Organic Matter Content: Soil organic matter in the surface layer increased due to the long-term application of organic amendment. The largest organic matter increase was in case of FYM followed by GMN, and WST (Table 1). The differences in soil organic matter content were probably related to the quantity and nature of organic matter in each treatment. Farmyard manure contained relatively fine grained, more humified organic matter with a narrower C:N ratio than the wheat straw. Further, in all the treatments the surface layer contained greater amount of organic matter than all other horizons. Since, there was no soil inversion treatment applied, the accumulation of organic

Table 2: Saturated hydraulic conductivity, matric flux potential, and soil bulk density of various horizons as affected by the long-term organic matter treatment.

Horizon	Depth	Qs	K_{fs}	m	ρb
	cm	mm h^{-1}	mm h^{-1}	mm^2 h^{-1}	Mg m^{-3}
Control					
Ap	0-14	8.54	1.65	136.8	1.41
AB	14-27	10.67	2.09	167.4	1.58
Bw	27-43	46.43	8.95	742.5	1.54
2Bwk	43-66	5.34	0.99	85.5	1.60
2BCk	66-90	-	-	-	1.70
Wheat straw					
Ap	0-14	17.08	3.24	272.7	1.41
AB	14-27	10.67	2.06	171.0	1.60
Bw	27-43	46.25	8.86	747.0	1.53
2Bwk	43-66	4.27	0.82	68.4	1.62
2BCk	66-90	-	-	-	1.62
Farmyard manure					
Ap	0-14	13.34	2.32	196.2	1.41
AB	14-27	11.77	2.03	171.0	1.61
Bw	27-43	21.35	3.84	323.1	1.53
2Bwk	43-66	-	-	-	1.56
2BCk	66-90	-	-	-	1.57
Green manure					
Ap	0-14	11.74	2.46	205.2	1.41
AB	14-27	10.67	2.26	188.1	1.60
Bw	27-43	59.77	11.61	976.5	1.56
2Bwk	43-66	-	-	-	1.56
2BCk	66-90	-	-	-	1.59

Legend: Qs, infiltration flux; K_{fs}, field saturated hydraulic conductivity; ⌀m, matric flux potential (Reynold *et al.*, 1985); an ρb, soil bulk density.

Table 3: Volumetric water fraction held various tension as affected by the treatments.

Treatments	Water content at various matric potentials in kPa					Available Water
	-5	-10	-50	-200	-1500	
	m^3 m^{-3}					cm
Control	0.485a	0.464a	0.320a	0.204a	0.120a	0.374a
Wheat straw	0.475a	0.457a	0.264b	0.168b	0.115ab	0.356a
Green manure	0.446a	0.448a	0.233b	0.163b	0.100bc	0.333ba
Farmyard manure	0.381b	0.388b	0.231b	0.144b	0.091c	0.300b
LSD(0.05%)						0.0438

The means are averaged over the profile.

Table 4: Number of macropores estimated from tension infiltrometer data and Poiseuilleus equation (equation 10).

Tension	Pore size range Green manure	Treatment Control	Farmyard manure		Wheat straw
mm (water)	um	no			
-40	375-150	1470	2210	1900	1630
-100	150- 83	21200	52900	51200	17600
-180	≤ 83	165000	357000	261000	188000
STDV (number = 3)		53.4	338	136	163
		2650	3530	5320	1020
		7360	11300	16400	27200

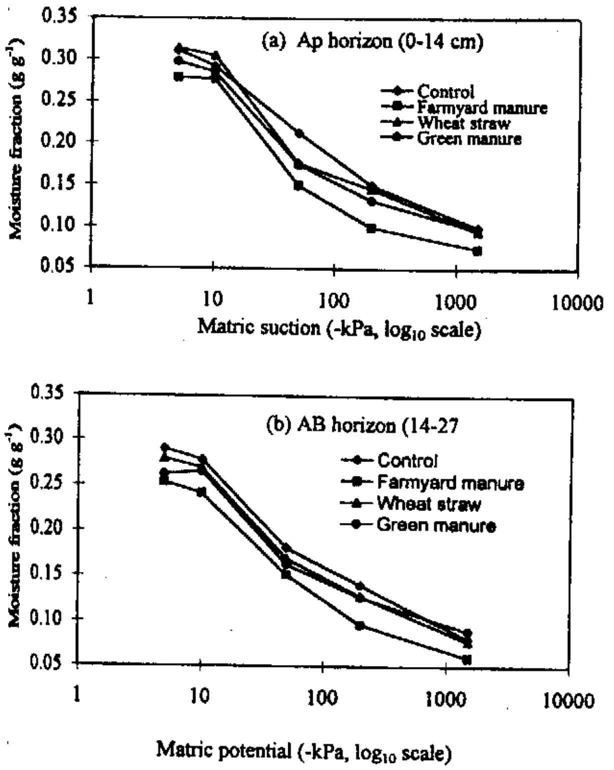

Fig. 1: Water retention characteristics as affected by the long-term organic matter treatment: (a) Ap and (b) AB horizon.

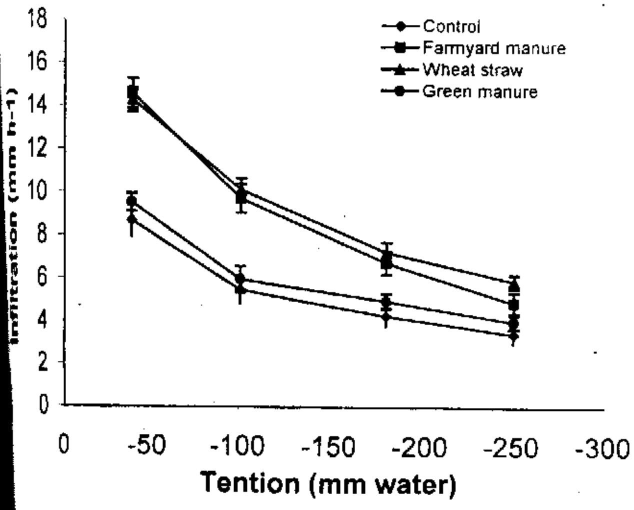

Fig. 2: Un-saturated infiltration of thesurface soil as affected by the long-term organicmatter treatment.

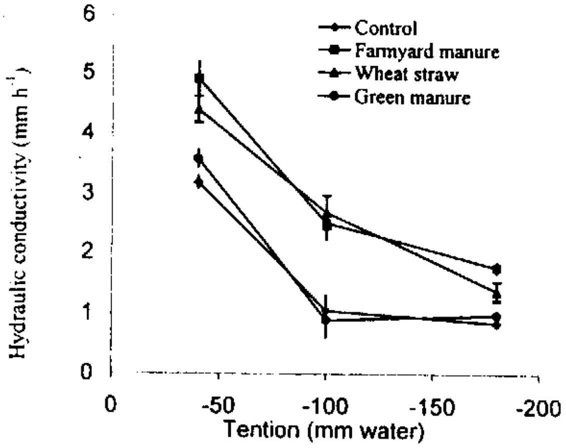

Fig. 3: Fig. 2 Un-saturated hydraulic conductivity of the surface soil as affected by the long-term organic matter treatment.

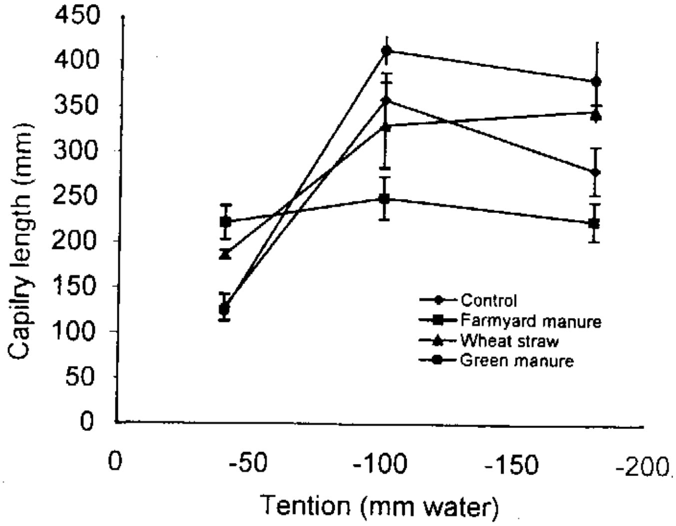

Fig. 4: Capillary length as determined tension infiltrometer.

matter was restricted to the top-soil only.

Soil Bulk Density (ρ_b): Average soil bulk density of the profile as determined by the Gamma probe remained unaffected by the organic amendments at this site, however, soil depth was a significant source of variation. In the upper part of profile (0-43 cm), ρ_b increased from 1.41 g cm^{-3} of Ap to 1.60 g cm^{-3} in the AB horizon. This increased ρ_b in the AB horizon (14 to 27 cm) might be due to the presence of plow pan. Bulk density decreased in the Bw horizon (27 to 43 cm) which is due to structural development. And in the second part of

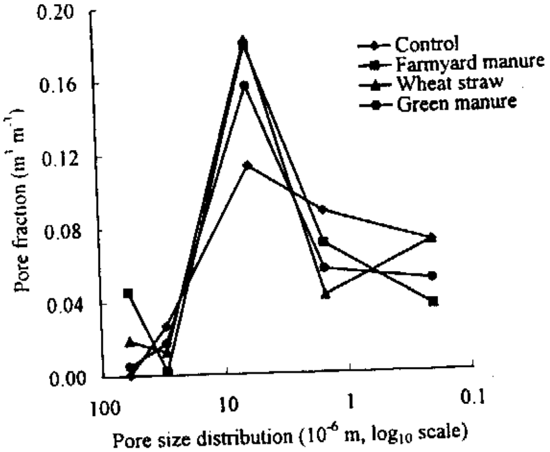

Fig. 5: Pore size distribution in the surface soil asaffected by the long-term organic matter treatment.

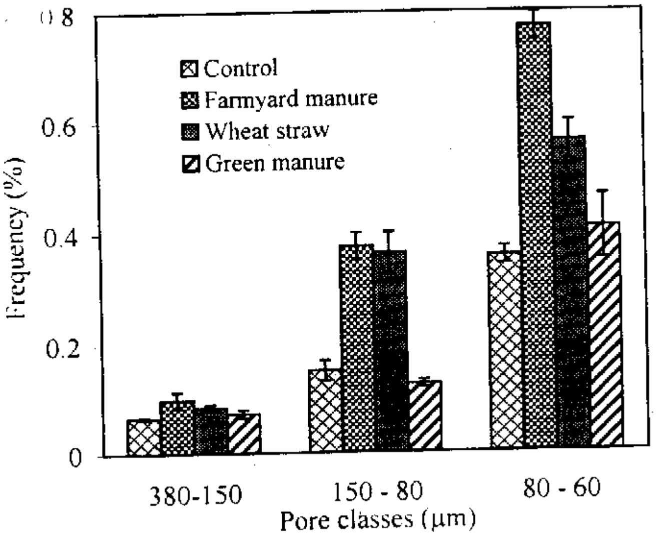

Fig. 6: Effective porosity in the surface horizon as determined tension infiltrometer.

the profile (43-90 cm), ρ_b increased with the depth and ranged up to 1.62 g cm^{-3} at 66 to 90 cm depth (Table 2). The treatment effect on soil bulk density was not detectable even in the surface horizon, while, overall the statistical model was highly significant ($P > 0.0001$). Break up of variability in the data suggested that depth was a significant source of variation.

Water Retention Characteristics: Treatment effect on water content held at various matric potentials was statistically significant. Application of wheat straw resulted in the highest plant available water content in Ap horizon. Selected data on water retention characteristics are presented in Figure 1. Two-way analysis of variance for the water content retained at various matric potentials, was done with treatment and depth as sources of variability. When averaged over the depths, θm (g/g dry soil) retained at -5 and -10 kPa matric suctions did not vary with the organic matter treatment but water at -50, -200, and -1500 kPa it was significantly greater in Control than the most organic matter treatments (data not presented). The volumetric water fraction ($\theta v = \theta m * \rho_b$, m^3 m^{-3} soil) held at all matric suction varied significantly with the organic matter treatments (Table 3). Volumetric water fraction held at −5 and −10kPa was statistically similar in Control, Wheat straw, and Green manure but greater than Farmyard manure; at −50 and -200kPa all the Wheat straw, Green manure, and Farmyard manure has similar θv but lesser than Control. Therefore, the easily available water fraction (the difference between θv at -10kPa and -200kPa) of the organic matter amended samples, except for the Farmyard manure, was greater than Control (Table 3).

Means averaged over the treatments were compared to determined differences among various horizons in the profile. Water retained at various matric suctions differ significantly (P 0.05) in different horizons. Water conten retained at -200kPa, -500kPa, -1500kPa matric suction increased towards the surface while at -50 kPa it remaine un-affected, and at -5kPa and -10kPa, it increased with th profile depth (data not presented). The differences wer ascribed to variations in the clay content among th horizons.

Data analysis was done to determine the treatment effec in the individual horizons, separately. The gravimetri moisture held at -5 and -10 kPa in Ap horizon did not var much with organic matter amendment. Treatment effe was relatively greater on the water fraction retained at -5 kPa and the greater matric suctions. In Ap horizon, th easily available water (the difference between θv at -10 a -200 kPa) was greater in the FYM (0.17 m^3 m^{-3}) follow by WST (0.16 m^3 m^{-3}), GMN (0.15 m^3 m^{-3}) and CON (0. m^3 m^{-3}) (Fig. 1a). Contrary to the Ap horizon, treatme effect in AB horizon held at various matric potentials w non-significant. (Fig. 1b) suggesting that treatment effe was limited to the surface horizon.

Plant available water : Average field capacity of the was 0.44 g g^{-1}, permanent wilting point 0.11g g^{-1}, mean plant available water was 0.33 g g^{-1}. Howev different organic matter treatments and the profile depth change the plant available water storage capacity. In upper 66 cm profile depth, mean available water was 2 mm in WST, 235 mm in CON, 222 in GMN, and 220 in FYM. The easily available water in the same profile d was in 205 mm in WST, 186 mm in GMN, 181 mm CON, and 158 mm in FYM treatment. It was evident wheat straw retained the greatest quantity of available water.

Saturated Infiltration: Mean infiltration rate, hydr conductivity (K_{fs}) and matric potential (·m) calculated the steady state water intake rate at a constant determined for each soil horizon are presented in Table 2.

Infiltration rate: The treatment effect on saturated infiltration was limited to surface horizon, where the wheat-straw had the highest infiltration rate and the control (no organic matter) had the lowest infiltration rate (Table 2). Saturated hydraulic conductivity of the Ap ranged from 1.65 to 3.24 mm h^{-1} and varied with the organic matter treatment. Wheat straw had the K_{fs} followed by green manure, farmyard manure and control. Wheat straw added was seen accumulated in the surface soil matric un-humified resulting in the largest hydraulic conductivity. Matric flux potential also followed the same trend. The WST had the highest ϕm (272.7 $mm^2 h^{-1}$) and control had the lowest value (136.8 $mm^2 h^{-1}$; Table 2).

In the entire experimental plot, saturated infiltration rate was the largest in the Bw horizon and the smallest in the 2Bwk horizon (Table 2). Saturated hydraulic conductivity of Bw horizon was approximately 5 times greater than that of Ap and 2 times that of AB horizon. The differences in K_{fs} of 27 to 43 cm depth was more due to variation in sedimentary features (texture) and less due to treatment effect. Statistical analysis indicated that K_{fs} and ϕm changed significantly with the profile depth, while the organic matter treatment effect was non-significant. The Bw horizon had significantly greater K_{fs} and ϕm ($P \le 0.001$) than the Ap and AB horizons, while both had similar K_{fs} and ϕm.

Un-saturated Infiltration (Surface Soil): From the *steady state* infiltration flux at –40, -100, and –180 mm water tension (ψ), the infiltration rate, un-saturated hydraulic conductivity ($K\psi$), and matric flux potential ($\phi\psi$) were calculated for the each ψ setting. Using the *steady state* infiltration flux at –40, -100, and –180 mm water ψ, the infiltration rate, K, $\phi\psi$ were predicted for the –250 mm ψ with regression analysis. Hydraulic conductivity and ϕ were determined for the pairs of the tension settings: -40 and -100 mm; -100 and –180 mm; and –180 and –250 mm (predicted) water tension. Hence, there are three $K\psi$ and $\phi\psi$ values from the three pairs.

Infiltration Rate: Infiltration rate decreased as ψ increased from -40 to -180 mm of water tension in all the treatments (Fig. 2). Infiltration rate ranged between 14 to 8 mm h^{-1} at -40 mm and, with successive increase in ψ, decreased from 8 to 5 mm h^{-1} at -180 mm of water (Fig. 2). The predicted infiltration rate at –250 mm is not depicted to limit to only observed data. This decrease in infiltration with increase in tension was due to the fact that at -180 mm tension macro-pores are left out of the water conducting process and only micro-pores conduct water. At -40 mm tension all sizes of pores, interpedal spaces, and sheer cracks conduct water.

The treatment effect on infiltration rate was significant ($P \le 0.05$). Farmyard manure and wheat straw application had statistically similar and approximately two times greater infiltration at all the ψ settings than the control and green manuring (Fig. 2). Control and green manuring had statistically similar infiltration. The magnitude of difference of infiltration rate between FYM/WST and the CON/GMN decreased at -180 tensions (Fig. 2). But WST had slightly greater infiltration than the green manuring and control not only at -40 mm ψ but also at –180 mm ψ setting.

Hydraulic Conductivity and Matric Flux Potential: Hydraulic conductivity ranged between 3.2 to 4.9 mm h^{-1} at -40 mm and decreased from 1.7 to 0.8 mm h^{-1} with successive increase in ψ (Fig. 3). Hydraulic conductivity was significantly affected by the organic matter treatment ($P < 0.05$). Farmyard manure and wheat straw application had statistically similar but greater K at all ψ than control and green manure, although the magnitude of difference among the treatment was greater at -100 mm water tension than -40 and -180 mm of water tension and statistically, the treatment tension interaction was non-significant. Standard deviation in $K(\psi)$ was greater at -40 mm water tension than -100 and -180 mm (Fig. 3).

The organic matter treatment and tension setting significantly influenced matric flux potential at various ψ setting and it had the similar trend as that of hydraulic conductivity. Matric flux potential ranged from 775 to 430 $mm^2 h^{-1}$ at –40 mm water tension decreased to 270 to 460 $mm^2 h^{-1}$ at –180 mm (data not presented). The long-term application of both farmyard manure and wheat straw resulted in a greater flux potential than the control and green manure. It was 775 to 758 $mm^2 h^{-1}$ at –40 mm tension and 390 to 460 $mm^2 h^{-1}$ at –180 mm in case of farmyard manure and wheat straw as compared to 430 to 465 $mm^2 h^{-1}$ at –40 mm 270 to 310 $mm^2 h^{-1}$ at –180 mm in case of green manure and control (data not presented).

Total Porosity and Pore Size Distribution as Indicators of Surface structure: Water infiltration in a slightly under-saturated environment as determined by tension infiltrometer provides a rapid and practical method for determining *in situ* changes in soil structure in relation to soil management factors. As an estimate of soil structure, total macroscopic capillary length, λc (equation 8); characteristic mean pore size, λm (equation 9); number of pores at given ψ, N (equation 10); and total effective macroporosity, Φm (equation 11) were calculated for the surface of Ap horizon in each treatment.

Macroscopic capillary length (λc) participating in infiltration at –100 mm and -180 mm water tension was greater than that of at –40 mm (Fig. 4), although the infiltration rate and $K\psi$ was greater in the later case. This suggested that only a small fraction of total porosity occurs as large pores, yet, it controlled a large portion of infiltration. Treatment effect on λc was significant ($p<0.05$). Farmyard manure application resulted in the greatest total capillary length of $\le$ 380 *μm* size pores followed by wheat straw, green manure and control (Fig. 4). Green manure and the control had statistically similar and the lowest total capillary length of 380 μm. The total capillary length of ≤ 150 μm was greater in the control and green manure than the farmyard manure and wheat straw but the same trend was not be carried over to the capillary length of ≤ 80 μm (Fig. 4). Representative mean pore radius size, λm, determined for farmyard manure at −40 mm was 70 μm and was around 30 μm at −180 mm. The sizes conform with that of White et al (1992). Change in the representative mean pore radius with the long-term organic matter treatments was significant (data not presented).

Number of pore increased exponentially with decrease in pore radius and varied with the organic matter treatment (Table 4). Pores of 375 to 150 μm radius ranged from 1500 to 2200 per m^2 and the farmyard manure and wheat straw had about 1.5 times greater number of pores in the pore class than green manure and control without organic matter. Pores of 150 to 80 μm radius ranged from 18000 to 53000 and farmyard manure and wheat straw had about three times greater number of pores in the pore class than green manure and control. Similarly, farmyard manure and wheat straw had significantly greater 80 to 60 μm than control and green manure. This was concluded when pore size distribution determined by water release characteristics and tension infiltrometer were combined (Fig 5).

Size distribution of further smaller pores was determined by water release characteristics (Fig. 5). The data revealed that the 30 to 60 μm pores remained un-affected by the organic matter treatments and 6 to 30 μm size pores were in larger number in wheat straw and farmyard manure than of green manure and Control treatments. However, the Control and green manure contained larger number of 1.5 to 6 μm and <1.5 μm size pores than wheat straw and farmyard manure. It may be concluded that although the total porosity remained un-changed by the organic matter treatments but the distribution of various sizes of pores changed with the treatments.

Comparison of different depths suggested that total porosity was the highest in Ap horizon and it decreased with the profile depth. Ap (0-14 cm), Bw (27-43), and Bk (43-66) horizons had greater total porosity than BA horizon (14-27 cm) (data not presented). The pores larger than 60 μm were the greatest in Ap horizon. Similarly, number pores of other sizes changed with profile depth. The decrease in total porosity in BA horizon was suggestive of plow-pan at that depth.

Effective macro-porosity, ratio of volume of various macropore-sizes to soil volume (Fig. 6), suggested that the volume of 375 −150 μm size ranged from 0.06 to 0.10 per 100 m^3 soil. Effective porosity increased exponentially with decreased in pore radius to 0.8 m^3 m^{-3} of 80 to 60 μm (Fig. 6). Treatment effect on effective porosity was significant. Effective macro-porosity of farmyard manure and wheat straw was significantly greater than control and green manure. Farmyard manure and wheat straw had similar effective macro-porosity of 380 to 80 μm pores but a difference was noted in 80 to 60 μm pores (Fig. 6)

Discussion

Crop stand, wheat root density, and yield increase due to application of farmyard manure was more than the wheat straw application, green manure, and control, which was attributed to improvement in physical environment as well as to greater N availability. Relatively greater root density in wheat straw as compared to green manuring or contro suggested improvement in root physical environment in this treatment also, but yield was depressed due t immobilization of N. It is believed that compensation for low C:N ratio will improve yield.

Accumulation of organic matter was limited to the Ap horizon and the largest organic matter increase wa observed in case of farmyard manure. The differences i soil organic matter contents were probably due to th varying nature of organic matter as well as total quantity i each treatment. Application rate of farmyard manure wa 5 times greater than wheat straw and it contained relativel large quantity of fine grained, more humified organic matte than the wheat straw.

Bulk density have strong negative correlation with so organic matter content (Ohu *et al.*, 1994) yet, th treatment effect on soil bulk density at this site was no detectable even in the surface horizon and change wa more due to the change in horizon than the organic matte treatment. Major factor may the high rate of oxidation the applied organic matter. However, the greater ρ_b of A horizon than Ap and Bw is suggestive of the presence plow pan.

Different organic matter treatments and profile depth affected plant available water and the result conforms those reported by Ohu *et al.* (1995). In this stud application of wheat straw resulted in greater pla available water than the farmyard manure application in th Ap horizon. The effect of addition of organic matter on s water retention characteristics is site specific and depend on initial soil organic matter level and rate of oxidatio Rapid microbial degradation of farmyard manure could responsible for lesser plant available water in FYM th wheat straw application

The treatment effect on infiltration parameters was limit to surface horizon. An increased infiltration rate due to t wheat straw conforms to previous studies done in cott soil (Baumhardt and Lascano, 1996) and the effect w attributed to interception of raindrop impact on soil surfa The wheat-straw added had accumulated in the soil matr yet, un-humified, resulting in improved hydrau conductivity. The variations in the infiltration paramet (K_{fs} and ϕm) with depth are mainly due to textu differences among the horizons and due to so anthropogenetic factors.

Infiltration rate decrease with increased tension from -40 -180 mm water was due to sequential emptying of sma and smaller pores (Wilson and Luxmoore, 1988). At grea tension macro-pores are left out of the water conduct process and only micro-pores conduct water. At low tension, all sizes of pores, interpedal spaces, and sheer cracks conduct water. Infiltration rate conform to previous reported studies (Logsdon *et al.*, 1993b; Somaratne and Smettem, 1993) and have practical implications for determining water use by the plants.

Application of farmyard manure and wheat straw resulted in greater number of large pores than the control (no organic matter) at the expense of smaller pores as indicated by under-saturation infiltration and retention characteristics. The results conform with previous studies (Mbagwu, 1993; Klik and Salekhe., 1994; Obi and Ebo, 1995; Ohu *et al.*, 1994). A close relationship between the labile organic fraction content and aggregate stability has been demonstrated (Studdert *et al.*, 1997). Tension infiltrometer gives access to the technique to quantify soil structure parameters and flow weighted mean pore sizes (Logsdon, 1993). Therefore, the method offers hydraulic technique to study the impact of management and environmental factors on *in situ* soil structure.

In the present study the largest pore quantified was around 380 μm in size. Still bigger could be determined using the range of 0 mm (near saturated) to -40 mm of water tension by combining saturated infiltration and tension infiltrometer data (Wilson and Luxmoore, 1988). As it is not possible to take measurements at 0 mm tension due to collapse of macro-structure under the infiltrometer disk. Alternatively, infiltration flux may be measured at a constant head of 50 mm using Guelph permeability meter, which equals to +50 mm of water tension. Discrepancy in the study remained that saturated infiltration was measured at 7.5 cm depth and un-saturated at the surface. The saturated infiltration flux was lesser than that of un-saturated which was due to change in the conducting depth.

Except for BA horizon, the total porosity increased towards the surface due greater biological activities. The lowest total porosity in BA horizon in the profile was due to compaction by the tillage. Total porosity did not change with the organic matter treatment even in the Ap, yet 6 to 0 μm increased due to organic matter added through armyard manure and wheat straw application.

eferences

ngulo-Jaramillo, R, F. Moreno, B. E. Clothier, J. L. Thony, G. Vachaud, E. Fernandez-Boy and J. A. Cayuela, 1997. Seasonal variation of hydraulic properties of soils measured using a tension disk infiltrometer. Soil Sci. Soc. Am. J., 61: 27-32.

nkeny, M. D., M. Ahmed, T.C.Kaspar and R. Horton, 1991. A simple field method for determining unsaturated hydraulic conductivity. Soil Sci. Soc. Am. J. 55: 467-470.

Ankeny, M. D., 1992. Methods and theory for unconfined infiltration measurements. pp. 123-140. *In* G. C. Topp *et al.* (eds.) Advances in measurement of soil physical properties: Bringing theory into practice. SSSA Special publication no. 30. Soil Sci. Soc. Am. USA.

Baig, M. S., Y. J. Mirza, M. R. Zaheer, A. Q. Khan and A. Janjua., 1970. Reconnaissance soil survey of Hyderabad. Soil Survey of Pakistan. Multan road, Lahore, Pakistan

Baumhardt, R. L. and R. J. Lascano, 1996. Rain infiltration as affected by wheat residue amount and distribution in ridged tillage. Soil Sci. Soc. Am. J., 60:1908-1913.

Darwish, O. H, N. Persaud and D.C. Martens, 1995. Effect of long-term application of animal manure on physical properties of three soils. Plant Soil, 176: 289-295

Hussen, A. A. and A. W. Warrick, 1993. Alternative analysis of hydraulic data from disk tension infiltrometers. Water Resouces Res., 29: 4103-4108.

Klik, A. and V. M. Salokhe, 1994. Soil conservation and crop productivity in Austrian vineyards.pp. 422-429. *In* Gajendra-Singh (ed.). Proc. Intl. Agri. Engin. Conf. Volume 2. Asian Inst. Techn., Bangkok, Thailand, 6-9, December, 1994.

Klute, A., 1986. Water retention: Laboratory Methods. pp.635-662. *In* Klute, A.(ed.) Methods of Soil Analysis part I: Physical and Mineralogical Methods. Agronomy Monograph no. 9 (2nd Ed.). Am. Soc. Agron. Soil Sci. Soc. Am., Madison, WI, USA.

Kooistra, M. J., 1991. Soil structure and soil biological interaction in three different agricultural practices. Advances in management and conservation of soil fauna. pp. 279-289. *In*: Verresh, G. K., D. Rajagopal, and C. Viraktamath, (eds.). A Proc. 10th Intl. Soil Zoology Colloquium, Bangalore, India, August 7-13, 1988. Oxford & IBH Co. New Delhi, India.

Logsdon, S. D., J. L. Jordahl and D. L. Karlen, 1993a. Tillage and crop effects on ponded and tension infiltration rates. Soil & Tillage Res., 28:179-189.

Logsdon, S. D., J. K. Radke and D. L. Karlen, 1993b. Comparison of alternative farming systems. I. Infiltration techniques. Am. J. Alternative Agri., 8:15-20.

Mbagwu, J. S. C., 1993. Improving the productivity of a degraded Ultisol in Nigeria using organic and inorganic amendments. Part 2: Changes in physical properties. Bioresource Tech., 42:167-175

McCoy, E. L., 1992. Quantitative physical assessment of organic materials used in sports turf root-zone mixes. Agronomy J., 84: 375-381.

Messing, I. and N. J. Jarvis, 1993. Temporal variation in the hydraulic conductivity of a tilled clay soil as measured by tension infiltrometers. J. Soil Sci., 44:11-24.

Obi, M. E. and P. O. Ebo, 1995. The effects of organic and inorganic amendments on soil physical properties and maize production in a severely degraded sandy soil in southern Nigeria. Bioresource Tech., 51: 117-123

Ohu, J. O., E. I. Ekwue and O. A. Folorunso, 1994. The effect of addition of organic matter on the compaction of a Vertisol from northern Nigeria. Soil Technology, 7: 155-162

Philip, J. R., 1985. Reply to "comments on steady infiltration from spherical cavities". Soil Sci. Soc. Am. J., 49: 788-789.

Reynolds, W. D., D. E. Elrick and G. C. Topp, 1983. Reexamination of constant head Permeameter method for measuring saturated hydraulic conductivity above the water table. Soil Sci., 136: 250-268.

Reynolds, W. D., D. E. Elrick and B. E. Clotheir, 1985. The constant head permeameter. Effect on unsaturated flow. Soil Sci., 139:172-180.

SAS Institute, 1992. SAS user's guide: Statistics. SAS Inst., Cary, NC. USA

Sen, D., E. F. Chen, X. C. Xu, J. H. Zhang and H. Z. Li, 1994. Effect of organic manure application on physical properties and humus characteristics of paddy soil. Pedosphere, 4: 127-135

Schindler, U., 1989. Effect of bulk density and humus content on pore size distribution and hydraulic conductivity in sandy soils. Archiv fur Acker und Pflanzenbau and Bodenkunde, 33: 3-9.

Somaratne, N.M. and K. R. J. Smettem, 1993. Effect of cultivation and raindrop impact on the surface hydraulic properties of an Alfisol under wheat. Soil and Tillage Res., 26: 115-125.

Soil Survey Staff, 1970. Reconnaissance soil survey of Hyderabad. Soil Survey of Pakistan. Multan road. Lahore.

Studdert, G. A., H. E. Echeverria and E. M. Casanovas., 1997. Crop pasture rotation for sustaining the quality and productivity of Typic Agriudool. Soil Sci. Soc. Am., J., 61: 1466-1472.

Sur, H. S., A. S. Sidhu, S. Rachhpal, G. C. Aggarwal and K. S. Sandhu., 1993. Long term effect of green mature on soil physical properties and production potential in green manure-maize-wheat sequence. Annals Agri. Res., 14:125-131

Watson, K. W. and R. J. Luxmoore, 1986. Estimating macroporosity in a forest watershed by use of tension infiltrometer. Soil Sci. Soc. Am. J., 50: 578 582.

White, I. and M. J. Sully, 1987. Macroscopic an microscopic capillary length and time scale from fiel infiltration. Water Resour. Res., 23:1514-1522.

White, I., M. J. Sully and K. M. Perroux, 1992 Measurement of surface soil hydraulic properties: Dis permeameters, tension infiltrometers, and othe techniques. pp. 69-103. *In* Topp, G. C., W. D. Rynolds and R. E. Green (eds.) Advances in measurement of so physical properties. Bringing theory into practice. SSS Special Pub. 30. Madison. USA.

Wilson, G. V. and R. J. Luxmoore, 1988. Infiltratio macroporosity, and mesoporosity distribution on tw forested watersheds. Soil Sci. Soc. Am. J., 52:32 335.

Zhu, H. X. and X. L. Yao, 1993. The physical effect organic material on rice-based cropping system. Ac Pedologica Sinica., 30: 137-145