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Effect of Subsurface Soil Compaction and Improvement Measures on Soil Properties

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ABSTRACT

Soil compaction is caused by tillage equipment, reduced use of organic matter, frequent use of chemical fertilizers and ploughing at the same depth for many years. In field experiments subsurface soil compaction was artificially created with seven tons roller. Number of rolling was considered the extent of compaction. In an adjacent field different improvement measures were incorporated in pre-compacted soil. Treatments were arranged in randomized complete block design replicated four times. After eight weeks soil samples were taken for determination of bulk density and porosity. Compaction treatments progressively increased bulk density between 15 to 26%, while decreased porosity in the range of 14 to 27% over control. An inverse relationship between bulk density and porosity was observed. Different improvement measures decreased bulk density in the range of 13 to 17% over control, however, increased porosity between 15 to 18% over control. Subsurface soil compaction may be redeemed by combination of different improvement measures such as addition of farm yard manure, gypsum and deep ploughing.

Key Words: Subsurface; Compaction; Bulk density; Porosity; Improvement measures

INTRODUCTION

Soil compaction is the main form of soil degradation, which affects 11% of the land area in the surveyed countries of the world. Compaction is caused by the use of heavy machinery, pressure from wheels, tillage equipment, trampling by animals, reduced use of organic matter, frequent use of chemical fertilizers and ploughing at the same depth for many years. The signs of soil compaction can often be seen by observing the crops growing in a compacted soil. Slow plant emergence, thin stands, un-even early growth, small grain heads, abnormal rooting patterns, shallow or horizontal root growth and reduced nutrients concentration can be a reflection of compaction. Excessive soil compaction impedes root growth and therefore limits the amount of soil explored by roots (Van Lynden, 2000). This, in turn, can decrease the plant's ability to take up nutrients and water. From the standpoint of production, the adverse effect of soil compaction on water flow and storage may be more serious than the direct effect of soil compaction on root growth.

Soil microbes play an important role in the breakdown of organic matter and fertilizer into useable plant nutrients so soil fertility may be reduced. Poor quality, low fertility organic matter accumulates on soil surface, because soil microbes are not present to breakdown crop residues. Organic matter decreases the bulk density of soil. This effect can occur either directly by "diluting" the soil with a less dense material, or indirectly through greater aggregate stability. Indirect effects seem to be the most important and are not dependent on soil textural class. Organic matter has a strong, positive effect on infiltration of water into soils. This effect is mainly due to a decrease in bulk density and improvements in aggregation and structure (MacRae & Mehuys, 1985). If compacted layers are present in the soil, the risk of soil erosion is increased. The movement of water into and through the soil is reduced resulting in greater overland flow and subsequent surface erosion. Bulk density has direct correlation with compacted stress. However, incorporation of organic matter in a compacted soil lowers the bulk density, increase electric charge thus increasing repulsive forces between soil particles and improves soil aggregate strength (Soane, 1990).

In general, increasing bulk density or aggregate size delayed emergence and reduced total emergence. However, the effect of bulk density was small in seedbeds with large aggregates and the effect of aggregate size was negligible in compacted seedbeds. Increased bulk density delayed emergence mainly by decreasing the volume of voids in the soil. Sub-soiling increased macroporosity by up to 27% of the soil volume and increased saturated hydraulic conductivity and air permeability by up to two orders of magnitude (Drewry *et al.,* 2000). In contrary to the above, Holmstrom and Carter (2000) found that sub-soiling provided only a marginal improvement in soil physical conditions. Addition of organic matter in compacted soil enhanced the population and growth of earthworms *D. smithii,* which will ultimately improve soil physical conditions (Jordan *et al*., 2000).

The rapid mechanization of farm operations, lesser amount of organic manures, frequent use of chemical fertilizer at farms and ploughing at the same depth in the country could be the major causes of de-proving soil physical conditions. Long term use of the same implements with less amount of organic manures could lead subsurface soil compaction which ultimately affect soil properties. This area of research has not attracted the attention of scientists. Thus necessitated that deleterious effects of subsurface soil compaction on soil properties be investigated. At the same time, it is also imperative to look into some cheap and affordable measures to address future problems of subsurface compaction. Thus, keeping in view the above problems in mind, the present study was contemplated to record the deleterious effects of subsurface soil compaction on soil properties and investigate some cheap measures to redeem compaction effects.

MATERIALS AND METHODS

Field experiments were conducted to document the effects of subsurface soil compaction and improvement measures on soil properties during 2002 - 03 and same was repeated during 2003 - 04. The experiments were conducted at the agricultural research station, Mingora, Swat, Pakistan. The research station is located at 34^o and 36^o North latitude and 72^o and 73^o East longitude and at an altitude of 975 m above sea level. The site is located in temperate region, about 1400 km north of Indian ocean having continental climate with comparatively cooler season due to surrounding mountains. The soil was well-drained silt loam. The soil comprised of 18.8% sand, 69.2% silt, 12.0% clay, 2.60% lime and 1.31% organic matter with pH of 5.9 (1:5 suspension) and electric conductivity (EC) of 0.167 mS cm^{-1} (Ghani & Ali, 2003). Subsurface compaction was artificially created. The 0.1 m surface horizon was removed from all the plots with the help of scraper. The subsurface was compacted using 7.0 tons iron made roller. The number of passes of roller measured the extent of compaction. The treatments were; Cp1 (control), Cp2: two passes, Cp3: four passes and Cp4: six passes of 7 tons roller. The compaction was carried out in soil at 19.06% moisture contents. In an adjacent field, 0.1 m surface horizon was removed from all the plots with the help of scraper. Following improvement measure treatments; Cp (compacted control), DP (deep ploughing), DP + FYM (deep ploughing + farm yard manure), DP + Gyp (deep ploughing + gypsum), DP + Gyp + FYM (deep ploughing + gypsum + FYM), farm yard manure and gypsum were added at the rate of 1400 kg ha^{-1} and 4000 kg ha^{-1}, respectively. Then subsurface was compacted with 7 tons roller with four passes. The top soil was evenly applied to the entire plot. In both the experiments treatments were arranged in randomized complete block design replicated four times. After eight weeks soil samples were taken to determine the subsurface soil bulk density and soil porosity from all plots.

Bulk density samples were collected in a cylindrical pot of known volume (13.84 cm^3), which was fitted in auger, from layers above and within the artificially compacted horizon (0.0 - 0.1 m & 0.1 - 0.2 m). In non-compacted plot, samples were taken from depth of the soil profile that corresponds with these horizons.

Bulk density (g cm^{-3}) was measured with the help of the following formula:

Bulk density = Mass of oven dried soil/Volume of soil (g cm^{-3}) (Tagar & Bhatti, 2001).

Total porosity (% pore space) was worked out using the same soil samples collected for soil bulk density. Porosity (%) was calculated with the help of the following formula:

Total porosity = 100 - (B.D. /P.D.X 100).

Where, B.D. = Bulk density, P.D. = Particle density or specific gravity of a known volume of soil sample, which was measured by weighing 25 g soil sample and putting it in a 100 mL graduated cylinder having exactly 50 mL of water. The volume of water displaced due to addition of soil sample was noted and particle density was calculated with the help of the following formula:

P.D. = (Mass of soil sample/volume of water displaced) (g cm^{-3})

Bulk density and particle density was worked out using the same soil samples (Tagar & Batti, 2001). Data thus recorded were statistically analysed using M. Stat. C. Treatment means were compared for significance at 5% level of probability using LSD (Steel & Torrie, 1980).

RESULTS

Subsurface soil bulk density was significantly affected by compaction treatments. The maximum bulk density (1.72) was exhibited by Cp4, which progressively decreased to the minimum (1.37) in Cp1 (control) during first year (2002 - 03). Similar trend of bulk density was recorded during second year (2003 - 04) with the maximum (1.71) bulk density recorded for Cp4 and the minimum (1.38) recorded for Cp1 (Table I). Treatment means pooled over years also showed statistically significant differences for subsurface soil bulk density. The Cp4 was significantly higher than Cp2 and Cp1 but at par with Cp3. Rest of the treatment combinations showed varying degree of differences. However, bulk density of all compacted treatments during second year was lower than that observed during first year except that of Cp1, which showed a small increase. The maximum decrease was observed for Cp2. Comparison of years as well as interactive effects (treatment x years) were statistically non-significant.

Porosity of subsurface soil was significantly affected by compaction treatments. The maximum porosity (47.4%) was exhibited by Cp1 (control), which progressively decreased to the minimum (34.1%) in Cp4 during first year (2002 - 03). Similar trend of porosity was observed during second year (2003 - 04) when the maximum (47.2%) porosity was exhibited for Cp1 (control) and the minimum (34.9%) recorded for Cp4 (Table II). Treatment means pooled over years also showed statistically significant differences for porosity. The Cp1 (control) was significantly higher than rest of the treatments the Cp2 was statistically at par with Cp3, while Cp3 remained statistically at par with Cp4. However, subsurface soil porosity of all compaction treatments during second year was higher than that observed during first year except Cp1 (control), which showed a small decrease. Comparison of years as well as interactive effects (treatment x years) were statistically non-significant.

Subsurface soil bulk density was significantly affected by improvement measures applied to the artificially compacted soil. The maximum bulk density (1.59) was recorded for Cp (compacted control), which decreased to the minimum (1.34) for DP + FYM + Gyp during first year (2002 - 03). Similar trend of bulk density was observed during second year (2003 - 04) when the maximum (1.56) bulk density was recorded for Cp (compacted control) and the minimum (1.32) recorded for DP + FYM + Gyp (Table III). Treatment means pooled over years also exhibited statistically significant differences. The Cp (compacted control) was significantly higher than rest of the treatments DP remained statistically at par with DP + Gyp, while DP + FYM was statistically at par with DP + Gyp and DP + FYM + Gyp. Comparison of years also exhibited statistically significant differences with comparatively higher bulk density recorded during first year (2002 - 03) as compared to that observed during second year (2003 - 04). Interactive effects (treatments x years) remained statistically non-significant (Table III).

Subsurface soil porosity was significantly affected by improvement measures applied to the artificially compacted soil. The maximum porosity was recorded for DP + FYM + Gyp (48.3%) followed by DP + FYM (48.2%), which decreased to the minimum (38.8%) recorded for Cp (compacted control) during first year (2002 - 03). Similar trend of porosity was observed during second year (2003 - 04) when the maximum (50.0%) porosity was again recorded for DP + FYM + Gyp followed by DP + FYM (49.8%) and the minimum (41.6%) recorded for Cp (compacted control). Treatment means pooled over the years also exhibited statistically significant differences (Table IV). The DP + FYM + Gyp and DP + FYM were statistically non-significant to each other but were significantly higher than Cp (control), DP and DP + Gyp however, DP and DP + Gyp were statistically non-significant to each other but significantly higher than Cp (control). Comparison of years also exhibited significant differences with comparatively high porosity recorded during second year (2003 - 04) as compared to first year (2002 - 03). Interactive effects (treatments x years) were statistically non-significant (Table IV).

Table I. Effects of subsurface compaction on subsurface soil bulk density (g cm^{-3})

Treatments	Year 2002-03	Year 2003-04	Treatment mean over years
Cp1	1.37	1.38	1.37 C
Cp2	1.59	1.53	1.57 B
Cp3	1.64	1.59	1.61 AB
Cp4	1.72	1.71	1.72 A
Years Mean	1.58	1.55	

SE: Treatments = 0.02, Years = 0.01, Interaction = 0.03

Table II. Effects of subsurface soil compaction on subsurface soil porosity (%)

Treatment	Year 2002-03	Year 2003-04	Treatment mean over years
Cp1	47.4	47.2	47.3 A
Cp2	38.3	41.6	40.0 B
Cp3	35.4	39.5	37.4 BC
Cp4	34.1	34.9	34.5 C
Years Mean	39.0	40.8	

SE: Treatments = 0.75, Years = 0.53, Interaction = 1.06

Table III. Effects of improvement measures on subsurface soil bulk density (g cm^{-3})

Treatment	Year 2002-03	Year 2003-04	Treatment mean over years
Cp	1.59	1.56	1.56 A
DP	1.39	1.37	1.38 B
DP+FYM	1.35	1.33	1.34 C
DP+Gyp	1.38	1.37	1.38 BC
DP+FYM+Gyp	1.34	1.32	1.33 C
Years Mean	1.41 a	1.39 b	

SE: Treatments = 0.01, Years = 0.005, Interaction = 0.01

Table IV. Effects of improvement measures on subsurface soil porosity (%)

Treatment	Year 2002-03	Year 2003-04	Treatment mean over years
CP	38.8	41.6	40.2 C
DP	46.6	48.1	47.3 B
DP+FYM	48.2	49.8	49.0 A
DP+Gyp	47.0	48.4	47.7 B
DP+FYM+Gyp	48.3	50.0	49.1 A
Years Mean	45.8 b	47.6 a	

SE: Treatments = 0.31, Years = 0.21, Interaction = 0.42
(Means sharing the same letters are non significant to each other at 5 % level of probability).

DISCUSSION

Bulk density changes with application of soil compaction. A compacted soil will have increased bulk density and vice versa. In present study, the subsurface soil compaction gradually increased from Cp2 to Cp4, bulk densities also increased in similar fashion. Thus, the results of present study are in agreement with Dauda and Samari (2002), who reported that subsurface soil bulk density increased with increasing the level of compaction. Similarly, Panayiotopoulos *et al.* (1994) concluded that compaction resulted in a progressive increase in bulk density and penetration resistance. Bulk density was closely correlated with compactness stress. Gysi *et al.* (2000) concluded that passes of machinery also causes compactness. This compaction was indicated by an increase in soil bulk density. Whereas, McNabb *et al.* (2001) found significant increase in bulk density after three cycles of compaction. Progressive increase of bulk density in our study due to compaction is in line with above conclusions. Bulk density of second year was observed to be less than that recorded during first year, which may be attributed to field variation.

Compaction of soil pushes the soil particles closer together, removes the pore space and so the bulk density is increased, while the total porosity is reduced (Coder, 2000). Compacted soils often have higher soil moisture contents, because soil water is un-able to drain away freely and air movement in the soil is restricted. Porosity depends on the extent of soil compaction. Increase in soil compaction decreases the soil pore space and vice versa. As a result of reduction in size and number of macropores in the soil and the subsequent reduction in aeration, microbial activity is reduced (Hamza & Anderson, 2005). In present study, the compaction of subsurface increased from Cp2 to Cp4, the porosity values decreased correspondingly. So, results of this study are in line with above findings. Inverse relationship (Fig. 1) between bulk density and soil porosity also confirm above conclusion. Progressive increase of bulk density decreased porosity in similar fashion. Compaction increased bulk density between 15 to 26%, while decreased porosity between 14 to 27% over control.

Organic matter decreases the bulk density of soil. This effect can occur either directly by "diluting" the soil with a less dense material, or indirectly through greater aggregate stability. Indirect effects seem to be the most important and are not dependent on soil textural class. Organic matter has a strong, positive effect on infiltration of water into soils. This effect is mainly due to a decrease in bulk density and improvements in aggregation and structure (MacRae & Mehuys, 1985). Apart from addition of organic matter some tillage practices also affect soil properties such as deep ploughing or sub-soiling and decreases soil bulk density. However, tillage systems may not affect soil bulk density up to three years. However if the same system is continued for many years it will effect physical properties and decrease grain yield. However, Yavuzcan (2000) was of the view that the chisel + cultivator-tooth harrow combination provides more desirable soil conditions for resisting further soil compaction. Apart from tillage system manures could leave positive effect on reducing soil compaction (Mosaddeghi *et al.,* 2000). However, Abu-Hamdeh (2003) concluded that deep tillage of compacted plots removed compaction effects and improved yield. Crop and soil management practices could be used to reduce soil compactibility problems thus increasing productivity of such soils (Anikwe *et al.,* 2003). However, Hamza and Anderson (2003) concluded that the combination of soil ripping and gypsum application in the presence of complete nutrients and annual return of crop residues to the soil had positive effects on the soil physical properties and grain yields. Whereas Lado *et al.* (2004) found that there was a significant interaction between organic matter content and aggregate size in seal formation

Fig. 1. Relationship between bulk density and porosity in response to compaction

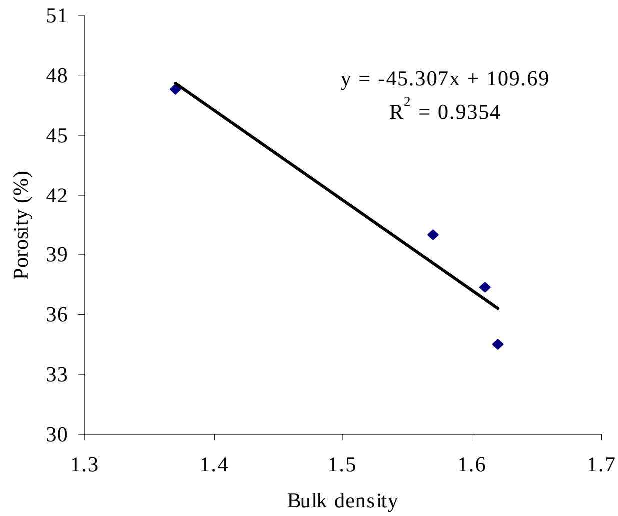
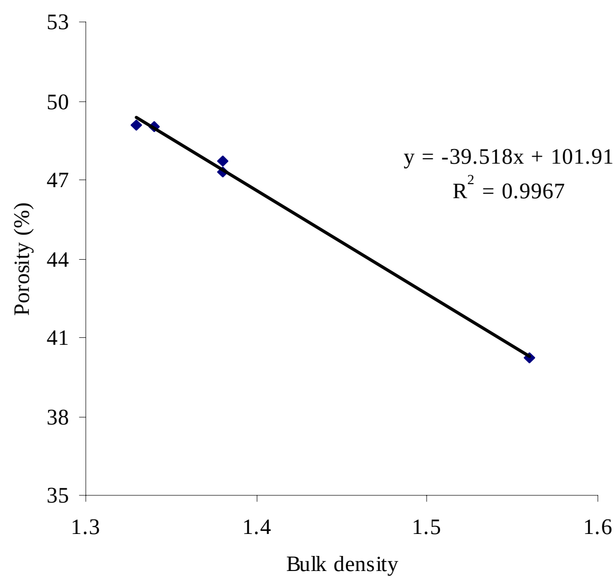


Fig. 2. Relationship between bulk density and porosity in response to improvement measures



and final infiltration. In our study deep ploughing and addition of farm yard manure caused significant reduction of subsurface bulk density as compared to other treatments applied to subsurface compacted soil, which increased the porosity. Addition of organic matter would have increased pores spaces, which decreased bulk density and increased porosity. Inverse relationship (Fig. 2) between bulk density and soil porosity due to improvement measures is in confirmatory to above conclusions. Addition of gypsum along with deep ploughing also left considerable positive effects on improvement of soil properties. However, deep ploughing and addition of farm yard manure proved to be the best combination to ameliorate compaction effects. Thus, results of our study are in line with above findings.

Improvement measures decreased bulk density between 13 to 17% over control, while increased porosity between 15 to 18% over control. It may be concluded from above results and discussion that degraded lands can be converted again to productive land by addition of farm yard manure and incorporation of that by deep ploughing or sub-soiling.

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