Relationships between depth of tillage and soil physical characteristics of sites farmed by smallholders in Mutoko and Chinyika in Zimbabwe

by

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Abstract

A study was conducted in two smallholder areas in Zimbabwe to relate the occurrence of a plough pan to tillage depth, under draft animal power situations. Bulk density (BD) and penetration resistance (PR) measurement was taken to quantify tillage-induced compaction. Soil mechanical analysis was also conducted to determine the effect of different sized particles on soil compaction. Cylindrical sampling cores of 5 cm diameter and 5 cm height were used to collect undisturbed soil samples at 10 depths. A penetrometer with a 12.83 mm diameter cone was used to measure PR to a depth of 52.5cm. The GENSTAT Procedure was used to conduct the statistical analysis. Ploughing depth measurements were carried out at 23 and 12 sites in Chinyika and Mutoko, respectively. It was noted that 89% (N=45) of the farmers in the two areas did not achieve the 23 cm recommended ploughing depth. Soils in Chinyika were basically loamy, whereas those in Mutoko were sandy. Bulk density values in Chinyika decreased with depth, whereas those in Mutoko increased with depth. Surface BDs in Mutoko were however, higher than those in Chinyika. This was attributed to the different soil textures. A highly significant linear relationship between BD and clay ($p<0.001$; $r^2=0.65$) and BD and sand ($p<0.001$; $r^2=0.58$) was observed in the top 12 cm of the soil. However, below 12 cm, no relationship between BD and soil texture was evident. Factors other than texture, such as tillage, were thus thought to determine the BD. Sixty nine percent of farmers in Mutoko (N=16) and 67% in Chinyika (N=25) had the problem of surface crusting and subsurface high BD values ($BD \geq 1.6$ Mgm^{-3}). The latter could be equated to plough pans. Forty-four of the farmers in Mutoko also had evidence of plough pan occurrence, approximately 8 cm below the average tillage depth. Penetration resistance measurements in Chinyika also indicated a high proportion of farmers with plough pan problems in the 17.5-35 cm region (83%; N=12). In general, high PR values in Chinyika were observed about 8 cm below tillage depth, and at almost the same level of average tillage depth in Mutoko.

1. Introduction

Tillage is normally performed on the onset or just after rains start. Due to limited feed resources at this time of the year, draft animals are usually weak, resulting in shallow ploughing where conventional tillage is practised. A considerable number of farmers meet the optimum planting dates by ploughing when the soils are still dry (before rains), thereby increasing the chances of shallow ploughing.

Plough pan development has been reported where ploughing was repeated at the same depth year after year (Waddington, 1991; Unger and Kasper, 1994). The shallower the tillage depth, the greater is the likelihood of a plough pan developing near the soil surface. When this happens, there is limited area for moisture and nutrient extraction for the crop since roots cannot penetrate the deeper soil layers. Runoff as well as erosion losses are also increased. All these factors result in decreased crop yields (Taylor and Burnet, 1964).

Draft requirement for tillage may also be drastically increased by soil compaction (Dannowski and Seidel, 1987). This could create problems during primary tillage since the animals are unlikely to handle the additional draft required.

Even though it is common knowledge that in Zimbabwe, subsoil compaction is caused by development of plough pans, little has been done towards quantification of this problem in the Communal areas (CAs) of Zimbabwe.

1.1 Objective

The objective of this paper is to determine the relationship between depth of tillage and soil

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physical and textural characteristics of soils farmed by smallholders in Chinyika and Mutoko areas.

2. Materials and methods

2.1 Examination of compaction in the field

To study the effect of tillage-induced compaction, bulk density (BD) and penetration resistance measurements were taken in Chinyika and Mutoko. Penetration resistance (PR) measurements were taken to complement bulk density measurements due to the numerous advantages that PR has over BD (Voorhees et al., 1983). A penetrometer is however, not appropriate for measuring surface crusting whereas bulk density measurements may detect it. There is need therefore to consider both PR and BD measurement.

2.2 Bulk density and solid moisture determination

Bulk density measurements were conducted in the two areas. Twenty and sixteen sites were chosen in Chinyika and Mutoko, respectively. Cylindrical sampling cores, of 5cm diameter and 5cm height with sharp cutting edges were used to collect undisturbed soil samples according to the method of Blake and Hartge (1986). Three replicate samples were collected at 10 depths at each site. The core samples were then oven dried for 24 hours at 105°C in the laboratory. Soil moisture was gravimetrically determined at the same time.

2.3 Penetration resistance

Penetration resistance was first measured in the farmers' fields at the same time as the bulk density measurements (1996). The same was repeated during the following season, one year later. Only twelve sites were measured in Chinyika. In addition, soil moisture data was collected at the 0-15, 15-30 and 30-50 cm depths at the time. This is because soil moisture has a strong influence on PR (Logsdon et al., 1987). Five soil strength measurements were taken at each site with each position chosen randomly throughout the field. These were measured in 15 cm depth increments using a hand-held Bush Penetrometer, with a 12.83mm diameter cone (Anderson et al. 1980) upto a depth of 52.5 cm.

2.4 Particle size analysis

Particle size analysis was used to determine the proportion of different sized particles of soils from the study areas using the procedures described by Head (1980). Sedimentation was used to separate silt and clay size fractions, based on the Stoke's Law relationship between the diameter of suspended particles and their rate of settlement in a liquid at constant temperature. Suspension densities were then measured using hydrometers. Dry sieving was used to measure the sand fractions.

2.5 Ploughing depth

Ploughing depths were measured at 23 and 12 sites in Chinyika and Mutoko, respectively; at ploughing time. Sites were randomly selected making sure that only one site was chosen per individual farmer. The ploughing depth was measured in six furrows which were randomly chosen during ploughing, with a minimum of three readings taken in each furrow.

2.6 Statistical analysis

The GENSTAT procedure was used to conduct statistical analysis. Analysis of variance was used to test for any significant differences in bulk density between different soil layers. The LSD test was used to separate the treatment means. Regression analysis was also carried out to test correlation between bulk density and soil texture.

3. Results and discussion

3.1 Ploughing depth in Chinyika and Mutoko

Ploughing depth values are shown in Table 1. Farmers who hired tractors are the ones who achieved greater ploughing depths of at least 20cm. These farmers have however been excluded from this study in order to concentrate on animal powered tillage. These farmers only constituted 17.4% in Chinyika whereas in Mutoko none of the farmers used a tractor at all.

Table 1: Ploughing depths for Chinyika and Mutoko farmers

Area	N	Depth range (cm)	Mean ± se
Chinyika	19	11.3-15.8	14.0±0.27
Mutoko	12	12.7-15.7	14.9±0.23

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One observation made in the two areas was that almost all the mouldboard ploughs had the hitch assemblies removed. The hitch assembly is useful in maintaining a desired tillage depth. All the farmers believed that this attachment would make the plough heavier for their small and weak draft animals. This is one reason why ploughing depths were not only shallow but also similar across the different sites.

3.2 Bulk density

In Chinyika, bulk density values consistently increased with depth (Table 2). Normally, bulk density tends to increase with soil depth mostly as a result of low organic matter (OM), less aggregation and root penetration as well as pressure exerted by overlying layers. Conversely, this was the reverse in Mutoko where bulk density values decreased with depth. The greater development of structure in the loamy textured surface soils of Chinyika could account for their low densities compared to more sandy surface soils in Mutoko. This explained why bulk density values were generally lower in Mutoko than in Chinyiki.

Table 2: Bulk density values at different soil depths for sites in Chinyika and Mutoko

	Mean bulk density (Mgm^{-3})	
Depth (cm)	Chinyika	Mutoko
0 – 12	1.39a	1.60a
12 – 30	1.47b	1.51b
30 – 48	1.52c	1.49bc
48 – 60	1.54c	1.46c

Means with the same letter in a column are not significantly different ($p<0.05$) based on LSD test.

In Mutoko, surface bulk densities were quite high compared to those in Chinyika, possibly due to their sandy texture. Eleven sites out of 16 had surface (0-12 cm) bulk density values greater than 1.6Mgm^{-3}. Of these, the values for layers just below (12-30 cm) were lower except at one site. This is an indication of surface bulk density greater than 1.6 Mgm^{-3}. The bulk of the surface values were around or below 1.4Mgm^{-3}.

In Mutoko, seven of the sites appeared to have high bulk density values between 20 and 25 cm depth. These dense layers were approximately 8 cm below average tillage depth. At some of the sites, more than one high-density peak was evident. Considering the farmers' shallow ploughing depths, there is a considerable chance that these layers will develop into restrictive "hard pans" with time. The result is restriction to root growth, which ultimately decreases crop growth.

De Geus (1973) quote bulk density values greater than 1.75 Mgm^{-3} for sands, as causing hindrance to root penetration. Taylor et al. (1966) however broadly classifies the range to between 1.6 and 1.8 Mgm^{-3}. The 1.75 Mgm^{-3} value was exceeded at three of the sites in Mutoko, while the 1.60 Mgm^{-3} value was exceeded in all but three of the 16 sites. In Chinyika, subsurface BD values of 1.6 were exceeded in 14 out of 21 sites, with six sites exceeding 1.7 Mgm^{-3}. Jones (1983) showed that rooting was restricted in loamy soils at densities greater than 1.6-1.7 Mgm^{-3}.

3.3 Relationship between bulk density and soil texture.

To distinguish between textural and tillage effects on bulk density, regression analysis was conducted. At the 0-12 cm depth there was a highly significant relationship between bulk density values and clay ($p<0.001$; $r^2 = 0.65$) as well as sand ($p<0.001$; $r^2 =0.58$). This means that the amount of clay and sand in a soil determines bulk density in the top 12 cm. Similar results have been reported elsewhere (Jones, 1983). However, at the 12-60 and 50-60 cm depths there were no significant relationships. This therefore means that bulk density values are due to some factors other than soil texture. Tillage is suspected to be playing an important role in determining bulk density just below the plough pan. Some management factors other than tillage and texture are however thought to be responsible for determining bulk density in the 50-60cm depth region. This is because tillage effects are not expected to show any influence at this depth. Generally, for the two sites, results of the regression analysis seem to exclude soil texture as the main determinant of the bulk density.

3.4 Penetration resistance (PR)

The first set of PR values taken in Chinyika showed very distinct layers of high resistance at 10 sites (N=12) between 17.5 and 35cm. These dense, hard layers are generally considered to be the same as "plough pans" as the hard layers restrict root growth. For the next season's readings in Chinyika (N=11) the maximum surface PR at crop harvesting was 3000 kPa. Most PR values except at two sites

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were found to exceed 2000 kPa, which is considered to be the limiting value for root growth (Blanchar et al., 1978; Gill and Miller, 1956; Olsen, 1993; Taylor et al., 1966; Vogel, 1992). The soil water content at the time of these measurements was, however, very low. Values greater than 4000 kPa were at times recorded at depths as low as 21cm at about 5% moisture content. Considering high PR and the farmers' shallow average ploughing depth, root penetration was restricted to 20cm only.

In Mutoko, out of the five sites measured, four had very distinct high PR values between 14 and 17.5 cm. PR thereafter decreased with depth in agreement with bulk density measurement. Only one field had a peak between 21 and 24.5cm with a sharp drop thereafter. This was contrary to results in Chinyika which showed evidence of plough pans between the 17.5 and 3.5cm depth, a situation commensurate with high bulk density values within the same region.

Average PR, readings did not differ much between the two seasons, there was a considerable drop around 14cm (close to average ploughing depth) relative to the underlying depths (Figure1). This meant that the topsoil layers were loosened by tillage during ploughing, leaving hard layers beneath plough depths. Generally, in Chinyika, plough pans due to tillage were quite evident, with some pans occurring as close as 3cm below the plough sole. Similar results have been reported elsewhere (Chuma, 1993; Grant et al., 1979; Vogel and Olsen, 1993). Table 3 shows the depth to the first maximum PR value, followed by a sudden drop in PR. It should however be noted that some peaks had further high PR value peaks beyond the first depth recorded.

Table 3: Depth to the first peak and maximum PR in relation to plough depth (1997)

Area	No. of farmers	Mean of plough depth (cm)	Mean depth (cm)	Mean PR (kPa)
Chinyika	9	14.3 ±0.27	22.2±2.92	3362±230.03
Mutoko	4	14.7 ± 0.68	14.88±2.20	2853±176.16

There is clear evidence that ploughing depth plays a very important role in determining peaks as indicated by the sudden rise in soil strength after 14cm in Chinyika. For both seasons, PR values beyond 35 cm were similar. The variation between 0 and 35cm is therefore thought to be determined by tillage whilst beyond 35cm soil structure is likely to be the main determinant. The occurrence of peaks and depressions at the same depths in both years inspite of the difference in magnitude is clear indication that plough pans exist at these depths.

The results in Table 3 illustrate contrasting behaviour between soils in Mutoko and Chinyika. Resistant compact layers occur in Chinyika at about 22cm, an average of 8cm below the plough depth (14cm). This concurs with results reported by Grant et al. 1979 and Chuma, 1993. In contrast, in Mutoko, the high PR layers occur at the same depth (±15cm) as the plough sole. This anomaly is probably due to the sandy nature of the soil. The structure in Mutoko could have a different packing arrangement resulting in a compact zone being formed immediately on impact of the plough.

4. Conclusion

Soils in Mutoko were very sandy throughout the 0-60 cm depth. Surface crusting was noted to be very common at most of the sites, with critical bulk densities of greater than 1.6g cm^{-3} exceeded at most sites. Clay contents were extremely low throughout. In Chinyika, the soils were predominantly loamy, with clay content increasing with depth. Bulk density values were generally lower than those in Mutoko.

Pronounced plough pans were evident approximately 8 cm below plough depth, particularly in Chinyika. This means that unless ameriolated the problem is likely to build up which would restrict root growth. The shallower the depth of the pan, the worse the water and nutrient status for the crop, particularly in an environment that is limiting. It is, therefore, important that adequate feed is administered to draft animals during ploughing time, when feed is particularly scarce.

It is anticipated that when draft animals are strong, ploughing depth is deeper, resulting in

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a larger water and nutrient extraction zone for the plant. In Chinyika, tillage needs to concentrate on breaking or minimising plough pans whereas in Mutoko, emphasis should be put more on breaking surface crusting.

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