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Full Length Research Paper

Aggregate stability and strength of a hardsetting soil amended with cattle manure

Adornis D Nciizah and Isaiah IC Wakindiki*

Department of Agronomy, University of Fort Hare, Private Bag X1314 King William's Town Road 5700 Alice, South Africa.

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Hardsetting soils are characterized by horizons with unstable soil aggregates and their responses to organic inputs are not clear. A laboratory study was conducted to determine the effect of cattle manure on aggregate stability and strength in three hardsetting soils. Two treatments were included; cattle manure applied at 0 (control) and 20 mg/ha. Aggregate stability was measured as mean weight diameter and it increased by approximately 51%, because cattle manure prevented aggregates from slaking upon wetting and significantly increased the proportion of the water stable aggregates (>0.5 mm). Cattle manure also significantly lowered the soils' strength as indicated by the lower penetration resistance, therefore cattle manure could be used to ameliorate the adverse physical properties in hardsetting soils.

Key words: Soil organic matter, mean weight diameter, soil penetration resistance, water stable aggregates, soil physical properties.

INTRODUCTION

Hardsetting soils are characterized by horizons with unstable soil aggregates (Chan, 1995; Mullins, 2000; Mullins et al., 1990). The mechanisms responsible for hardsetting phenomenon are not entirely known but many authors have proposed that during wetting the soil aggregates breakdown by slaking and dispersion into microaggregates. Slaking is the breakdown of soil aggregates into micro-aggregates when immersed in water (Le Bissonnais, 1996) while dispersion is a physico-chemical process that induces the separation of soil particles that migrate in suspension (Bresson and Cadot, 1992). As the soil dries, the matric suction increases and the fine particles mostly clay and silt form strong structural connections between the coarser particles (Chan, 1995; Fabiola et al., 2003), resulting in hardsetting phenomenon (Chan, 1995; Mullins, 2000).Organic inputs are known to gradually contribute to soil organic matter (SOM), which stabilizes aggregates against disruptive forces (Abiven et al., 2009). However, soils with low SOM contents are more susceptible to to hardsetting and crusting (Mullins, 2000; Mullins et al., 1990). Mandiringana et al. (2005) reported that SOM content was less than 1% in many soils in Eastern Cape. Consequently, regular inputs of organic matter have been recommended to improve soil productivity (Mandiringana et al., 2005; Mills and Fey, 2004; Murungu et al., 2010).

Cattle manure is a good source of SOM and an excellent ameliorant in soil productivity restoration (Miller et al., 2009; Nyamangara et al., 2001). In many regions, cattle manure has often been used to improve plant nutrition and yield (Miller et al., 2009; Mugwira and Mukurumbira, 1984; Obour et al., 2010). Moreover, addition of manures has been used to improve soil physical properties (Busscher et al., 2010), especially aggregate stability (Lado and Ben-Hur, 2004) and penetration resistance in fine-textured soils (Mijangos et al., 2010) and loam soils (Alvarez et al., 2009). Improvements in soil chemical properties like pH and nutrients have also been observed after amending the soils with cattle manure (Whalen et al., 2000). Nevertheless, the effectiveness of cattle manure depends on many factors like manure quality, climate, soil type,

*Corresponding author. E-mail: iwakindiki@ufh.ac.za.

crop type, extent of soil degradation and management (Sui et al., 2009). In South Africa, cattle manure is an important source of plant nutrients in smallholder farming systems (Yoganathan and van Averbeke, 1996). Although manures have been shown to improve soil properties in many environments, little is known about its effect in hardsetting soils. Materechera (2009) reported improved aggregate stability, soil strength and bulk density after applying 5 Mg/ha of cattle manure on a hardsetting and crusting chromic Luvisol in South Africa and Nyamangara et al. (2001) made similar observations in Zimbabwe. We hypothesized that higher amounts of organic input will result in increased aggregate stability and strength. Therefore the objective was to determine the effect of cattle manure on aggregate stability and strength in some hardsetting soils.

MATERIALS AND METHODS

Soils from three sites (Alice, Guquka and Hertzog) were sampled within central Eastern Cape Province, South Africa. Soils from these sites are known to be hardsetting soils (Land Type Survey Staff, 2001; Ristori and D'acqui, 2007; Smith and Johnson, 2001). Alice is located at 32°46' S and 26°50' E at an altitude of 535 m above sea level. The site has a warm temperate climate with a mean annual rainfall of about 535 mm received mostly in summer. Guquka is located at 32°39' S and 26°57' E at an altitude of 770 m. The site has a sub humid climate and receives summer rainfall with a mean of 750 mm. Hertzog is located at 32°35' S and 26°43' E. The altitude in this area is about 792 m and the rainfall is about 565 mm in summer (Laker, 1978). The soils in the three sites are classified as Cambisols according to the World Reference Base for Soil Resources (WRB) system (IUSS Working Group WRB, 2006). A completely randomized design was used in this study. Two cattle manure treatments, 0 (control) and 20 mg/ha, were applied. The three locations, Alice, Guquka and Hertzog constituted the replicates. In each location a 0.5 ha uniform field was selected and 15 soil samples obtained randomly using a spade. Subsequently, a composite soil sample was prepared, from which three subsamples were drawn for analysis. Each subsample was analyzed separately. The soils were taken to the laboratory, air-dried and sieved through a 4 mm sieve and later passed through a 2 mm sieve. The fraction that passed through the 2 mm sieve was used for initial soil characterization. Particle size distribution was determined using the hydrometer method after oxidizing SOM with hydrogen peroxide as described by Gee and Or (2002). The SOC. content was determined by the Walkely-Black procedure as described by Nelson and Sommers (1996).SOM estimation was done by multiplying the SOC by a conversion factor of 1.72.The pH of the soil solution was measured after shaking the suspensions for 30 min and equilibrating for 10 min at soil-water ratio of 1:2.5 (Okalebo et al., 2002) and for the cattle manure at manure-water ratio of 1:5 (Ndegwa and Thompson, 2001) using a pH meter (model pH 25, Crison Instruments, South Africa). More water was required for the manure-water mixture to create enough slurry for proper electrode operation. The same suspensions were used to measure electrical conductivity (EC) after allowing them to settle for 1 h using an EC meter (model CM 35, Crison Instruments, South Africa). Sodium content was determined after wet digestion with sulphuric acid and hydrogen peroxide (Okalebo et al., 2002) using a Varian 700-ES Model simultaneous inductively coupled plasma-optical emission spectrometer (ICP-OES, Varian, Inc., USA). Total N in cattle manure was determined colometrically as described by Okalebo et al. (2002). Some of the soil properties and cattle manure are shown in Tables 1and 2, respectively.

5 kg of the aggregates between 4 and 2 mm were put in the 18 pots (three locations × two treatments × three sub samples) with 0.3 m diameter, which served as experimental units. The two cattle manure treatments were then applied; 0 mg/ha in nine pots and 20 mg/ha in the remaining 9 pots. The cattle manure was mixed thoroughly but carefully to minimize breaking the soil aggregates. Gypsum blocks were inserted about 5 cm into each pot and left undisturbed to monitor the matric suction which was read using soil moisture meter each day. The soil was then gently brought to field capacity using a hand held watering can. The gypsum blocks were calibrated to give the actual volumetric water content against the meter reading for each soil. At the same time, PR was determined daily with a hand-held penetrometer from five random positions at the soil surface in each pot until the matric suction reached ~500 kPa.

Afterwards aggregate stability was determined according to the fast wetting method described by Le Bissonnais (1996).The fast wetting method was chosen because it largely accounts for slaking, which is the main mechanism responsible for aggregate disintegration in hardsetting soils (Chan, 1995; Mullins, 2000; Mullins et al., 1990). The soils were once more sieved through 4- and 2-mm sieves to obtain calibrated aggregates, which were put in an oven at 40°C for 24 h to bring them to the same soil wetness. A 5 g sample of aggregates was taken and immersed in a beaker containing 50 mL deionized water for 10 min. The water was sucked off with a pipette, and the soil material was gently transferred to a 50 µm sieve previously immersed in ethanol. The sieve was gently moved up and down in ethanol five times to separate the fragments < 50 µm from those > 50 µm. The > 50 µm fraction was oven dried and its size distribution was measured by gently dry sieving by hand on a column with sieves of 2, 1, 0.5, 0.2, 0.1 and 0.05 mm. The weight of each fraction was measured; the <0.05 mm was calculated as the difference between the initial weight and the sum of the weights of the other six fractions. Aggregate stability was determined as the mean weight diameter (MWD, mm) as in Equation 1.

$$MWD = \sum_{i=1}^{7} \bar{x}_i w_i \qquad (1)$$

Where w_i was the weight fraction of aggregates in the size class i with a diameter $\bar{x}$ (Le Bissonnais, 1996).

The data were subjected to analysis of variance using the general linear model for a completely randomized design (Steel et al., 1980) to obtain an F value of the significant effect of the model. Significance of treatment differences was examined using Duncan's new multiple range tests for $P \leq 0.05$. Regression analysis was done to test the effect cattle manure on soil strength.

RESULTS

The addition of manure increased MWD by ~51% (Table 3) and significantly increased the water stable aggregates (> 0.5 mm). Conversely, the micro aggregates (< 0.5 mm) were higher in the cattle manure treatment compared to the control (Figure 1). Application of 20 mg/ha decreased micro-aggregates. Cattle manure did not show any significant effect on the soils' aggregate stability between the locations. The dispersion effect of both cattle manure and the soils were low as indicated by their electrical conductivity of ≤ 0.23 dS/m (Tables 1 and 2).

Table 1. Some physical and chemical properties of soils from Alice, Guquka and Hertzog.

Site	Sand (%)	Silt (%)	Clay (%)	SOM (%)	pH	EC (dS/m)	Na ($cmol_c$/kg)
Alice	48	28	24	2.58	6.7	0.14	0.62
Guquka	50	28	22	1.36	5.2	0.13	0.43
Hertzog	52	24	24	1.84	7.5	0.14	0.77

SOM: Soil organic matter; EC: electrical conductivity.

Table 2. Some properties of the cattle manure used in the experiment.

N (%)	OM (%)	C:N	EC dS/m	pH
2.2	48.7	12.8	0.23	7.5

OM: organic matter.

Table 3. Mean weight diameter (MWD) values in the three hardsetting soils as affected by cattle manure.

Cattle manure (Mg/ha)	MWD (mm)
0	0.41^a
20	0.62^b

Values followed by different superscript letters in a column indicate a significant difference at the $P \leq 0.05$ level.

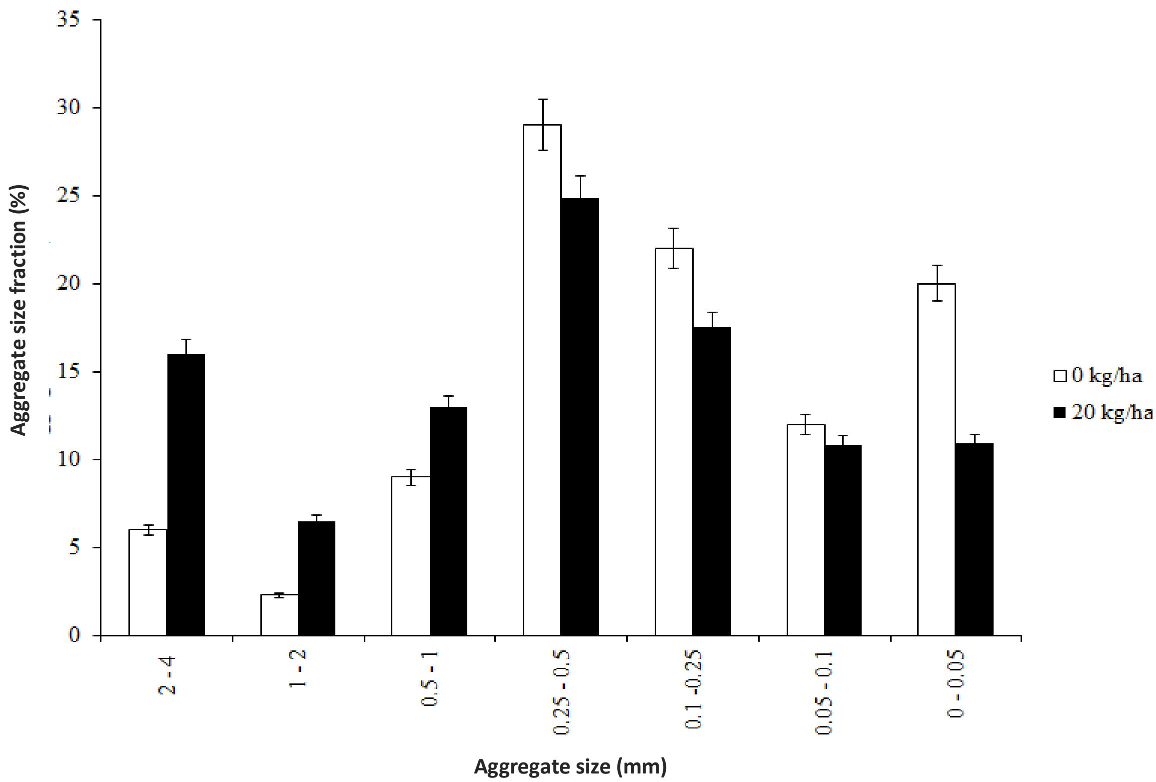

Figure 1. Effect cattle manure on aggregate size distribution in the three hardsetting soils. Bars represent standard error, P ≤ 0.05.

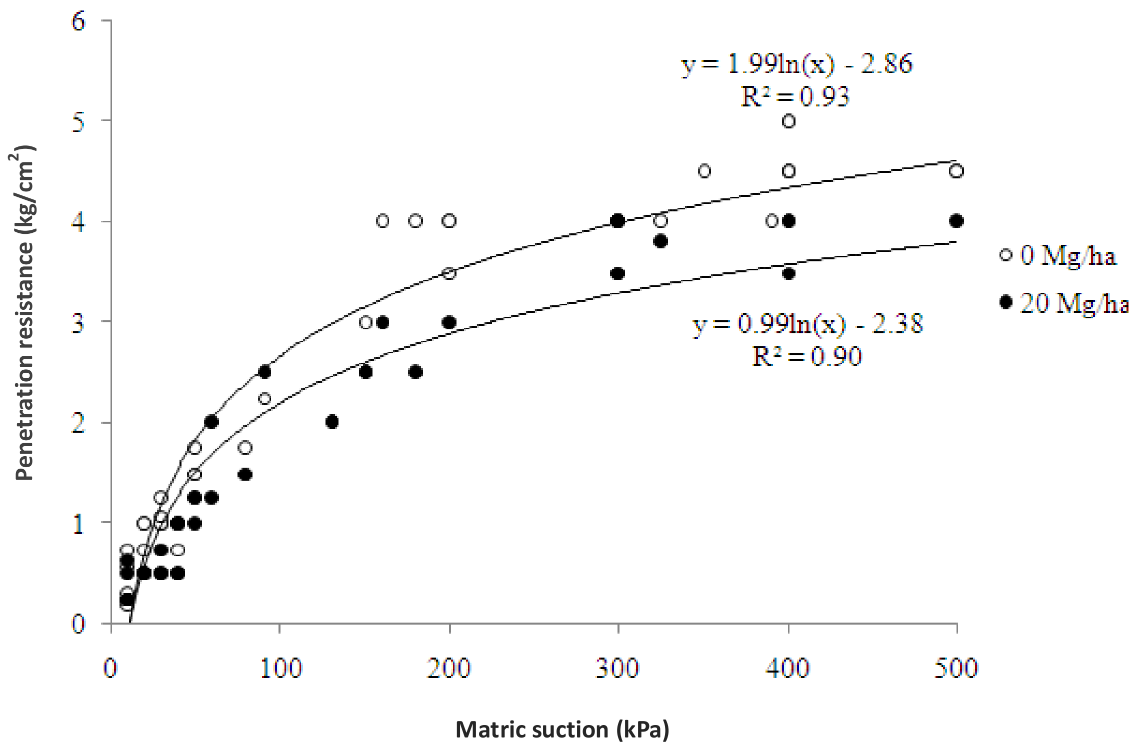

Figure 2. Effect cattle manure and increasing matric suction on soil strength in the three hardsetting soils.

The soil strength was significantly lowered by cattle manure (Figure 2). Moreover, soil PR increased with an increase in matric suction (Figure 2). Furthermore, this relationship was characterized by an initial sharp increase in soil PR with small increases in matric suction below ~100 kPa followed by significant decrease in the rate of increase in soil PR beyond approximately 100 kPa (Figure 2). Cattle manure did not show any significant effect on the soils' strength between the locations.

DISCUSSION

MWD is related to aggregate stability (Nimmo and Perkins, 2002) because higher MWD values correspond to higher aggregate stability (Le Bissonnais, 1996). Le Bissonnais suggested five classes of stability, with a MWD < 0.4 mm classified as very unstable, 0.4 to 0.8 mm; unstable, 0.8 to 1.3 mm; medium, 1.3 to 2.0 mm; stable whilst MWD values > 2.0 mm are classified as stable. Therefore, the soils used in this study were unstable (Le Bissonnais, 1996) and amending them with cattle manure increased their aggregate stability (Table 3). Chan (1995); Mullins (2000); Mullins et al. (1990) suggested that slaking and dispersion are the dominant mechanism by which aggregate breakdown occurs in hardsetting soils. Moreover, the fast wetting method (Le Bissonnais, 1996) that was followed in this study largely mimics slaking of aggregates. Slaking is mainly affected by SOM content and texture (Lado and Ben-Hur, 2007). In our study, cattle manure increased SOM. Since the three soils contained ~50% silt plus clay fraction (Table 1), the contribution of texture was assumed to be similar in both treatments. The dispersion effect in the cattle manure and the soils was low as indicated by their low Na content, EC and approximately neutral pH (Tables 1 and 2).Therefore, it was likely that the increase in MWD and hence aggregate stability was as a result of decreased slaking. Similarly, Materechera (2009) observed a significant reduction in the slaking of aggregates following the addition of several organic amendments including 5 mg/ha cattle manure on a hardsetting and crusting chromic Luvisol in South Africa. Nyamangara et al. (2001) reported an increase in the stability of a hardsetting Haplic Lixisol in Zimbabwe after adding cattle manure and attributed this to an increase in the water stable aggregates. Our results highlight the benefits of cattle manure in improving aggregate stability in hardsetting soils, which was achieved by cattle manure preventing aggregates from slaking upon wetting (Table 3) and increased the water stable aggregates (Figure 1).

Likewise, cattle manure reduced soil PR (Figure 2) by weakening the interparticle cohesion within the aggregates (Chan, 1995). Previous studies have shown that strength development in hardsetting soils increase markedly between 6 to 100 kPa (Ley et al., 1995). This phenomenon was also observed in this experiment; a rapid rate of increase in soil PR below 100 kPa and thereafter a significant decrease in the rate of increase in PR (Figure 2). Strength development in hardsetting soils is caused by an increase in effective stress which results from the increase in matric suction as the soil dries (Chan, 1995). During drying, mobilized material is carried behind the retreating water meniscus and rearranged to occupy concavities or form annular bridges on the surface of sand grains (Mullins et al., 2000). Such a rearrangement ultimately results in a closer packing and a higher number of contacts and hence higher strength. In the current study, the increase in PR was attributed to the silt plus clay content which was ~50% (Table 1), the main material responsible for hardsetting. Our result compared well with those of Ley et al. (1995), who worked with soils containing ~41% silt plus clay. On the other hand, Chan (1995) worked with soils containing 28% silt plus clay and showed that strength development extended over a much wider range of matric suction.

Conclusions

Cattle manure increased aggregate stability, the proportion of the water stable aggregates and decreased soil strength. An increase in aggregate stability was associated with a decrease in PR. Therefore cattle manure could improve the physical properties of hardsetting soils.

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