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Soil Water Use and Bulk Density as Affected by Tillage and Fertilizer in Rain-fed Wheat Production System

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Abstract: The study on conventional cultivator, moldboard and subsoiling as tillage methods combined with organic and mineral fertilizers demonstrates effect on wheat yield, soil physical properties, and soil water use. Moldboard tillage resulted greater bio-mass and grain yield than conventional cultivator. Increase in grain yield with moldboard plowing was 18% greater than that of cultivator plowing. Also, grain to straw ratio was greater with moldboard than that of cultivator and subsoiling. Biomass and grain yield with farmyard manure was similar to that with 200 kg N ha^{-1} but it had the highest grain:straw ratio. Different tillage operations changed soil bulk density to their tilling depth and farmyard manure decreased bulk density only in the surface horizon. Specifically, in 0 to 15 cm depth, moldboard resulted in the lowest bulk density and the subsoiling resulted in the highest bulk density. Soil water did not vary with tillage. During the growth period rainfall was 400 mm and crop water requirement was 385 mm. The decrease in soil water from 160 ± 5 to 140 ± 5 mm in the presence of greater rains than the water requirement suggested an overall runoff from the field. Soil water content in the profile remained between suction rang of 0.3 bar and 10 bars. Since moldboard had to support a greater biomass and consequently, greater evapotranspirative demand, therefore, water intake in moldboard appeared to be greater than that of conventional tillage.

Key words: Tillage, fertilizer, wheat, bulk density, soil water, crop water use

Introduction

Soil water conservation is a critical issue in dryland, semi-arid grain production system of Pakistan (Campbell and Akhtar, 1990), where tillage involving conventional tine cultivator has resulted in a compact soil layer immediately below the plow zone due to repeated operations (Razzeq *et al.,* 1989). Soil water is the primary yield limiting factor and manipulating soil moisture dynamics with deep tillage may turn out to be one of the most feasible ways of increasing average yield in barani areas.

The majority of soils under cultivation in the Pothwar area are susceptible to compaction under pressure by tillage equipment due to un-stable soil structure. Unstability of soil structure results from low organic matter (generally <0.3%), high silt content and an early stage of profile development. Soil compaction leads to the restricted roots in a shallow zone. Deep cultivation or subsoiling are recommended to break any compacted layers. Deep primary tillage in the areas resulted in, on en average, 38% yield increase (Razzeq *et al.,* 1989). Similar better crop yields due to deep plowing than topsoil plowing were shown else where (Lavado and Cairns, 1980). Danilov and Kargin (1979) showed that deep plowing reduced weeds, erosion and soil compaction but promoted the accumulation of moisture. Studies by Reddy *et al.* (1977) in Anantpur, India, revealed that breaking up of the hard layer below the plow sole by deep plowing increased the water intake rate and hydraulic conductivity. This resulted in an enhanced root growth and increased yields of castor, redgram and bajra.

Deep tillage is an energy-expensive operation but may be justified only if there is a greater production and the effect is sustainable. The effect of deep tillage on moisture conservation and rainfed wheat is erratic varying with soil and rain received (Khokhar and Nizami, 1987). The earlier work done on deep tillage in the area hypothesized that gain in agronomic yield due to better root growth, greater uptake of nutrients and water under deep tillage (Razzeq *et al.,* 1989; Campbell and Akhtar, 1990) but actually did not report data on these parameters.

Objective of the study was to determine the effect of deep tillage combined with organic and mineral fertilizers on wheat yield, soil physical properties and soil water use.

Materials and Methods

A field study was conducted during the year 1997-98 in Fatah Jang area, district Attack. The site consisted of a sandy clay loam soil developed from the parent material derived from loess. The following tillage treatments were applied in the main plot: (a) Conventional tillage (farmer practice), (b) Moldboard and (c) Subsoiling. The conventional tillage consisted of four plowing with tine cultivator and two planking, Moldboard consisted plowing with moldboard and two planking by dragging 100 kg wooden log behind a cultivator and Subsoiling was subsoiling to a minimum depth of 40 cm with a tractor-mounted single tine sub-soiler. The cultivator was an eleven-tine plow tilling upto a minimum depth of 10 cm. Moldboard plow was a four blades reversible plow, tilling upto a minimum depth of 25 cm with two blades used at a time. After tillage, DAP was applied as basal fertilizer to make a level of 30-80-0 kg NM ha^{-1} in all the treatments. Then, each main plot was split into four subplots: (a) Control, no additional N or FYM over the basal dose; (b) FYM, farmyard manure applied at 10 Mg ha^{-1}; (c) N120, addition of 90 kg N ha^{-1} over the basal dose and (d) N200, addition of 170 kg N ha^{-1} over the basal dose. Urea was added to make up the remaining N such that half of the N was applied as basal dose and the remaining half applied at the booting stage. The experiment was conducted in a split plot design in three replications. Wheat (*Triticum aestivum* L. var. Inclab-91) was sown on 18th November 1997 with a seed drill using seed rate 100 kg ha^{-1}. Soil bulk density and soil water contents at 0-15 cm, 15-30 cm, 30-45 cm and 45-60 cm, were measured by CPN Gamma probe, Model 501 DR. after 10 days of sowing and subsequently on 18 November, 23 December, 3 February, 24 March and 14 April. The crop was harvested on 30th April 1998 and biomass and grain yield was recorded.

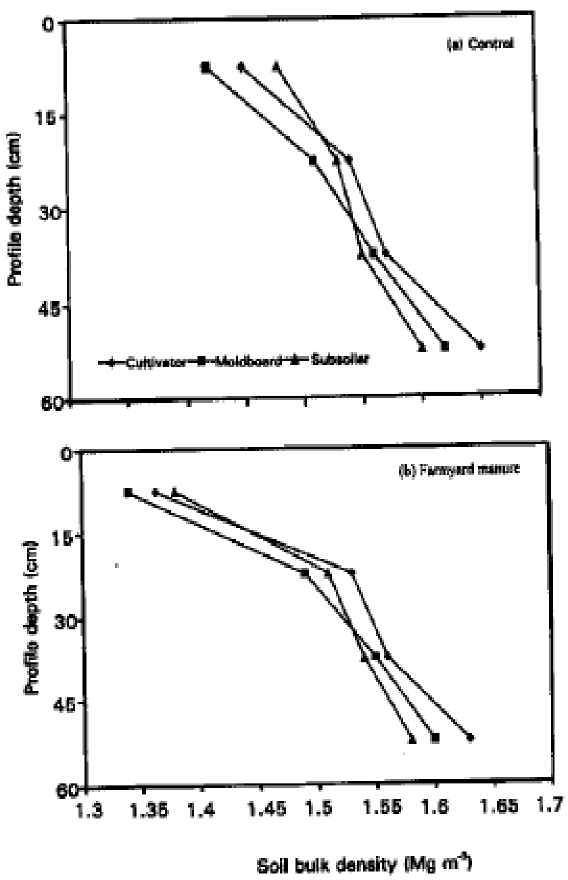

Fig. 1(a-b): Soil bulk density as affected by (a) tillage and (b) fertilizer treatments

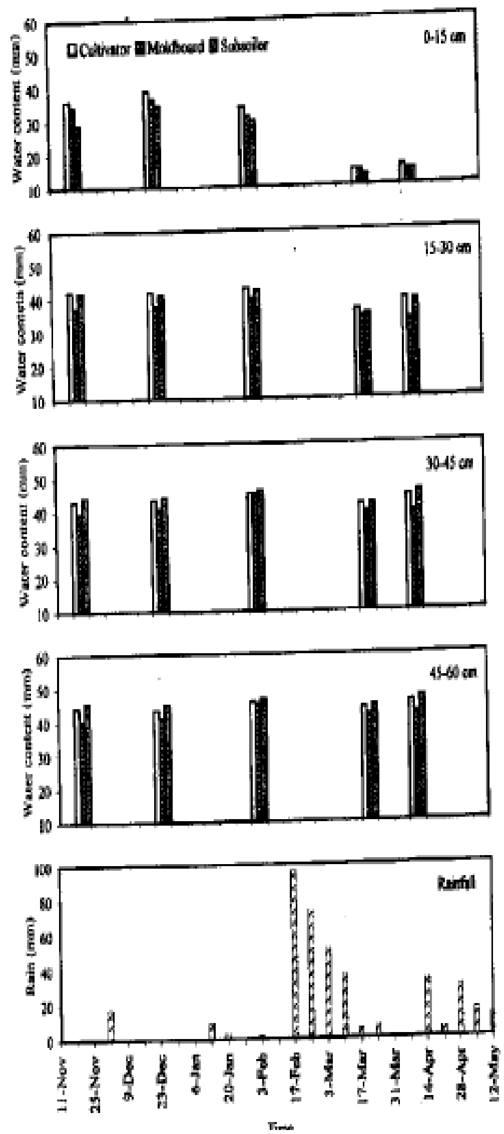

Fig. 2: Soil water at various depths as affected by tillage treatments and rainfall during the wheat growth period

Results and Discussion

Bio-mass and Grain Yield: The biomass, which includes grain and straw, increased by 15 percent with moldboard over conventional cultivator, while increase with subsoiling was about 8 percent over the conventional tillage (Table 1). The increase both with moldboard and subsoiling was statistically non-significant because of greater variability in the field at this site. Grain yield with moldboard was significantly greater than with cultivator and the gain in yield was over 18%. Grain yield with sub-soiling was lesser than the moldboard but greater than the conventional tillage and was statistically similar to both the treatments (Table 1). Grain to straw ratio was greater with moldboard than with cultivator and subsoiling.

Previously, a significant increase in wheat biomass by moldboard plow as compared to conventional cultivation at nearby site (Campbell and Akhtar, 1990) and in other countries (Drezgic and Jevtic, 1963; Reddy and Dakshinamurti, 1971; Kaddah, 1976) was reported and attributed to better physical soil environment. Campbell and Akhtar (1990) speculated that there was enhanced root growth due to moldboard and in turn shoot growth was due to increased water and nutrient uptake. In an other study, 8 to 12% grain yield increase with sub-soiling and chisel over cultivator was reported (Khokhar and Nizami, 1987).

The fertilizer treatment effect on biomass production and grain was highly significant. Maximum biomass and grain yield was obtained with treatment and it was statistically similar to that of FYM. The increase in biomass with FYM, N120 and N200 over the Control was 20, 10 and 25%, respectively. Similarly, grain increase with FYM, N120 and 14200 was 30, 20, 30 percent over the Control, respectively. Farmyard manure had the highest grain:straw ratio which was statistically similar to that of N120 while with N200 grain:straw ratio decreased but remained greater than the Control (Table 1).

Soil Bulk Density: Bulk density of native soil profile at the site, generally, increased with depth as depicted by bulk density of cultivator plots in the Control fertilizer treatments (Fig. 1). Different tillage operation changed soil bulk density to their tilling depth and farmyard decreased bulk density only in the surface horizon.

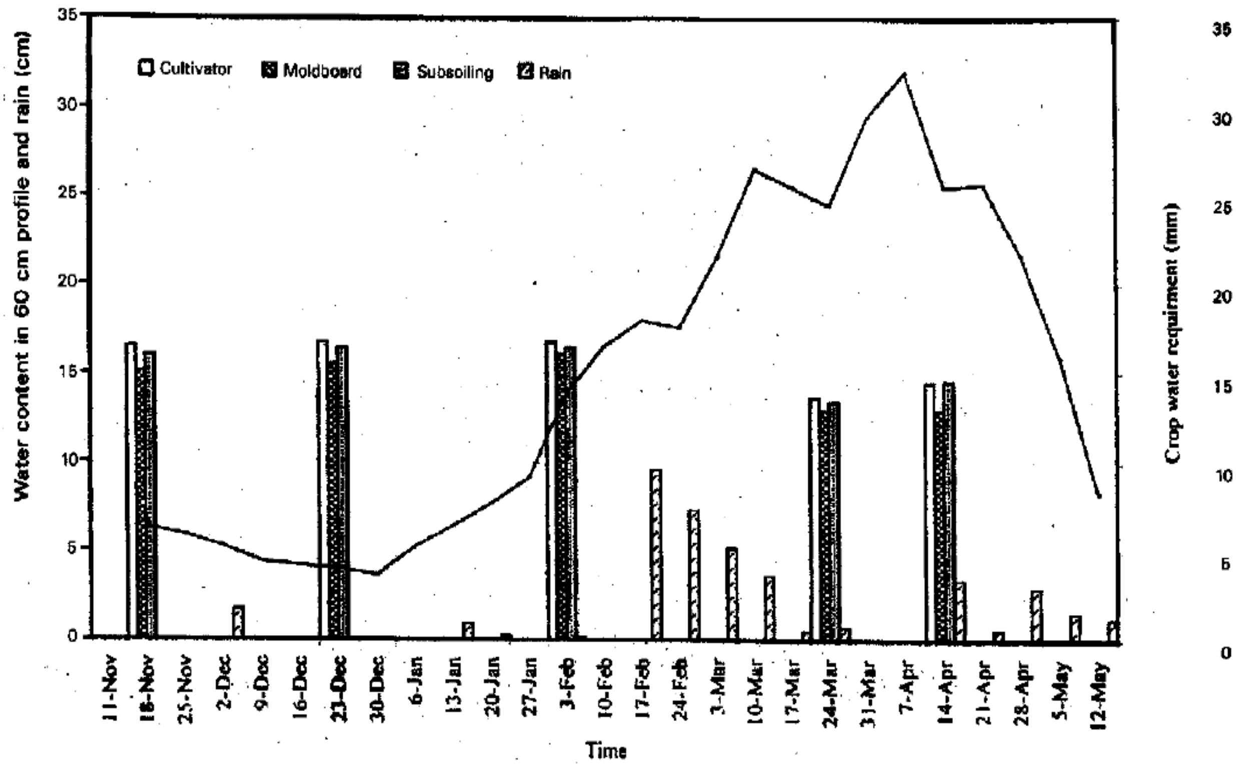

Fig. 3: Soil water in the profile, rainfall and crop water requirement (Doorenbos and Pruitt, 1977) during the wheat growth period

In the 0 to 15 cm depth, Moldboard resulted in the lowest bulk density and the subsoiling resulted in the highest bulk density. Moldboard also had the lowest bulk density at 15-30 cm depth but unlike 0-15 cm Subsoiling resulted in lesser bulk density than Cultivator at this depth. Subsoiling resulted in the lowest bulk density in the 30 to 46 cm layer but the difference among the tillage treatments was non-significant (Fig. 1a) at that depth.

Bulk density is nearly always altered by tillage operations is (Cassel *et al.*, 1978) and further changes in the soil physical environment are mediated through bulk density. Lower bulk density with moldboard plow at 15-30 cm indicates the pulverizing effect to that depth. Similarly, a greater bulk density with Subsoiling than that of Cultivator at 0-15 cm depth suggested a compaction by the tractor weight but it did shatter the 30-45 cm layer. Chaudhary *et al.* (1985) determined effect of cultivator, chisel, moldboard and digging (to 45 cm) as tillage treatments pre-sowing maize on a loamy sand. They reported lower bulk density of 10-30 cm layer than that of 0-10 cm layer in chiseled furrows and in the dug plots than the corresponding layer of surface tilled Cultivator plots.

Fertilizer treatment comparison indicated that farmyard manure reduced bulk density of the surface layer in all the tillage operation. While bulk density of subsurface remained unaffected. Average bulk density of the surface layer in Control (Fig. 1a) was 1.45 Mg m^{-3} and with farmyard manure it reduced to 1.36 Mg m^{-3} (Fig. 1b). This difference was statistically significant. The other fertilizer treatments (N120 and N200) were statistically similar to the Control (data not presented). Therefore, farmyard manure reduced the bulk density over control and the N120 and N200 treatments did

Table 1: Biomass and grain yield and affected by tillage and fertilizer treatments

Tillage	Fertilizer treatment				
	Control	FYM	N120	N200	Mean
		Biomass (Mg ha^{-1})			
Cultivator	10.1	12.1	11.5	12.8	11.6a
Moldboard	11.8	14.2	12.9	14.5	13.3a
Subsoiler	11.1	13.1	12.2	13.8	12.6a
Mean	11.0c	13.1a	12.24	13.7e	
		Grain yield (Mg ha^{-1})			
Cultivator	2.9	3.8	3.5	4.0	3.6b
Moldboard	3.6	4.5	4.1	4.4	4.2a
Subsoiler	3.2	4.2	3.8	4.2	3.8ab
Mean	3.2c	4.1a	3.8b	4.2a	
		Grain:Straw			
Cultivator	0.40	0.45	0.44	0.45	0.44
Moldboard	0.44	0.47	0.47	0.44	0.46
Subsoiler	0.41	0.47	0.45	0.43	0.44
Mean	0.42	0.46	0.45	0.44	

Legend: Control, control without any (or N) fertilizer; FYM, farmyard manure at 10 Mg ha^{-1}, N120, 120-80-0 kg he N200, 200-80-0 kg ha^{-1}

* Means sharing same letters are statistically non-significant

** Values in parenthesis show % Increase over cultivator

not result in any significant change in bulk density than control. The results conform to other studies in the area (Akhtar *et al.,* 1999) where a combined application of farmyard manure and NP resulted in significantly lower average p_b. In this study the effect of farmyard was greater incase of moldboard than cultivator. Similarly, a decreased in bulk density as a result of long-term manuring (Sur *et al.,* 1993; Ohu *et al.,* 1994) and organic matter application (Sommerfelt and Chung, 1985) have also been reported.

Change in soil bulk density changes its porosity and interparticle contact while in turn influence the hydraulic properties, consequently the soil water content (Prihar, 1990).
Total porosity, 1-p_b/p_p where p_b and p_p are bulk density and particle density (2.65 g cm^{-3}), respectively is a mirror image of bulk density. Total porosity was greater in the top-soil than that of subsoil. Also, Moldboard plow resulted in the highest total porosity upto 30 cm depth as well as the farmyard manure increased the total porosity significantly over control.

Soil Water: The Fig. 2 depicts soil water content in the profile measured at various time intervals over the crop growth period as affected by the tillage treatments. Starting from just after tillage application and seed-bed preparation, on November 18 to February 3 (next year), the soil water remained statistically similar among the tillage treatments at all depths except 0-15 cm. At this depth, cultivator had the highest soil water followed by moldboard and subsoiling. The moldboard and subsoiling resulted in drying at the surface probably due to limited capillary rise as a result of disruption in the pore continuity.
During this period there were exceptionally few rains with a shower of less than 20 mm rainfall on December 2nd, which was not sufficient to initiate drainage in the profile. Hence no significant difference in soil water due to subsoiling or moldboard plow was observed, except a nominal increase in moldboard tillage at 15-30 cm depth during 23rd December to 3rd February. Similar non-significant differences among tillage treatments (chisel, sub-sailer, and cultivator) were attributed to a complete drought during first three month of wheat crop by Khokhar and Nizami (1987). Campbell and Akhtar (1990) observed general pattern of greater soil water at 30-45 cm depth in deep moldboard plowed plots as compared to shallow tined tilled during the initial monitoring period of low rainfall. There were rains between 3rd February and 24th March amounting to 285 mm spread over the period but soil water content decreased at all depths especially in the surface layer (Fig. 2). Although statistically non-significant, Moldboard had the lowest soil water especially at 15 to 30 cm depth. During this period crop water requirement was the highest (Fig. 3) and the moldboard had to support a greater biomass (Table 1). Consequently, there was higher soil water uptake from moldboard plowed treatments due the evapotranspirative demand resulting in less water in soil in these treatments. Reddy *et al.* (1977) observed that deep plowing increased the water intake rate due to enhanced root growth.

Crop Water Use: The Fig. 3 depicts soil water in the profile, rainfall and crop water requirement during the wheat growth period. Water requirement was based on long-term meteorological data and calculated with modified Panmann Montieth method (Doorenbos and Pruitt, 1977). in the absence of rainfall, total water was 160$\pm$5 mm in 60 cm profile and there was no significant difference in soil water among the tillage treatments. Soil water remained unchanged until about end of January mainly due to minimum evapotranspirative demand resulting from limited crop growth. Rains during 18th Of November to end of January amounted to 31 mm and crop water requirement was 62 mm.
During 1st week of February and end of growth period (May 12), rainfall was 370 mm and water requirement was 323 mm. Soil water in the profile was 137, 130 and 135 mm in cultivator, moklboani and subsoiler, respectively, on March 24. In the same treatments it was 145, 130 and 146 mm on April 14 (Fig. 3). The decreased soil water in the presence of greater rains than the water requirement suggested an overall runoff from the field. The heavy rain-showers, amounting to one 3rd of total rain, during February might have actually caused the runoff. Water retained by a typical silty clay loam ranges from 0.26 at 0.3 bars to 0.18 at 15 bars metric suction (Oosterveld and Chang, 1980). Soil water content in the profile remained between suction rang of 0.3 bar and 10 bars.
The tillage treatment differences were non-significant in soil water content but significant in bio-mass production: moldboard yielded a greater bio-mass. It is apparent that greater evapotranspiration demand would have been met from the moldboard plots. Therefore, water intake in moldboard appeared to be greater than conventional tillage but was consumed to meet the evapotranspiration demand.

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