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Bulk Density, Infiltration, and Water-retention in a Sandy Loam Soil under Long-term Tillage and Fertilizer Treatments

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Abstract: A tillage-fertilizer combination that can improve physical soil quality is urgently needed to keep the resource base from further degradation. Long-term (5-year) study on moldboard ploughing and combined application of chemical fertilizer with (annual) farmyard manure (FYM) improved wheat-maize cropping system yield on a sandy loam soil. The combination of the treatments removed the compact layer, reduced soil bulk density, and increased the infiltration as compared to shallow tine cultivation. In shallow cultivation the AB horizon, which had the lowest infiltration, remained intact. Bulk density correlated better with changes in 60-300 μm sized pores than that of any other pore sizes determined by water retention. Originally, AB horizon had the lowest 60-300 μm radius pores, although, the 30-60 μm radius and smaller pores were greater or equal. To its effective depth, moldboard tillage increased 60-300 μm size pores, especially when the chemical fertilizers and FYM were applied in combination.

Key Words: Long-term moldboard tillage, shallow cultivation, bulk density, saturated hydraulic conductivity, water retention, pore size distribution

Introduction

Soil degradation is an important issue in semi-arid and sub-humid areas where soil is inherently low in organic matter content and cropping intensity is high due to population pressure. As a result crop residue recycling is minimum due to high fodder demand (Lal, 2000). In high potential agro-ecosystem, research studies are needed to quantify the long-term changes in soil structure to minimize the risks of soil degradation by compaction and erosion (Mahboubi and Lal, 1998). Although tillage restores soil-plant physical conditions for next crop but continuous tillage at certain depth or multiple passes of tillage implements create a compacted sub-surface layers with small aggregat size-distribution (Alakukku, 1996) as compared to the horizons above and below. Particularly, in Pakistan, continuous shallow tillage with a tine cultivator has created 1.60 to 1.75 Mg m^{-3} bulk density layer at 12-20 cm profile depth in the loam(±) soils (Akhtar and Qureshi, 1999). Consequently, the roots are restricted in a shallow zone. Although a deep tillage will pulverize the compacted sub-surface layers (Bennie and Botha, 1986), but the effect may not be sustainable because of unstable soil structure due to high base saturation and low organic matter content (Watts and Dexter, 1998; Rahimi *et al.*, 2000; Lal, 2000).

Average 36% yield increase by moldboard ploughing over routine tine cultivator tillage have been demonstrated (Razzaq *et al.*, 1989) and 30 % yield increase associated with bulk density decrease has also been reported by Akhtar and Qureshi, 1999. The crop yield increase by moldboard ploughing are attributed to reduced soil compaction, greater accumulation of moisture (Danilov and Kargin, 1979) and increase in water intake rate (Gill *et al.*, 2000).

Soil organic matter facilitates granulation (Chenu *et al.*, 2000) and increases the porosity (Akhtar *et al.*, 1999) that favors good tilth, promotes water infiltration and increases the available water capacity (Sommerfeld and Chang 1985). In the arid sub-tropics, summer soil temperature is high enough to accelerate the oxidation of organic matter. Organic matter in a vast majority of these soil is <0.1% (unpublished Pakistan soil survey data), while, about 3% is deemed necessary for optimum soil physical conditions (Soane, 1990). High organic matter (>4% w/w of total C content) is closely related to zero coalescence (Cockroft and Olsson, 2000). Soil compaction is sensitive to small changes in organic matter and is reduced with increased organic matter levels (Soane, 1990).

Tillage plays its' role in two opposing ways, first, it enhances the decomposition of native organic matter which otherwise is protected by soil micropeds (Chenu *et al.*, 2000; Balesdent *et al.*, 2000; Stenberg *et al.*, 2000) and second, it protects the applied organic matter by deeper incorporation. Thus, the appropriate combination of tillage and soil organic matter interaction is necessary in order to protect soil structure. Deep tillage is an option for removing subsoil compaction and increasing rainwater intake, which is desperately needed in rainfed crop production. However, it is an energy-expensive operation and can be justified only if there is a greater production and the effect is sustainable. Relatively scantly information is available on the sustainability of soil structure under various tillage and fertilizer options in semi-arid environment. Comparative changes in bulk density, saturated infiltration, water retention, and structure of a sandy loam soil and the rain-fed wheat-maize cropping system yield under long-term tillage with tine cultivator and moldboard both with farmyard manure and chemical fertilizer, alone and in combination are reported.

Materials and Methods

The National Agricultural Research Center, Islamabad initiated a long-term field trial in 1992 with the objective to determine crop yield response to tillage and fertilizer management. While the experiment is continuing, selected soil physical parameters of the surface-soil (Akhtar *et al.*, 2001) and the profile were measured to determine the soil physical health.

Site Description: The site was located approximately at longitude 72.1° E and latitude 34.4° N and represented by Nabipur series, a sandy loam, mixed, Typic Camborthid. The soil was weakly differentiated and contained <0.25% organic matter in the surface. The mean precipitation in the area is 650 mm (Khanzada, 1976).

Field Operations: The tillage treatments, cultivator and moldboard plough, were in the main plots. The tine cultivator tillage consisted of two passes in a criss cross direction followed by two plankings. The moldboard plough tillage consisted of one ploughing followed by two planking operations. The tine cultivator depth was 0-12 cm while the moldboard plough depth was 0-25 cm. Wheat (*Triticum valgare* L.) was planted in 2nd weak of November and maize

(Zea mays) was planted in 2nd weak of July each year after tillage operations.

The four fertilizer treatments, each in three replications, applied to the subplots were: (i) 100-70-0 kg nitrogen, phosphorus, and potassium ha^{-1} to wheat and 110-140-0 kg ha^{-1} to maize (NPK); (ii) 5000 kg of well decomposed farmyard manure ha^{-1} (FYM); (iii) a combination of the treatments i & ii (NPK+FYM); and (iv) no NPK or FYM (Control). Plot size of 17×6 m. Each year wheat grain and maize fodder yield was recorded. During September 1997, approximately 45 days after maize planting, saturated infiltration and bulk density were determined in the field and water retention in laboratory using intact samples. All the three parameters were determined for genetic horizons including Ap (0-11cm), AB (11-23 cm), Bw (23-32cm), and Btk (32-75 cm) in each plot.

Soil Physical Characteristics: Water retention characteristics were determined using undisturbed soil cores (5 cm diameter) collected from each plot. The water content in the cores equilibrated at -1, -5, -10, -30, -50, -200, and -1500 kPa matric potential applied on tension table and pressure plate extractor was recorded. From above data field capacity, permanent wilting point, available equivalent water depth for each horizon and the total plant available water depth in the profile were calculated (Klute, 1986). In each plot, bulk density was measured by placing a calibrated Gamma probe (CPN 501) at the middle of each horizon. Saturated infiltration was measured *in situ* for each horizon using a constant-head (+50 mm) well permeameter (Reynolds and Elrick, 1985). Once steady state condition reached, at least four readings of the drop in water levels in the reservoirs were recorded at constant time interval. The infiltration flux ($L^3 t^{-1}$), infiltration rate ($L t^{-1}$), field saturated hydraulic conductivity (K_{fs}) ($L t^{-1}$), and matric flux potential (ϕm) ($L^2 t^{-1}$) were calculated using the rate of drop ($L t^{-1}$) in the cylindrical reservoir (Reynolds *et al.*, 1983). Pore size distribution was calculated from the soil water retention data using the soil-water capillary model (Bouma, 1991).

Statistical Analysis: The depth-wise effect of the fertilizer amendments and the tillage on the soil physical properties and possible interactions were evaluated using a three-way analysis of variance. The variables were arranged with tillage in the main plot, fertilizer in the sub-plot, and the depth in the sub-sub-plot. A two-way analysis of variance was used to determine whether grain yield and surface structure varied by fertilizer treatment or tillage. Comparison of treatment means was made using the Duncan's Multiple Range test (SAS Institute, 1992).

Results

Crop Yield: Crop yield was consistently greater with moldboard tillage, although in some years the yield difference was not statistically significant. In the selected years the interaction between tillage and the fertilizer treatment was non-significant and the yield data are summarized according to the main effects (Table 1). An application of NPK resulted in significantly greater (α 0.05) yield than that of the Control and FYM. The combined application of NPK and FYM resulted in the greatest yield although in some years the difference was not statistically significant with that of NPK yields (Table 1).

Soil Bulk Density (ρ_b): Soil profile ρ_b, averaged over the 75 cm depth, decreased from 1.57 Mg m^{-3} to 1.53 Mg m^{-3} due to moldboard ploughing. The application of FYM reduced the profile average ρ_b to 1.52 Mg m^{-3} as compared to 1.56 Mg m^{-3} with continuous use of NPK fertilizer. Since fertilizer - tillage and fertilizer - depth interactions were significant, the main effect could not be interpreted independently. Long-term moldboard ploughing combined with an application of NPK and FYM resulted in the lowest ρ_b of 1.40 Mg m^{-3} in the Ap horizon (Fig. 1). The moldboard ploughing also resulted in lower ρ_b in the AB horizon compared to cultivator tillage, except when manure was used without the chemical fertilizers. Moldboard ploughing also had a low ρ_b in the Bw and Btk1 horizons when NPK was applied.

Saturated Infiltration and Hydraulic Conductivity (K_{fs}): The moldboard ploughed soil profile had saturated infiltration rate of 41 mm h^{-1}, which was significantly greater than 26 mm h^{-1} for tine cultivated profile (Table 2). So, profile K_{fs} of the moldboard ploughed plots was significantly greater (8 mm h^{-1}) than the cultivator tilled plots (5 mm h^{-1}). Moldboard ploughing particularly increased the infiltration and K_{fs} in the upper 0-32 cm profile with the application of NPK alone or in combination with FYM but the two tillage treatments had a statistically similar infiltration and K_{fs} (for the Ap horizon) under Control and FYM alone. The average infiltration in the cultivator plots was greater in the Ap than the AB horizon, whereas the moldboard plots had a similar infiltration rate for both the Ap and AB horizons.

Infiltratbility (averaged over the tillage treatments) ranged from 20 mm h^{-1} in the Control to 44 mm h^{-1} with combined application of FYM and NPK (Table 2). Similarly, the combined farmyard manure and NPK application resulted in greater K_{fs} and matric flux potential. The fertilizer treatment effect on infiltration was limited to the upper depths. Control had less infiltration at all depths compared to the other three treatments (Fig. 2). The AB horizon in the Control plots had the least infiltration but such an effect is not observed in the FYM and/or NPK treated plots. The three-way interaction between tillage, fertilizer treatment, and the profile depth was also significant. The moldboard plots that received the combined application of FYM and NPK had the highest average K_{fs} (11 mm h^{-1}). On the other hand the cultivator plots without any fertilizer application had the lowest K_{fs} (3.0 mm h^{-1}).

Water Retention Characteristics: The moldboard ploughed plots retained more water at a given matric potential compared to that of the tine cultivator tilled (Table 3), although the magnitude of difference decreased as the potential level became more negative, but it remained statistically significant. The water retention below 32 cm depth did not change with the tillage treatments. FMY alone or in combination with NPK retained more water than control, at same metric potential. At -30 kPa, the application of FYM alone or in combination with NPK had θ_m 0.152 g g^{-1} as compared to 0.136 g g^{-1} in control.

The water retained at various matric potentials varied with the horizon depth as well. Generally, the Btk (32-75 cm) and Bw (23-32 cm) horizons retained greater water than Ap (0-11 cm) and AB (11-23 cm) horizon at a given matric potential.

Plant Available Water: The moldboard plots had more plant available water (water content between −30 and −1500 kPa) and easily available water (water content between −30 and −200 kPa) compared to that of the cultivated plots, except in control (Fig. 4 & Table 4). This trend was more pronounced in the magnitude of easily available water (Fig. 4b). Plant available water was approximately 8 to 10 cm per 75 cm profile in the cultivated plots with no statistical difference among the fertilizer treatment means. Plant available water

Table 1: Copy yield (Mg ha^{-1}) in selected years as affected by the tillage and the fertilizer treatments

Treatments	Crops				
	Maize (fodder)			Wheat (grain)	
	1996	1997	1998	1996-97	1997-98
Tillage					
Moldboard	23.30a	16.20a	30.30a	2.50a	2.10a
Cultivator	19.60b	15.00a	26.60b	2.20a	1.80b
Fertilizer					
Control	16.10b	10.60c	18.00b	1.90bc	1.10b
NPK	27.00a	18.10b	32.70a	2.60ab	2.60a
FYM	17.75b	11.40c	19.60b	2.10bc	1.10b
NPK+FYM	30.25a	22.30a	38.50a	2.90a	2.80a

Tillage and fertilizer treatments means sharing the same letter do not differ significantly (α 0.05)

Table 2: Infiltration rate, field saturated hydraulic conductivity (K_{fs}) and matric flux potential (ϕ_{fs}) determined using saturated infiltration measured *in situ* using a constant-head well permeameter (Reynolds, 1983)

Treatment	Depth (cm)	Infiltration rate mmh^{-1}	K_{fs} Mmh^{-1}	ϕ_{fs} mm^2h^{-1}
Tillage$				
Cultivator		25.9b	5.2b	420.0b
Moldboard		40.8a	8.1a	670.0a
Fertilizer$				
Control		19.4b	3.9b	330.0b
NPK		34.7a	7.2a	580.0a
FYM		35.5a	7.3a	610.0a
NPK+FYM		43.8a	8.0a	670.0a
Horizon$				
Ap	0-11	37.0a	7.0ab	580.0ab
AB	11-23	34.2a	6.6ab	530.0ab
Bw	23-32	22.4b	4.8b	390.0b
Btk	32-75	39.7a	8.2a	690.0a

$, Tillage and fertilizer means are averaged on the profile and horizon means are averaged over both tillage and fertilizer treatments. Means sharing the same letter do not differ significantly (α 0.05)

Table 3: Water retained at various matric potentials as affected by tillage and fertilizer

Treatments	Depth (cm)	-30 kPa	-50 kPa	-200 kPa	-500 kPa	-1500 kPa
		$g\ g^{-1}$				
Tillage$						
Cultivator		0.140b	0.122a	0.096b	0.074b	0.057b
Moldboard		0.155a	0.127a	0.101a	0.078a	0.063a
Fertilizer$						
Control		0.136b	0.177b	0.095b	0.074bc	0.058b
NPK		0.149ab	0.128a	0.097b	0.072c	0.057b
FYM		0.152a	0.130a	0.105a	0.082a	0.065a
NPK+FYM		0.152a	0.125a	0.098b	0.077ab	0.063a
Horizon$						
Ap	0-11	0.140ba	0.120b	0.092c	0.070c	0.055c
AB	11-23	0.136c	0.119b	0.086d	0.066c	0.055c
Bw	23-32	0.160a	0.127ab	0.104b	0.080b	0.061b
Btk	32-75	0.153ab	0.133a	0.112a	0.089a	0.072a

$, Tillage and fertilizer means are averaged on the profile and horizon means are averaged over both tillage and fertilizer treatments.
Means sharing the same letter do not differ significantly (α 0.05)

Table 4: Plant available water and total porosity.

Treatment	Depth (cm)	Plant available water cm per 75 cm	Easily available cm per 75 cm	Total porosity m^3m^{-3}
Tillage$				
Cultivator		8.20a	4.00b	0.41b
Moldboard		9.60a	5.75a	0.42a
Fertilizer$				
Control		7.70b	3.74b	0.41a
NPK		9.90a	5.56a	0.41a
FYM		8.80a	4.58a	0.43a
NPK+FYM		9.25a	5.56a	0.41a
Horizon$		cm per horizon depth		
AP	0-11	1.42b	0.80b	0.43b
AB	11-23	1.60b	1.00b	0.38c
Bw	23-32	1.43b	0.80b	0.40
Btk	32-75	4.46a	2.30a	0.45

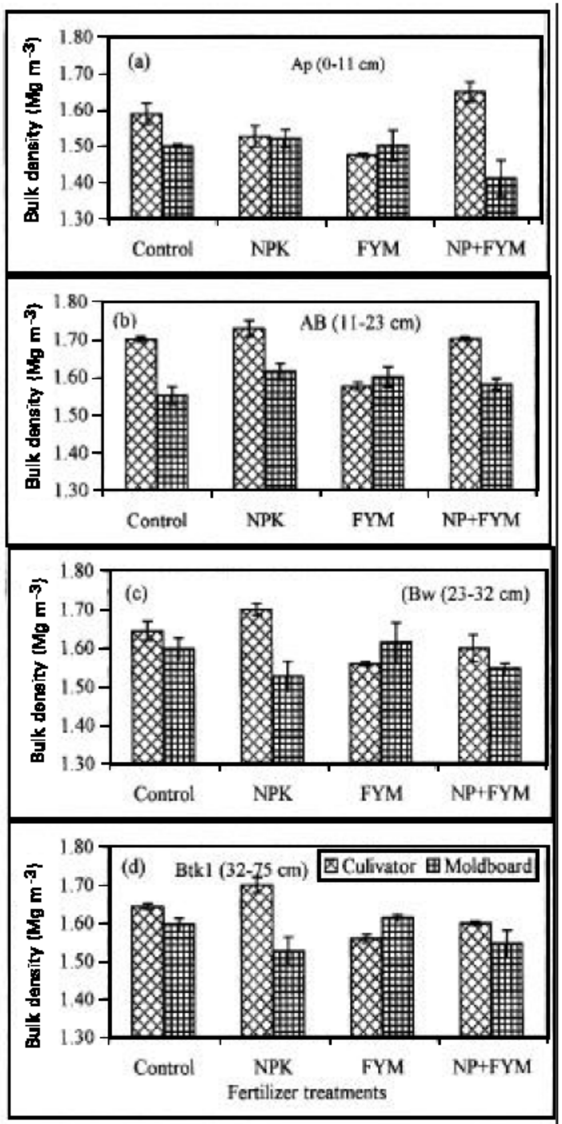

Fig. 1: Changes in soil bulk density due to the long-term tillage and fertilizer treatments in the upper four horizons: (a), Ap (0-11 cm); (b), AB (11-23 cm); (c), Bw (23-32 cm); and (d), Btk (32-75 cm).

with moldboard ploughing increased from zero in control to 4 and 5 cm per 75 cm profile in FYM and NPK treatment. Easily available water in the cultivator tilled plots remained unchanged by the application of NPK and FYM when applied both separately or in combination (Fig. 4b). Although the Bw horizon had the highest plant available water and easily available water fractions but due to greater total depth the Btk horizon had significantly larger water depth than the other horizons (Table 4).

Pore Size Distribution: In the cultivator plots, where pulverizing was limited to the surface 0-11 cm, the AB horizon had the lowest quantity (or volume) of 60-300 μm radius pores, although, the 30-60 μm radius and smaller pores were greater or equal to the above or below horizons (Fig. 5).

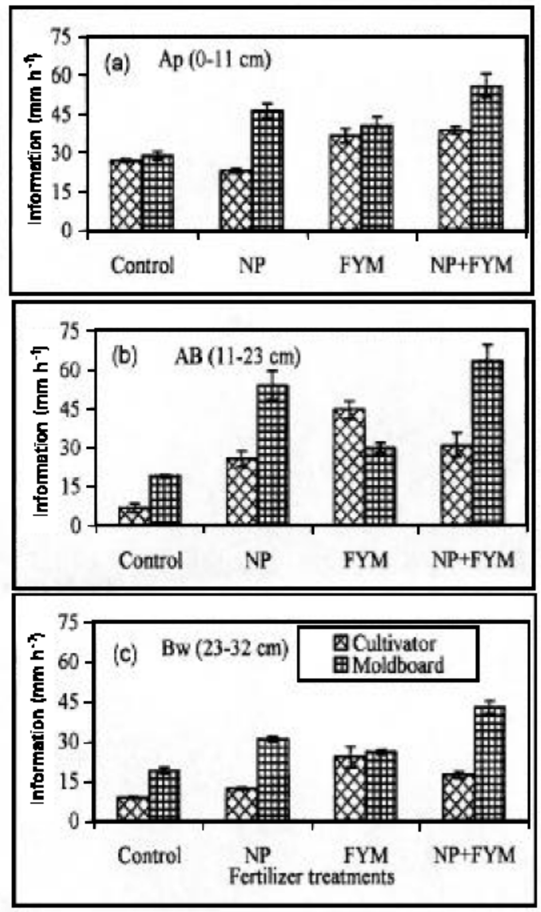

Fig. 2: Infiltration rate as affected by the tillage and the fertilizer treatments in the upper three soil horizons: (a), Ap (0-11 cm); (b), AB (11-23 cm); and (c), Bw (23-32 cm).

Discussion

The study demonstrates benefits of moldboard ploughing in the rainfed crop production system. The decrease in soil bulk density, increase in water infiltration, and more water storage capacity due to the long-term moldboard ploughing combined with NPK and FYM translated into agronomic yield gains. The decreased bulk density as a result of long-term continuous use of FYM conforms to previous studies (Sur *et al.*, 1993). A bulk density reduction of 0.004 Mg m^{-3} per Mg manure ha^{-1} under moldboard and $\leq$ 0.001 Mg m^{-3} per Mg manure ha^{-1} under rotatiller and cultivator was reported by Sommerfeldt and Chang (1987). At this site, the difference in ρ_b values in the Ap with and without FYM was 0.13 Mg m^{-3} which is well within the stipulated values of 0.1 Mg m^{-3} decrease in ρ_b with 5 Mg ha^{-1} applied over 5 years. However, this is in contrast to numerous other results where moldboard ploughing resulted in a lower bulk density in surface soils compared to long-term no tillage or reduced tillage (Azooz *et al.*, 1996; Bordovsky

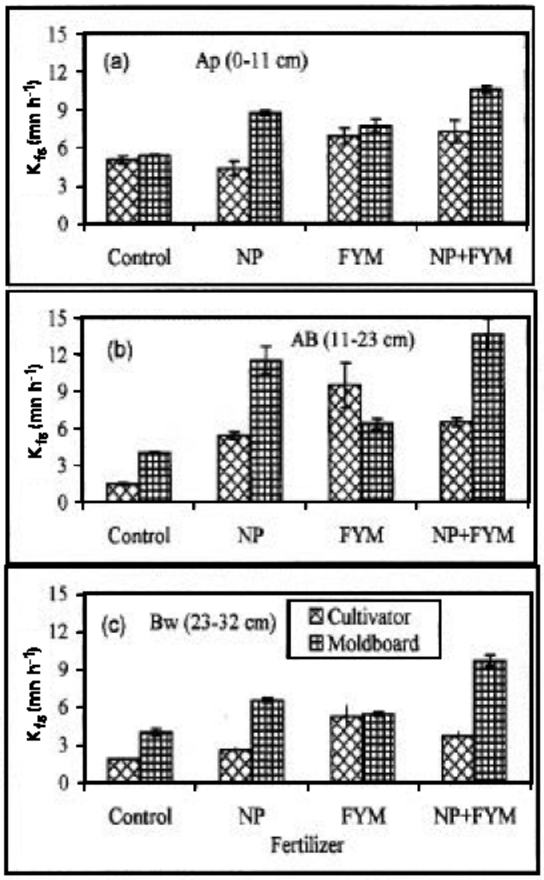

Fig. 3: Saturated hydraulic conductivity as affected by the tillage and the fertilizer treatments in the upper three soil horizons: (a), Ap (0-11 cm); (b), AB (11-23 cm); and (c), Bw (23-32 cm).

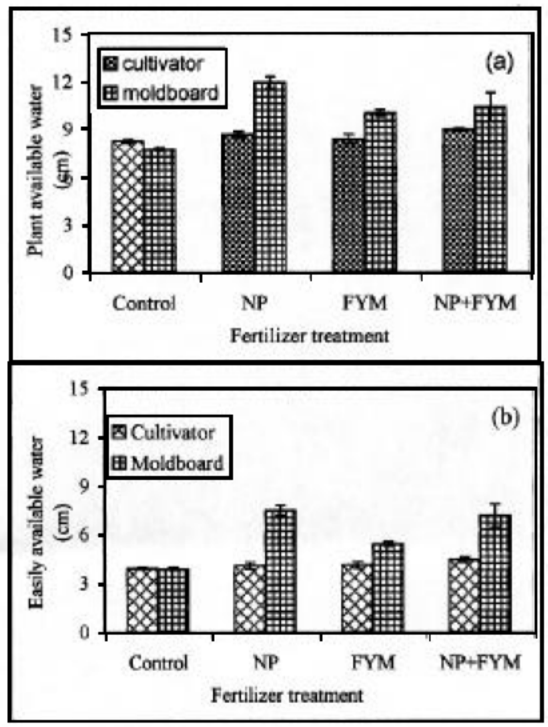

Fig. 4: Plant available water in 75 cm profile depth of each fertilizer plot under moldboard and cultivator: (a) total available water, water retained between −30 and −1500 kPa matric potential and (b) easily available water, water retained between −30 and -200 kPa matric potential.

et al., 1999). Soil bulk density is directly affected by tillage methods (Unger, 1992) and, specifically, to the depth at which the tillage is carried out (Gill *et al.*, 2000).

The smaller reduction in bulk density in the cultivator plots compared to that of the moldboard plots, when both had received FMY, may be attributed to a difference in incorporation zone (Kooistra, 1990). The type and quantity of organic matter (Bordovsky *et al.*, 1999) or residue cover at the time of vehicular traffic also determines variability in bulk density (Lal *et al.*, 1994). Moldboard tillage has been reported to increase organic matter turnover rates (Balesdent *et al.*, 2000) but ubiquitous results cannot be expected due to their strong interaction with regional climate and the soil physical properties.

The saturated hydraulic conductivity is a highly variable soil parameter (CV > 100%; Hill, 1980) and it is difficult to ascertain a treatment effect. Nevertheless, the mean K_{fs} values in this study are similar to those reported for sandy loam, e.g., 11 mm h^{-1} under moldboard (Azooz *et al.*, 1996). At this site, the moldboard treatment increased the saturated water transmission by over 33 %, which may be ascribed to the increased total void spaces in the soil (Chang and Lindwall, 1992; Gomma and El-Naggar, 1995). In this study, the moldboard ploughing pulverized both Ap and AB horizons and brought their infiltration to a similar level, whereas in the cultivator tillage, the AB horizon remained untilled and resulted in lower K_{fs}. Organic matter addition also increases infiltration and hydraulic conductivity (Fig. 2). These results were in accord with many other studies (Nnabude and Mbagwu, 1999; Klik *et al.*, 1994).

Increased infiltration as a result organic matter application can be attributed to an increased porosity and decreased bulk density (Ali and Swartzendruber, 1994).

The increased water retention under moldboard ploughing may be attributed to change in pore size distribution as we discuss later. Akhtar and Qureshi (1999) also reported increased soil water retention at low metric potential and a decrease at high metric potential due to moldboard ploughing in the rice-wheat system.

FYM alone or in combination with NPK improved water retention in the sandy loam soil more than the fertilizer control at all metric potentials (Table 2) due to increased air filled porosity (Zhu and Yao, 1993). Similar results, and the fact that the magnitude of the effect depends upon soil texture, were reported by Darwish *et al.* (1995). Increased water retention at given tensions with poultry manure (Obi and Ebo, 1995) and green manuring (Sur *et al.*, 1993) has also been reported. The general consensus is that the magnitude of positive effects of organic matter addition on soil water retention characteristics is site specific, and depends greatly

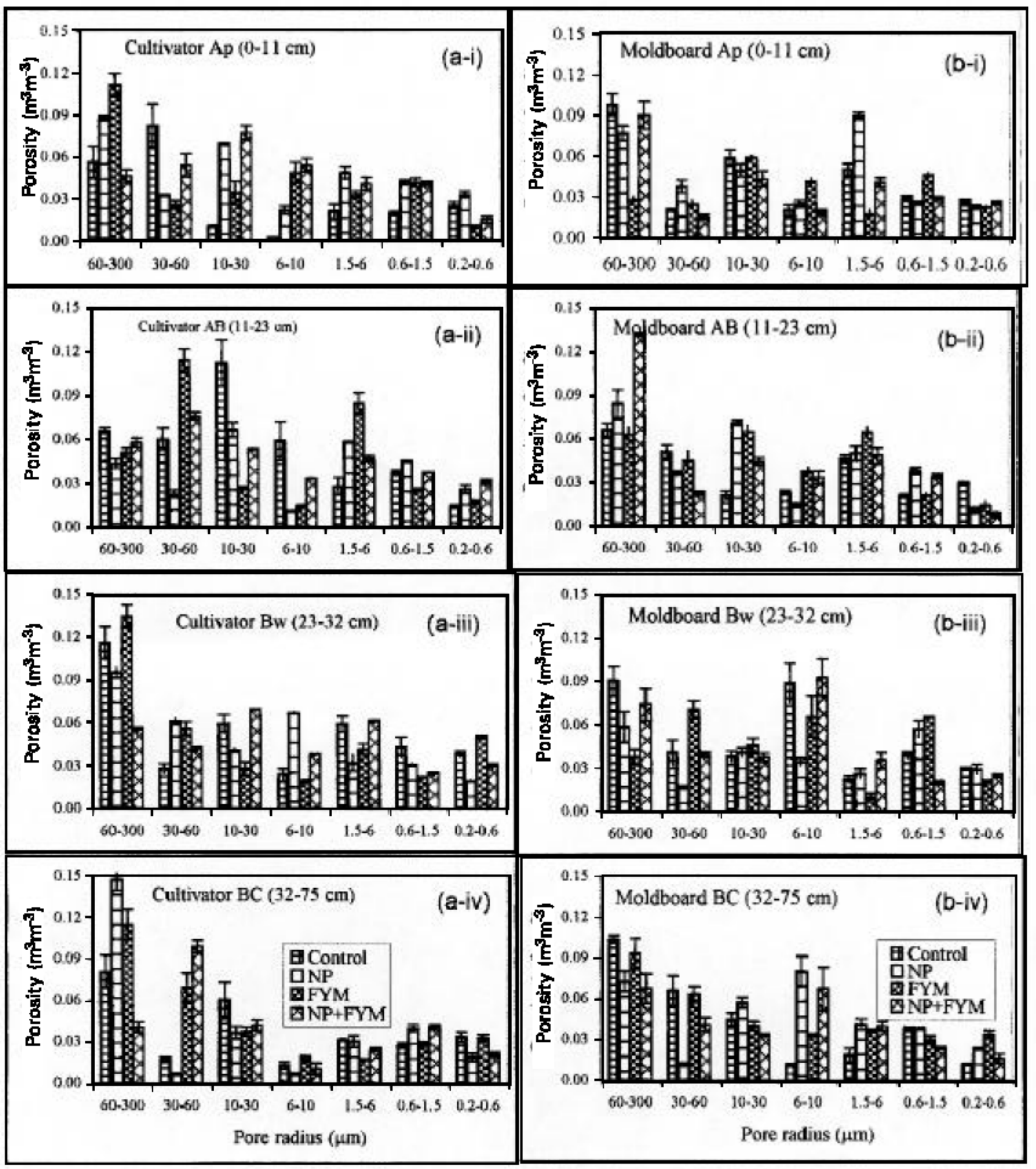

Fig. 5: Pore size distribution in upper four soil horizons of each fertilizer plot under moldboard and cultivator as determined by water retention characteristics.

on the initial soil organic matter level and rate of oxidation. The water retained at various metric potentials varied with the horizon as well. Generally, the Btk and Bw horizons retained more water than the Ap (0-11 cm) and AB (11-23 cm) horizons at a given metric potential (Table 2). The Btk horizon retained more water than that of the Bw horizon at both low tension and high tension which is characteristic of a clayey fine textured material. The Btk horizon had a higher clay content and had better-developed structure based on visual observation in the field. The AB horizon retained the lowest water, consistently, for given potential range. It had the greatest bulk density (Fig. 1) and the lowest macroporosity (discussed later).

Pore Size Distribution: Pore size distribution varies with horizon in an undisturbed genetic soil profile and tillage affects the tilling depth. In the cultivator plots, where pulverizing was limited to the surface 0-11 cm, the AB horizon had the lowest quantity (or volume) of 60-300 µm radius pores. Though, the 30-60 µm radius and smaller pores were greater or equal to the above or below horizons for the cultivator treatment, the AB horizon had the highest bulk density. The contribution of smaller pores to total porosity is generally insignificant (Drees *et al.*, 1994). Consequently, the increased bulk density appeared to correlate better with the 60-300 µm size pores decrease than the change in any other size radius pores (Asare *et al.*, 1999; Akhtar *et al.*, 2001). Moldboard ploughing increased the quantity of 60-300 µm size pores in the AB horizon, especially when both NPK and FYM were applied in combination. This again conforms to the reduction in bulk density. It also indicates that incorporated organic material may correct tillage induced degradation of soil physical properties (Oyedele *et al.*, 1999). Incorporation of organic matter increases the number of macropores (Akhtar *et al.*, 1999) by encouraging granulation and by creating void space as the large organic material is decomposed (Asare *et al.*, 1999),

The application of FYM alone or in combination with NPK resulted in a greater volume of various size pores than the control. The manure application effect varied with tillage but generally the results conformed to earlier investigations that organic matter improves soil structure through the stimulation of structure-forming soil fauna (Kooistra, 1990). An increase in total porosity and macro-porosity (Obi and Ebo, 1995) and decreased bulk density (Zhu and Yao, 1993) has been reported with long-term manuring. An increase in soil porosity of < 250 µm effective pore radius with long-term manure application was also reported by Pikul and Zuzel (1994). These increases in macropores, ranging from 50-500 µm, in soil treated with organic fertilizers is reported to be mainly due to an increase in elongated pores, which are considered important both in soil-water-plant relationships and in maintaining a good soil structure (Marinari *et al.*, 2000).

The long-term field experiment fertilizer treatments under rain-fed wheat-maize system has shown moldboard tillage and NPK and annual application of FYM increased the crop yield by improving in physical condition of the sandy loam soil. The same treatment reduced soil bulk density, increased saturated infiltration, and increased the plant available water compared to that of tine cultivator. The primary benefit of the moldboard ploughing and combined application of FYM and NPK was also the increased macroporosity and saturated infiltration in the upper 0-32 cm profile. The compact AB horizon, which had the lowest volume of 60-300 µm radius pores before ploughing, was pulverized by the moldboard treatment.

The Bt (32-75 cm) horizon is the main reservior for plant available water. This horizon is completely recharged during the repetitive monsoon rain events and helps to keep optimum water supply to the Rabi crop (wheat) during November and December. Recharge of the subsoil during scantly westerly rain showers in the region falling in late December and January is more critical for optimum wheat yield, which can only be achieved by pulverizing the compact AB horizon. Future research to investigate independently the soil water balance would be beneficial to corroborate the results of this study. Although no soil penetrometer or root mass measurement were carried out, it is quite likely that moldboard ploughing helped to remove physical constraints to root development.

References

Akhtar, M. S. and S. Qureshi, 1999. Soil hydraulic properties and root development as influenced by tillage in rice-wheat system. Pa. J. Bio. Sci., 2:1245-1251.

Akhtar, M. S., K. S. Memon and S. Qureshi, 1999. Soil surface structure and hydraulic properties as affected by long-term organic matter management in Cotton-Wheat System. Pak. J. Bio. Sci., 2: 1322-1331.

Akhtar, M. S., A. Hussain, M. A. Naeem and S. Qureshi, 2001. Surface structure of a sandy loam soil as affected by long-term tillage and fertilizer in Pothwar plateau of Pakistan. Sci. Vision (submitted).

Alakukku, L., 1996. Persistence of soil compaction due to high axle load-traffic. II. Long term effects on the properties of fine textured and organic soils. Soil Till. Res., 37:223-238.

Ali, A. S. I. and D. Swartzendruber, 1994. An infiltration equation to assess cropping effects on soil water infiltration. Soil Sci. Soc. Am. J., 58: 1218-1223.

Asare, S. N., R. P. Rudra, W. T. Dickison and A. Fenster, 1999. Quantification of soil macroporosity and its relationship with soil properties. Canadian Agric. Engin., 41:23-34.

Azooz, R. H., M. A. Arshad and A. J. Franzluebbers, 1996. Pore size distribution and hydraulic conductivity affected by tillage in Northwestern Canada. Soil Sci. Soc. Am. J., 60: 1197-1201.

Balesdent, J., C. Chenu and M. Balabane, 2000. Relationship of soil organic matter dynamics to physical protection and tillage. Soil Till. Res., 53: 215-230.

Bennie, A. T. P. and F. J. P. Botha, 1986. Effects of deep tillage and controlled traffic on root growth, water-use efficiency and yield of irrigated maize and wheat. Soil Till. Res., 7:85-95.

Bordovsky, D. G., M. Choudhary and C. J. Gerard, 1999. Effect of tillage, cropping, and residue management on soil properties in the Texas Rolling Plains. Soil Sci., 164:331-340.

Bouma, J., 1991. Influence of soil macroporosity on environmental quality. Adv. Agron. 46. Academic Press. San Diego, CA. pp:1-37.

Chang, C., and C. W. Lindwall, 1992. Effects of tillage and crop rotation on physical properties of loam soil. Soil Till. Res., 22:383-389.

Chenu, C., Y. Le Bissonnais and D. Arrouays, 2000. Organic matter influence on clay wettability and soil aggregate stability. Soil Sci. Soc. Am. J., 64: 1479-1486.

Cockroft, B. and K. A. Olsson, 2000. Degradation of soil structure due to coalescence of aggregates in no-till, no-traffic beds in irrigated crops. Australian J. Soil Res., 38:61-70

Danilov, G. G. and I. F. Kargin, 1979. Efficacy of deepening the plough layer of leached chernozem. Soviet Soil Science, 11:617.

Darwish, O. H., N. Persaud and D. C. Martens, 1995. Effect of long-term application of animal manure on physical properties of 3 soils. Plant Soil, 176:289-295.

Drees, L. R., A. D. Karathanasis, L. P. Wilding and R. L. Blevins, 1994. Micromorphological characteristics of long-term no-till and conventionally tilled soils. Soil Sci. Soc. Am. J., 58:508-517.

Gill, S. M., M. S. Akhtar and Z. Saeed, 2000. Soil water use and bul;k density as affected tillage and fertilizer in rain-fed wheat production system. Pak. J. Bio. Sci., 3:1223-1226.

Gomaa, M. R. and H. M. M. El-Nagger, 1995. Influence of tillage, weed control and phosphorus fertilizer treatments on sunflower productivity and soil properties. Annals Agri. Sci. Moshtohor, 33: 1179-1193.

Hillel, D., 1980. Applications of soil physics. Academic Press, New York.

Khanzada, S. Khan, 1976. Soils and land capability Pakistan Agricultural Research Centre Islamabad. Soil Survey of Pakistan. Multan road, Lahore. Pakistan

Klik, A., V. M. Salokhe and S. Gajendra, 1994. Soil conservation and crop productivity in Austrian vineyards. Proc Intl. Agric. Engin. Conf. 2. Asian Institute of Technology Bangkok, Thailand, December 6-9, 1994. pp: 422-429.

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

Kooistra, M. J., 1990. 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 Proceeding 10th International Soil Zoology Colloquium, Bangalore, India, August 7-13, 1988. Oxford and IBH Co. New Delhi, India.

Lal, R., 2000. Soil management in developing countries. Soil Sci., 165:57-72.

Lal, R., A. A. Mahboubi and N. R. Fausey, 1994. Long-term tillage and rotation effects on properties of a Central Ohio soil. Soil Sci. Soc. Am. J., 58:517-522.

Mahboubi, A. A. and R. Lal, 1998. Long-term tillage effects on changes in structural properties of to soils in central Ohio. Soil Till. Res., 45:107-118.

Marinari S, G. Masciandaro, B. Ceccanti and S. Grego, 2000. Influence of organic and mineral fertilisers on soil biological and physical properties Bioresource Technology, 72:9-17.

Nnabude, P. C. and P. Mbagwu, 1999. Soil water relations of a Nigerian typic haplustult amended with fresh and burnt rice-mill wastes. Soil Till. Res., 50:207-214.

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. Bio-resource Technology, 51: 117-123.

Oyedele, D. J., P. Schjonning, E. Sibbesen and K. Debosz, 1999. Aggregation and organic matter fractions of three Nigerian soils as affected by soil disturbance and incorporation of plant material. Soil Till. Res., 50: 105-114.

Pikul, J. L. and J. F. Zuzel, 1994. Soil crusting and water infiltration affected by long-term tillage and residue management. Soil Sci. Soc. Am. J., 58:1524-1530.

Rahimi, H., E. Pazira and F. Tajik, 2000. Effect of soil organic matter, electrical conductivity and sodium adsorption ratio on tensile strength of aggregates. Soil Till. Res., 54:145-153.

Razzaq, A., N. I. Hashmi, B. Khan, B. R. Khan and P. R. Hobbs, 1989. Wheat in Barani areas of northern Punjab: A synthesis of on-farm research results 1982-1988. PARC/CIMMYT Paper 90-2. Coordinated Wheat Program, Pakistan Agri. Res. Council, Islamabad. Pakistan.

Reynolds, W. D. and D. E. Elrick,1985. In situ measurement of field saturated hydraulic conductivity, sorptivity, and the a-parameter using Guelph parameter. Soil, 140:292-302.

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

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

Soane, B. D., 1990. The role of organic matter in soil compactibilty: A review of some practical aspects. Soil Till Res., 16:179-201.

Sommerfeldt, T. G. and C. Chang, 1987. Soil water properties as affected by twelve annual applications of cattle feedlot manure. Soil Sci. Soc. Am. J., 51:7-9.

Stenberg, M., B. Stenberg and T. Rydberg, 2000. Effects of reduced tillage and liming on microbial activity and soil properties in a weakly-structured soil. Applied Soil Eco., 14:135-145.

Unger, P. W., 1992. Infiltration of simulated rainfall: Tillage system and crop residue effects. Soil Sci. Soc. Am. J., 56:283-289.

Watts, C.W. and A.R. Dexter, 1998. Soil friability: theory, measurement and the effects of management and organic carbon content. European J. Soil Sci., 49: 73-84.

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