CATTLE MANURE, SCALPING AND SOIL WETNESS EFFECTS ON SOME PHYSICAL PROPERTIES OF A HARDSETTING SOIL AND ASSOCIATED EARLY MAIZE GROWTH

BY

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DECLARATION

I, **Adornis Dakarai Nciizah,** declare that the dissertation hereby submitted for the degree of Master of Science (MSc) at the University of Fort Hare is my work and has not been previously submitted to another university

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PREFACE

This dissertation consists of five chapters. Chapter one provides the background, justification and objectives of the study. Chapter two gives a general review of the literature relevant to the study. Chapter three covers the materials and methods used in this study. The fourth chapter reports the findings (results) of the study. Chapter five covers discussion of results, conclusions and recommendations for further studies.

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ABSTRACT

Most soils in the Eastern Cape Province, South Africa are shallow and are low in organic matter. Therefore these soils are structurally fragile and highly susceptible to inherent degradative processes like hardsetting. The objective of this study was to determine the effect of cattle manure, scalping and soil wetness on aggregate stability, penetration resistance and early maize growth in hardsetting soils. Glasshouse and field studies were conducted to determine the effect of cattle manure on aggregate stability and penetration resistance of freshly exposed topsoils by scalping at 0, 10 and 20 cm depths. In the glasshouse cattle manure was applied at 0 and 20 Mg/ha and matric suction was kept at ~ 30 and ~ 400 kPa; contrasting high and low soil wetness. Three soils were put in pots and arranged in a randomized complete block 3 × 2 × 2 factorial design. The field study was done at the University of Fort Hare research farm and the treatments were arranged in a split-plot complete randomized design with three replications. Scalping treatment was the main plot whilst the quantity of the cattle manure applied was the sub plot. Cattle manure increased mean weight diameter (MWD) by between 48% and 71% under glasshouse and between 18% and 33% under field conditions, depending on the soil wetting rate. Cattle manure reduced MWD when the soil under field condition was subjected to mechanical shaking. Soil penetration resistance decreased linearly, with increasing soil wetness but it rapidly increased with increase in matric suction up to ~200 kPa and thereafter the rate of increase reduced. In the glasshouse, all treatments had no significant effects on shoot dry weight but low matric suction increased root dry weight by 133%. Interaction of cattle manure and low matric suction reduced shoot length by 6%, shoot fresh weight by 25%, root surface area by 36%, root length by 5% and root fresh weight by 29% compared to the control. In contrast, application of cattle manure and high matric suction increased shoot length by 37%, shoot fresh weight by 136%, root surface area by 159%, root length by 94%

and root fresh weight by 119%. In the field, cattle manure application increased root length density and shoot dry matter by 26% and 30% respectively. Cattle manure improved the stability of aggregates of the hardsetting soil under rapid or slow water intake conditions experienced during rainfall or irrigation. However, under field conditions cattle manure acted as a deflocculant and decreased the stability of aggregates when mechanical stress was applied. The effectiveness of cattle manure in improving maize growth in hardsetting soils was determined by matric suction.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Crop production in the Eastern Cape Province, South Africa is limited by soil degradation (Fox and Rowntree, 2001), especially low soil organic matter (SOM) content (Mandiringana *et al.*, 2005). The soil organic carbon cycle is interrupted by continuous conventional tillage, removal of crop residues, frequent burning and intensive grazing (Mills and Fey, 2004). Consequently, the soils are structurally fragile and highly susceptible to inherent degradative processes like hardsetting (Van der Merwe and de Villiers, 1998).

Many workers have investigated soil degradation processes like erosion, acidification, depletion of organic matter and nutrients (Fox and Rowntree, 2001; Mills and Fey, 2004), but only a few investigations focus on hardsetting in South Africa (Smith and Johnston, 2001; Materechera 2009). Hardsetting soils are widespread in Australia and Africa (Mullins *et al.*, 1990; Chan, 1995; Mullins, 2000). These soils set to a hard structureless mass during drying until the profile is rewetted (Mullins *et al*., 1990). The resultant high soil strength delays tillage operations, seedling emergence and restricts root growth leading to low crop stand and poor yield. The poor structural stability of these soils also leads to poor soil aeration, low infiltration, high runoff and erosion hazard (Mullins *et al.*, 1990).

Hardsetting soils are characterized by horizons with unstable soil aggregates (Mullins *et al.*, 1990; Chan, 1995). 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. As the soil dries and the matric suction exceed 100 kPa, the fine particles mostly clay and silt form strong structural connections between the sand particles (Fabiola *et al.*, 2003), resulting in a hard structureless mass of soil with high penetration resistance that restricts plant root growth (Bengough 1996). Moreover, erosion is common in hardsetting soils due to reduced infiltration rate and increased runoff (Mullins, 2000).

The development of high soil strength upon drying leads to high soil mechanical impedance to plant root growth and a subsequent reduction in water and nutrient uptake (Bengough, 1996). Soil mechanical impedance is the resistance offered by the soil matrix against deformation by a root growing in a homogeneous non-structured soil (Laboski *et al.*, 1998). Plant roots grow by penetrating through pore spaces by moving soil particles from their path. However, root pressure must exceed the soil mechanical impedance for root growth to occur. An increase in soil mechanical impedance approximated with penetrometer measurements due to hardsetting reduces root elongation, root dry weight and root distribution, which are important for water and nutrient uptake (Chassot and Reichner, 2002).

Another important consequence of hardsetting is increased soil erosion due to low infiltration rates and increased runoff (Mullins *et al.*, 1990). In addition to the loss of top soil and its constituent nutrients, soil erosion exposes the less fertile subsoil, increases loss of SOM and hence leads to

further soil structural degradation (Laker, 1999). The artificial erosion approach where topsoil is artificially removed through scalping is a method widely used to study general erosion-productivity relationships (Izzauralde *et al.,* 1998; Sui *et al.,* 2009). In addition, soil scalping also provides information on hardsetting behavior as a function of soil depth. Soil organic matter is known to decrease with soil depth (Wright *et al*., 2007) as soil strength and hardsetting tendency increase (Ruehlmann and Körschens, 2009). Wright *et al*. (2007) measured a 404% decrease in SOM between the 0 to 5 cm and 80 to 105 cm soil layers. Ruehlman and Körschens (2009) also reported bulk density values ranging from 2.1 Mg/m^3 at 0.86% SOM content to 0.3 Mg/m^3 at 69% SOM content. Chan (1995) reported a four-fold increase in hardsetting tendency when soil depth increased from 0 to 15 cm. In addition, hardsetting has been shown to be influenced by water content. Strength development in hardsetting soils increase markedly between 100 and 1000 kPa (Chan, 1995) and 6 to 100 kPa (Ley *et al*., 1995).

1.2 Justification of the study

Soil organic matter plays an important role in improving crop growth and yield by supplying nutrients or by modifying soil physical properties (Rees *et al.,* 2000). Furthermore, SOM acts as both a bonding and dispersing agent by increasing interparticle hydrophobicity and cohesion within aggregates (Mullins 2000; Abiven *et al.,* 2009). This in turn improves the root environment and promotes crop growth. However, most soils in Eastern Cape Province of South Africa have low SOM content, which exacerbates their vulnerability to hardsetting (Land Type Survey Staff 2001; Mills and Fey, 2004). For example, Mandiringana *et al.* (2005) reported SOM content ≤ 1% in many soils in Eastern Cape. Consequently, regular inputs of SOM have been recommended to boost soil productivity (Murungu *et al.,* 2010).

Cattle manure is a good source of SOM and an excellent ameliorant in soil productivity restoration (Izaurralde *et al.,* 1998; Nyamangara *et al.,* 2001; Miller *et al.,* 2009). In many regions, cattle manure has often been used to improve plant nutrition and yield (Mugwira and Mukurumbira, 1984; Miller *et al*., 2009; Obour *et al*., 2010). Moreover, cattle manure has been used to improve soil physical properties (Busscher *et al*., 2010) especially aggregate stability (Lado *et al.,* 2004) and reduce penetration resistance in fine-textured soils (Mijangos *et al*., 2010) and loam soils (Alvarez *et al*., 2009). Improvements in soil chemical properties like pH 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; its quality, climate, soil type, crop type, extent of soil degradation and management (Sui *et al.,* 2009). Therefore investigations on the effects of cattle manure on soil properties should be localized.

In South Africa, cattle manure is an important source of plant nutrients in smallholder farming systems (Yoganathan and van Averbeke, 1996). Therefore application of cattle manure on hardsetting soils may prove to be an innovative and sustainable strategy for improving crop productivity in hardsetting soils. Materechera (2009) has reported improved aggregate stability, reduced soil strength and bulk density and increased bambara nut growth and yield after applying 5 Mg/ha of cattle manure on a hardsetting and crusting chromic Luvisol in South Africa. Nyamangara *et al.* (2001) made similar observations in Zimbabwe. However, little is known about the effectiveness of cattle manure in improving aggregate stability, penetration resistance and early maize growth of freshly exposed soil surfaces due to erosion in hardsetting soils. Mtambanengwe *et al.* (2006) observed significant biomass differences in maize within two weeks from emergence under various organic inputs. Their study also indicated high N requirement during early growth

and it was suggested that an early and consistent supply of N determines yield. The study also revealed a positive linear relationship between grain yield and maize biomass at two weeks after emergence and hence the focus on early maize growth in this present study. Early growth in this study refers to 0 to 4 weeks after planting.

1.3 Objectives

The general objective of this study was to determine the effect of cattle manure on physical properties of a hardsetting soil and associated early growth response of maize.

1.4 Specific Objectives

1. Determine the effect of cattle manure, scalping, soil wetness on aggregate stability and penetration resistance in hardsetting soils.

2. Determine the effect of cattle manure, scalping, soil wetness on early maize growth in hardsetting soils.

1.5 Hypotheses

1. Incorporation of cattle manure, scalping and soil wetness affect aggregate stability and soil penetration resistance in hard-setting soils.

2. Incorporation of cattle manure, scalping and soil wetness affect early maize growth in hardsetting soils.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The nature of hardsetting soils and their distribution

Hardsetting soils were first identified and described by Northcote in 1960 in Australia. The term was later adopted and used in other countries (Mullins, 2000). These soils set to a hard structureless mass during drying and are thereafter difficult to cultivate until the soil is rewetted (Mullins *et al.,* 1990). This reversibility differentiates between hardsetting and permanent cementation which occurs in fragipans and duripans (Chartres *et al.,* 1990). A more recent and generally agreed description of hardsetting was presented by Mullins (2000); "a hardsetting horizon sets to an almost homogeneous mass on drying with occasional cracks at a spacing of ≥ 0.1 m. A dry hardset horizon is hard and brittle and it is not possible to push the index finger through the profile. Such horizons can have a tensile strength of ≥ 90 kN/m^2. Soils that crust are not necessarily hardsetting since a hardsetting horizon is thicker than a crust. Hardsetting soils are not permanently cemented and are often soft when wet. The clods in a hardsetting horizon that has been cultivated will partially or totally disintegrate upon wetting. If the soil is sufficiently wetted, it will revert to its hardset state on drying".

Soil properties that are associated with hardsetting have been reviewed by Mullins *et al.* (1990) and later by Mullins (2000). These soils have variable texture ranging from, loamy sands to sandy clays but are characterized by high contents of silt plus clay, and sometimes fine sand, exchangeable sodium and siliceous cements (Harper and Gilkes, 1994; Mullins 2000). The clay mineralogy of hardsetting soils is dominated by non-swelling minerals such as hydrous mica

(illite) and/or kaolinite (Mullins, 2000, Igwe *et al.,* 2006). In addition, low SOM promotes hardsetting. Soils with SOM ≤

2% undergo sufficient structural collapse to become hardsetting on drying (Mullins, 2000)

In Africa, hardsetting soils have been widely observed in Cameroon and Nigeria (Chan, 1995; Igwe *et al.,* 2006), the Sahel region (Valentin 1995), Zimbabwe (Gwenzi, *et al.,* 2009), Zambia and Botswana (Mullins *et al.,* 1990) as well as South Africa (Smith and Johnston, 2001; Materechera, 2009). Materechera (2009) reported extensive soil hardsetting in the Northwest Province of South Africa extending into Botswana whilst soils in the central Eastern Cape have also been noted to display hardsetting tendencies (Smith and Johnson, 2001; Ristori and D'Acqui, 2007). In these regions, the SOM content has been noted to be very low; often ≤ 1% which, increases the soil's susceptibility to hardsetting (Mills and Fey, 2004). A study by Mandiringana *et al.* (2005) also showed that most of the soils in the Eastern Cape Province are dominated by hydrous mica and kaolinite in the clay fraction. Moreover, Luvisols, Planosols and Solonetz have been shown to posses some hardsetting properties (Mulins *et al.,* 1990). These soils are common in South Africa especially the Eastern Cape Province (Mullins *et al.,* 1990; Laker 1999).

2.2 Mechanisms involved in hardsetting

Hardsetting consists of two distinct processes: (i) slumping due to structural breakdown of aggregated soil on wetting by slaking and dispersion into micro-aggregates and (ii) uniaxial shrinkage due to hardening without restructuring on drying (Mullins, 2000).

2.2.1 Structural breakdown

Soil aggregate breakdown occurs in response to various forces and environmental conditions such as tillage, raindrop energy sources or internally generated forces due to rapid wetting under rainfall or irrigation in the field (Le Bissonais, 1996; So, 2006). Structural breakdown causes slumping, which is a bulk volume reduction caused by particle or aggregate breakdown and/or rearrangement (Mullins, 2000). Le Bissonais (1996) categorized mechanisms of aggregate breakdown into four: (i) Slaking as a result of breakdown by compression of entrapped air, (ii) breakdown by differential swelling of clays, (iii) mechanical breakdown by raindrop impact and (iv) physico-chemical dispersion.

Slaking

Slaking occurs when aggregates are suddenly immersed in or placed in contact with water (Mullins, 2000) because of the stress resulting from rapid water uptake (Le Bissonais, 1996). Increased pressure within entrapped air pockets from the tensions exerted by the water meniscus results in mini-explosions of the soil aggregates (Le Bissonais, 1996; So, 2006). The macro-aggregates break into micro-aggregates of 20 to 25 µm in diameter (So, 2006). Slaking is affected by antecedent matric potential, rate of wetting, SOM content and clay mineralogy (Mullins, 2000). The size of micro-aggregates resulting from slaking increases in size with an increase in clay content due to increases in clay volume and resistance (Le Bissonais, 1996).

Physico-chemical dispersion

Dispersion is caused by the breakdown of clay aggregates into individual clay particles. It results from the reduction of the attractive forces between colloidal particles during wetting (Le Bissonais, 1996). It is associated with soil sodicity and is sensitive to the Na percentage of the soil and to the threshold electrolyte concentration of the soil solution (Mullins, 2000). Dispersion is also caused by mechanical disturbance of the soil through tillage when the soil is wet (Peverill *et al.*, 1999), resulting in the production of elementary particles rather than microaggregates. It is one of the most effective processes of aggregate breakdown which also influences the effect of other breakdown mechanisms (Le Bissonais, 1996). During wetting, the dispersive soils undergo breakdown of the clay structures that bind fine aggregates and larger particles: sand and silt, individual clay particles go into suspension (Peverill *et al.*, 1999). The dispersed clay moves into the soils pores and blocks water, air flow and storage pores (Le Bissonais, 1996).

Breakdown by differential swelling

Differential swelling and shrinkage of clay minerals during wetting and drying of clay soil results in a microcracking of aggregates (Le Bissonais, 1996). The development of a shear plane on the wetting front, can break many of the bonds between particles ion hydration and osmotic swelling forces pull water into interlayer spaces between the clay platelets, thereby pushing clay particles apart and causing the breakdown of the aggregates of swelling soils (Kemper and Rosenau, 1986). Microcracking or differential swelling depends on clay mineralogy and its properties such as cation size, valence and the composition of soil solution (Zhang and Horn, 2001). Unlike slaking,

breakdown by differential swelling occurs under slow wetting conditions, and increases with increasing clay content (Le Bissonais, 1996).

Mechanical breakdown by raindrop impact

Mechanical breakdown of aggregates by raindrop impact usually occurs in combination with other mechanisms if the kinetic energy of the raindrops is great enough (Le Bissonais, 1996). Raindrop impact plays a dominant role when the soil aggregates are wetter because the aggregates are weaker (Wuddivira *et al.,* 2008). Raindrop impact promotes erosion due to detachment of soil material and runoff shear as well as by the transport of the resulting sediment by raindrop splash (Le Bissonais, 1996; Mamedov *et al.,* 2002). Although the kinetic energy for splash by raindrops is more than required for runoff shear, sediment transport is mainly by runoff water (Mamedov *et al.,* 2002). The fragments resulting from raindrop detachment are elementaty particles or small microaggregates < 100 µm (Le Bissonais, 1996).

2.2.2 Strength development in hardsetting soils

Structural breakdown brings soil particles to closer proximity with each other which contributes to the increase in strength upon drying hardsetting soils. Hardsetting soils display sharp increases in strength during drying. Mullins *et al.* (1990) reported pronounced strength increases, up to a factor of 3, between matric suction of 0.1 to 1000 kPa. Ley *et al.* (1995) observed strength increases ranging from 1.3 to 4.4 times after drying soils from 6 to 100 kPa. Mullins *et al.* (1990) and

Mullins (2000) suggested three different processes that could be responsible for this observed strength development:

(i) Wetting of the system mobilizes some or all the silt plus clay fraction, this may occur through slaking and/or dispersion.

(ii) During the early stages of drying, the mobilized material is carried behind the retreating meniscus to occupy concavities on the surface of sand grains and any remaining aggregates, or to annular bridges between this larger stable material.

(iii) An increase in strength due to an increase in effective stress which results from the increase in matric suction as the soil dries. This process occurs in all soils during the early stages of drying before the water between the aggregates is replaced by air.

2.3 Effects of hardsetting on soil physical properties

Hardsetting results in poor infiltration, high runoff and high erosion hazard (Mullins *et al.*, 1990). Soil erosion involves two major processes namely; (i) detachment of soil material from the soil surface; and (ii) transport of the resulting sediment (Ben-Hur and Lado, 2008). Low aggregate stability and organic matter levels can lead to surface crusting, which gives rise to low surface infiltration and hence high run-off and associated soil detachability (Murphy and Flewin, 1994). Low infiltration rate is also explained by (i) a physical disintegration of surface soil aggregates, caused by the impact energy of the raindrops; and (ii) the physicochemical dispersion of soil-clays, which migrate into the soil with the infiltrating water and clog the pores immediately beneath the surface to form the 'washed-in' zone (Ben-Hur and Lado, 2008). Therefore, conditions that increase slaking and dispersion such as hardsetting increase erosion (Lal, 2001). Murphy and

Flewin (1994) determined the importance of rill erosion on a structurally degraded hardsetting soils in Australia and showed an extremely high soil erodibility value of 0.35 t/ha per unit of erosivity. This was attributed to low aggregate stability and organic carbon levels which resulted in the soil breaking down into ultimate particles on wetting. Furthermore, particles can be readily detached and transported in water (Murphy and Flewin, 1994; Ben-Hur and Lado, 2008). Soil erosion exposes fresh surfaces which may be more susceptible to further degradation. For example, erosion of a crusting surface exposes more erodible underlying material (Harper *et al.,* 2010). Although hardsetting is a horizon effect, in some soils, loss of top soil exposes much stronger subsoil. Harper and Gilkes (1994) observed a higher mean subsoil strength of 162 kPa exposed by erosion compared to 110 kPa for the topsoil. Therefore, in such soils, erosion increases mechanical impedance and hence reduces crop performance. The artificial erosion approach where topsoil is manually removed through scalping is the most widely used method to study general erosion-productivity relationships (Izaurralde *et al*., 1998; Sui *et al*., 2009).

2.4 Effects of hardsetting on plant growth

Hardsetting of the soil affects plant growth through its primary effects on root growth and function. Hardsetting causes significant reductions in root growth, seedling growth and shoot extension (Mullins *et al.,* 1990). The penetration resistance in hardsetting soils is in most cases likely to exceed 3 MPa, which is sufficient to impede root and shoot growth before the soils has reached wilting point (Mullins, 2000). This high soil strength increases the soil's mechanical impedance, which is defined as the resistance offered by the soil matrix against deformation by a root growing in a homogeneous non-structured soil (Laboski, 1998). This high soil strength creates

unfavourable conditions for root growth and leads to reduced water and nutrient uptake (Bengough *et al.*, 2006). Cook *et al.* (1996) studied the effects of mechanical impedance on root growth and showed that impedance firstly reduced growth rate and therefore final length of the root axis. Secondly, it reduced the number and/or delayed the production of the nodal axis. Overall hardsetting reduces root elongation, root dry weight and root distribution which are all important for water and nutrient uptake (Chassot and Reichner, 2002).

In addition to limiting root growth, several studies have shown that mechanical impedance also reduces shoot growth. For example, Masle and Passioura (1987) showed that high soil strength reduced growth of wheat shoots through root-shoot signaling mechanism which causes a reduction in the extension of the shoots in direct response to high mechanical impedance on roots, even in the absence of water stress. Similar observations were made by Young *et al.* (1997) who observed no decreases in stomatal conductance accompanying increased mechanical impedance, suggesting no decreases in hydraulic conductivity. Therefore, their findings proved that shoot-inhibiting signals are generated by roots growing in a medium of large mechanical impedance. Bingham (2001) established that high mechanical impedance causes root to releases a hormone, abscisic acid that is transported to the shoots where it inhibits leaf expansion and induces stomatal closure before a change in the water and nutrient status of the leaves is observed. Therefore, hardsetting may affect shoot growth directly in addition to the associated consequences of restricted root growth.

Removal of top soil due to soil erosion leaves behind a subsoil with high mechanical impedance to root growth in hardsetting soils. A four-fold increase in erosion as depth increased from 0 to 15 cm was reported by Chan (1995) due to a decrease in SOM (Wright et al., 2007). Furthermore, Harper and Gilkes (1994) reported a 47% increase in soil strength due to exposure of the subsoil by erosion. This increase in mechanical impedance restricts the elongation of the main root axis, stimulate branching of the lateral roots and thickening of the roots (Bengough *et al.,* 1997). Although this thickening allows the root to prevent buckling, these thicker roots have less absorbing surfaces and subsequently low water and nutrient uptake (Cook *et al*., 1996; Bengough *et al.,* 1997). Moreover mechanical impedance occurring during the vegetative development decreases growth, impairs the development of reproductive structures and may lower grain yield (Lorens *et al.,* 1987). Kuchenbuch and Barber (1988) showed strong correlations between maize root length density below the 30 cm depth at silking and the growing degree days for the 2 weeks following planting. Furthermore, a study by Mtambanengwe *et al*. (2006) showed a strong linear relationship between maize biomass at two weeks after emergence and grain yield.

2.5 Management of hardsetting soils

Hardsetting is an inherent tendency of some soils but it can be increased by poor soil management practices, even in soils that are not naturally hardsetting (Mullins *et al.,* 1990). Inappropriate management practices that lead to the deterioration of physical properties of surface soils especially soil aggregation are common in the semi-arid areas. Therefore, to prevent hardsetting, it is essential to create and stabilize soil aggregates (Mullins, 2000). Several substances that have been used to stabilize aggregates, and hence reduce hardsetting, include lime (Scott *et al.,* 2003),

polyacrylamides (Sivaplan, 2002), gypsum (Mullins *et al.,* 1990; Materechera, 2009), polymer gel (Materechera, 2009), poultry biochars (Chan *et al.,* 2007), metal hydroxides (Breur and Schwertmann, 1999), cyanobacteria (Maqubela *et al.,* 2008) and SOM (Mossadhegi *et al.,* 2009, Materechera, 2009). The addition of these materials decreases soil tensile strength by improving aggregation which in turn reduces the movement of fine particles with the retreating meniscus on drying. Lime increases aggregate stability by increasing formation of bonds between organic matter and clay mineral surfaces involving Ca-ion bridges (Scott *et al., et al.,* 2003).

2.6 Effect of soil organic matter on soil aggregation

Soil organic matter is a major factor affecting aggregate stability and its abundance and characteristics can be modified by agricultural practices (Abiven *et al.,* 2009). Several studies have shown that the stability of soil aggregates to disruptions in water is depended on SOM (Nyamangara *et al.,* 2001; Shirani *et al.,* 2002). However, SOM and soil structure, which determine to a large extent soil workability and availability of water and nutrients to crops, are greatly influenced by management practices (Sui *et al.,* 2009). Mandiringana *et al.* (2005) reported organic matter contents < 1% in some Eastern Cape soils due to soil management practices that increase SOM oxidation and this was associated with soil aggregates that were prone to slaking, dispersion and consequently hardsetting.

Soil organic matter stabilizes aggregates against disruptive forces by increasing interparticle hydrophobicity and cohesion within aggregates (Abiven *et al.,* 2009). According to Amezketa

(1999), SOM forms a hydrophobic coating around the aggregates thus reducing soil wettability which slows the wetting rate and consequently reducing the sensitivity to slaking. The stabilizing effect of SOM results from the combination of the transient aggregating effect of polysaccharides on micro-aggregates, the temporarily stabilizing effect of roots and hyphae on macro-aggregates, and the persistent effect of polymers and aromatic compounds on micro-aggregates. Conversely, SOM has dispersive a effect due to the following mechanisms:

(i) The blocking of positively charged edges of clay minerals by negatively charged organic anions,

(ii) The complexation of polyvalent cations by organic matter, and

(iii) The steric repulsion resulting from the overlap of adsorbed organic polymer layers

2.7 Effect of soil organic matter

Due to the low SOM content in Eastern Cape soils, regular SOM inputs have been recommended to boost soil productivity (Murungu *et al.,* 2010). According to Abiven *et al.* (2009) different types of organic matter have different effects on the cohesion and hydrophobicity of soil, depending on their intrinsic characteristics and that of their decomposing microflora or exudates. A review by Amezketa (1999) drew the following observations:

(i) Crop residues retained on or near the soil surface usually dissipate raindrop energy, thus minimizing aggregate breakdown and surface sealing

(ii) Straw left on top of the soil increase aggregate stability by reducing the wetting rate.

(iii) Soil incorporated residues maintain favorable soil porosity and SOM contents.

(iv) Retention of crop residues on the soil surface has greater importance in improving water storage than improving soil aggregation.

(v) The amount, C/N ratio, of the residues and their decomposition rates influence the response pattern of soil structure.

(vi) Organic fertilizers such as manure act to increase C and N, resulting in increased microbial biomass C and N and thereby increasing soil micro-aggregation.

2.8 Cattle manure as a source of organic matter

Cattle manure is considered a good source of SOM and an excellent ameliorant in soil productivity restoration (Nyamangara *et al.*, 2001; Miller, 2009). In many smallholder farming systems, including the Eastern Cape, cattle manure is an important source of plant nutrients (Yoganathan and van Averbake, 1996; Obour *et al*., 2010). Significant increases in SOM content have been reported following application of cattle manure. In a study by Shirani *et al.* (2002) manure application rates of 30 and 60 Mg/ha increased OM three fold and fivefold for row tracks and two-fold and four-fold for inter-row tracks, respectively. Application of cattle manure also improves soil pH (Whalen *et al.*, 2002) and reduces penetration resistance in fine textured soils (Mijangos *et al.*, 2010) and in loam soils (Alvarez *et al.*, 2009).

Materechera (2009) observed 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. These soil improvements were accompanied by improved bambara groundnut growth and yield.

Mosaddeghi *et al.* (2009) reported improved maize root length density, soil strength and bulk density after applying 30 and 60 Mg/ha cattle manure on a top-crusted soil prone to hardsetting. Nyamangara *et al.* (2001) reported improved aggregate stability after applying 20 Mg/ha of cattle manure on a degraded soil in Zimbabwe. Humic substances in cattle manure increase clay hydrophobicity, and hence aggregate stability, when manure is added to soil (Mullins *et al.,* 1990; Abiven *et al.,* 2009). Moreover cattle manure is readily available in most parts of the Eastern Cape; it is therefore a viable option to restore soil physical structure and crop productivity.

Most South African soils are extremely vulnerable to various forms of degradation and have low resilience (Laker, 1999). The reviewed literature showed that some soils in the Eastern Cape Province are highly susceptible to hardsetting due to low SOM. Therefore, proficient management of these soils is an imperative factor in ensuring sustainability of soil resources. Current literature has revealed the potential of different soil amendments, including lime, gypsum, poultry biochars and cattle manure, in restoration of hardsetting soils (Mullins *et al.,* 1990; Scott *et al.,* 2003; Materechera, 2009). Cattle manure is a good source of SOM and is ready availability in the Eastern Cape Province, which makes it a viable option to ameliorate hardsetting soils.

Effectiveness of cattle manure depends on its quality, climate, soil type, crop type, extent of soil degradation and the level of management (Sui *et al.,* 2009). No information could be accessed in the literature on the effects of manure application on hardsetting soils that have experienced varying levels of erosion, on aggregate stability, penetration resistance and associated early maize growth. There is, therefore, a need to understand the effect of cattle manure, scalping and soil

wetness on aggregate stability and penetration resistance in hardsetting soils, and subsequently, on early maize growth.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Site description

The study was done both in the glasshouse and field. Soils for the glasshouse experiment were obtained from Alice, Guquka and Hertzog. These sites are located within the central region of the Eastern Cape Province, and represent some of the known hardsetting soils in South Africa (Land Type Survey Staff, 2001; Smith and Johnson, 2001; Ristori and D'acqui, 2007). Alice is located at 32º46' S and 26º50' 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. The Land Type Survey Staff (2001) classified the soil as the Ritchie family of the Oakleaf form in the South African soil classification system (Soil Classification Working Group, 1991) which is a eutric Cambisol according to the World Reference Base for Soil Resources (WRB) system (IUSS Working Group WRB, 2006). Guquka is located at 32º39' S and 26º57' E at an altitude of 770 m. The site has a sub humid climate and receives summer rainfall with a mean of 750 mm. The soil is classified as the Oakleaf form in the South African soil classification system which is a ferric Luvisol according to the World Reference Base for Soil Resources (WRB) system (IUSS Working Group WRB, 2006). Hertzog is located at 32º35' S and 26º43' E. The soil is of the Oakleaf form (Jozini and Limpopo series) according to the Land Type Survey Staff (2001).

3.2 Soil sampling

At the start of the experiment soil samples were obtained from the top 0 to 20 cm depth using a soil auger from a disturbed site and mixed thoroughly. These samples were air-dried and passed through a 2 mm sieve for initial soil characterization. Concomitant soil samples were obtained during the penetration resistance measurements for the determination of moisture content, and at the end of the experiment soil samples were obtained for aggregate stability determination.

3.3 Initial soil and cattle manure characterization

Some of the soil properties are shown in Table 3.1 while that of manure are shown in Table 3.2. Particle size distribution was determined using the hydrometer method after oxidizing SOM with hydrogen peroxide as described by Gee and Or (2002). The SOM content was determined by the Walkely-Black procedure as described by Nelson and Sommers (1996). Soil pH was measured in water at soil-water ratio of 1:2.5, and for cattle manure the ratio was 1:5 using a pH meter (model pH 25, Crison Instruments, South Africa) after shaking the suspensions for 30 min and equilibrating for 10 min (Okalebo *et al.*, 2000). 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). Total Na, K and Mg in both soil and manure were estimated following wet digestion with sulphuric acid and hydrogen peroxide (Okalebo *et al.*, 2000). The cations were determined using a Varian 700-ES Model inductively coupled plasma-optical emission spectrometer (ICP-OES, Varian, Inc., USA). Total N and P were determined colometrically as described by Okalebo *et al.* (2000).

Table 3.1 Some physical and chemical properties at 0 to 0 cm soils from Alice, Guquka and Hertzog #

Site	Sand	Silt	Clay	SOM	pH	EC	Na	Mg	N	P	K
	%					d/Sm	$cmol_c/kg$				
Alice	48	28	24	2.58	6.7	0.14	0.62	0.66	0.80	3.50	1.19
Guquka	50	28	22	1.36	5.2	0.13	0.43	0.13	0.03	0.74	0.68
Hertzog	52	24	24	1.84	7.5	0.14	0.77	0.62	0.05	2.89	1.42

#SOM, soil organic matter; EC, Electrical conductivity

Table 3.2 Some properties of the cattle manure used#

N	P	K	OM	C:N	EC	pH
%					dS/cm	
2.2	5.7	8.9	48.7	12.8	0.23	7.5

#OM, Organic matter

3.4 Cattle manure and scalping effects on some physical properties of a hardsetting soil and associated early maize growth under glasshouse conditions

A randomized complete block design with a 3 × 2 × 2 factorial treatment structure and three replications was used. Factor one was scalping, where topsoil was scalped to three depths, 0, 10 and 20 cm. Factor two comprised cattle manure applied at two rates of 0 and 20 Mg/ha. The third factor was soil wetness at two matric suction; ~ 30 and ~ 400 kPa. The two water regimes were employed to vary amount of water and to contrast its effect on soil structure. The control treatment received no manure application and was not scalped and wetness was maintained at ~400 kPa matric suction. The three soils; Alice, Guquka and Hertzog were used as the blocks. Soil for the glasshouse study was taken from the top 0 to 5 cm after creating the three depths at each of the three sites by manually scalping to the respective depths with a shovel. The soil was air-dried and sieved through a 4 mm sieve. Pots with a 30 cm diameter were filled with 10 kg soil. Cattle manure applied in some of the pots was mixed thoroughly with the soil before planting. Five maize seeds (DKC 61-25B) were planted ~ 3 cm deep in each pot and thinned to one a week after emergence to minimize competition. The matric suction was measured daily using gypsum blocks, which were inserted into each pot and left undisturbed until the end of the experiment. The matric suction was read using a Delmhorst® KS-D1 digital soil moisture meter (Delmhorst Instrument Company). The lower matric suction was chosen to exclude hardsetting while the higher value was chosen to simulate water conditions that allow hardsetting (Chan, 1995; Ley *et al.*, 1994). Gypsum blocks were calibrated to give the actual volumetric water content against the meter reading for each soil. Matric suction was monitored and adjusted daily**.** At the same time, penetration resistance was determined with a hand-held penetrometer from five random positions in each pot. The experiment was terminated four weeks after planting.

3.4.1 Effect of cattle manure on aggregate stability of hardsetting soils

Soil samples were collected from the top 5 cm of each pot four weeks after planting and placed in rigid containers to avoid further breakdown. The soil samples were air dried and large clods broken by hand. The air dried material was passed through a 5 mm sieve. Visible roots and debris were discarded. The samples were oven dried at 40 ºC for 24 h and aggregate stability was measured according to Le Bissonais (1996). The samples were subjected to three wetting regimes, that is, fast wetting, slow wetting and mechanical shaking to check for slaking, micro-cracking and mechanical breakdown in the hardsetting soils.

(i) Fast wetting

A 5-g air dry sample of aggregates was immersed in 50 mL deionised water for 10 min. Three replicates were used per sample. 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 remaining > 50 µm fraction was oven dried and gently sieved by hand on a stack of sieves of 2000, 1000, 5000, 200, 100 and 50 µm pore size. The weight of each fraction was then measured, the < 50 µm was calculated as the difference between the initial weight and the sum of the weights of the other six fractions.

(ii) Slow wetting

5-g air dry samples replicated three times were placed on a filter paper and maintained at a matric suction ~ 30 kPa for 30 min. Aggregate size distribution was determined as described in detail under the fast wetting method.

(iii) Mechanical shaking

A-5 g air dry sample of aggregates was immersed in 50 mL of ethanol for 10 min. Three replicates were used per sample. The ethanol was sucked off with a pipette, and the aggregates were transferred to a 250 mL flask with 50 mL of deionised water. The flask was filled with 200 mL of deionised water, agitated end-over-end 20 times and left to stand for 30 min to allow sedimentation of coarse particles. Excess water was then sucked off with a pipette and residual aggregates collected and the procedure continued as described for fast wetting. The aggregate stability of each soil sample was expressed as mean weight diameter (MWD) of the seven classes as follows:

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

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

3.4.2 Effect of cattle manure on early maize growth in hardsetting soils

Days to emergence were determined by counting the number of days taken to reach 50% emergence. At harvesting shoot length was measured from the base to the tip of the youngest leaf before harvesting. Fresh shoot weight was determined by weighing the shoot with an electronic

balance just after harvesting (four weeks after planting). The shoots were then oven dried at 65 ºC for 48 h and weighed to determine dry weight. The roots were washed over a 53 µm sieve and stained by placing them in a 0.001% methyl violet solution overnight to facilitate image analysis. The roots were then preserved in containers with 30% ethanol solution and stored in a cold room at 4 ºC until ready for root measurement. The stained roots were suspended evenly in a thin layer of water and evenly distributed on a glass tray and scanned using an HP Scanjet G3110 flatbed scanner to obtain JPEG images. The scanned images were analysed to measure root length and surface area using Medealab Count and Classify Image Analysis Software (MTG Vertrieb GmbH, Altdorf, Germany). After scanning, the roots were oven dried at 65 ºC for 48 h and weighed with an electronic scale to determine the dry weight.

3.5 Cattle manure and scalping effects on some physical properties of a hardsetting soil and associated early maize growth under field conditions

The field experiment was done at the University of Fort Hare farm at Alice. The land was ploughed to a depth of 20 cm and disc harrowed. Three top soil scalping depths were created by scalping or desurfacing in increments of 0, 10 and 20 cm. A split-plot treatment structure in a randomized complete block design with three replications was laid out. The depth of scalping constituted the main plots. Sub-plots comprised cattle manure applications at two quantities: 0 and 20 Mg/ha. The cattle manure was broadcast by hand and incorporated into the soil three days before planting. Each plot measuring 4 m × 3.6 m was surrounded by a 0.5 m buffer strip. Maize variety DKC 61-25B was planted on 19th December 2009. The seed was placed at ~ 3 cm deep in single rows at spacing of 0.9 m × 0.3 m. Basal fertilizer (3:2:1 (25) + Zn) was applied at a rate of

300 kg/ha (Van Averbeke and Marais, 1991). Basagran® (bentazon) and Atrazine® (atrazine) at 2 L/ha were tank-mixed and applied post emergent for the control of grasses, mostly sedges and broad-leaved weeds. Soil penetration resistance was measured with a flat cone hand-held penetrometer (Geotest Instrument Corp) from ten random positions in each plot just prior to irrigation. Concomitant soil samples were obtained during the penetration resistance measurements for the determination of soil wetness. The experiment was terminated after 9 weeks on 23rd February 2010.

3.5.1 Effect of cattle manure on aggregate stability of hardsetting soils

Soil samples for aggregate stability were collected from the top 0 to 15 cm depth with a spade at four weeks after planting. The samples were placed in rigid boxes to minimize breakdown. Aggregate stability was determined as described in section 3.4.1.

3.5.2 Effect of cattle manure on early maize growth in hardsetting soils

Days to emergence were determined by counting the number of days taken to reach 50% emergence. The number of days to flowering was determined as the number of days from germination to the day silks were visible on the topmost ear of 50% of plants in any plot. Plant height was measured from the base of the stem to the tip of the youngest leaf using a tape measure at flowering. Root sampling was done at flowering by obtaining soil cores of 76 mm diameter and 76 mm length. The cores were immersed in water with 30 ml of 10% sodium hexametaphosphate solution for 24 h to disperse the soil. The roots were then washed and prepared for root measurement as described for the glasshouse study. The root length per sample, divided by the

core volume was used to calculate the root length density, RLD in cm roots per cm^3 soil. Soil penetration resistance readings were taken simultaneously from ten random positions using a pocket penetrometer.

3.6 Analysis of data

Analysis of variance (ANOVA) was performed using JMP 8.0 (SAS Institute Inc, Cary, North Carolina). Mean separations were done using Fisher's protected least significant differences (LSD) at $P \leq 0.5$ Since pots from each of the three soil sampling sites used in the glasshouse study were grouped together, interaction with this factor was not assessed, and was instead treated as blocking factor.

CHAPTER FOUR

4.0 RESULTS

4.1 Glasshouse experiment

4.1.1 Mean weight diameter as affected by scalping, matric suction and cattle manure application

Scalping had no significant effects on MWD but application of 20 Mg/ha cattle manure increased MWD by between 48% and 71% (Table 1). Maintaining soils at low matric suction increased MWD by 22% when the soils were slowly wetted but when the soils were shaken the MWD was reduced by 24%. There were no significant interactions between soil scalping, matric suction and cattle manure application

Table 4.1 Effect of soil scalping, cattle manure and matric suction on mean weight diameter

Treatment	Fast wetting	Slow wetting	Shaking
Scalping, cm			
0	0.57[a]	0.62[a]	0.53[a]
10	0.50[a]	0.64[a]	0.55[a]
20	0.47[a]	0.57[a]	055[a]
Cattle manure, Mg/ha			
0	0.41[a]	0.45[a]	0.44[a]
20	0.62[b]	0.77[b]	0.65[b]
Matric suction, kPa			
~30	0.51[a]	0.68[b]	0.49[a]
~400	0.52[a]	0.55[a]	0.60[b]
Analysis of variance			
Matric suction	0.0056	ns	0.0290
Scalping	ns	ns	ns
Cattle manure	0.0000	0.0004	0.0001

[#] Values followed by different superscript letters within a column and treatment indicate a significant difference ≤ 0.05; ns; not significant.

4.1.2 Effect of matric suction on soil penetration resistance in hardsetting soils amended with cattle manure

In general, soil penetration resistance increased logarithmically with an increase in matric suction (Fig 4.1a). However, this relationship had two distinct phases; an initial stage characterized by sharp increase in soil penetration resistance with small increases in matric suction below ~200 kPa and a second stage characterized by a significant decrease in the rate of increase in soil penetration resistance beyond ~200 kPa. Plotting the two segments; less than ~200 kPa and beyond ~200 kPa separately gave significant linear functions (Fig 4.1b).

(a)

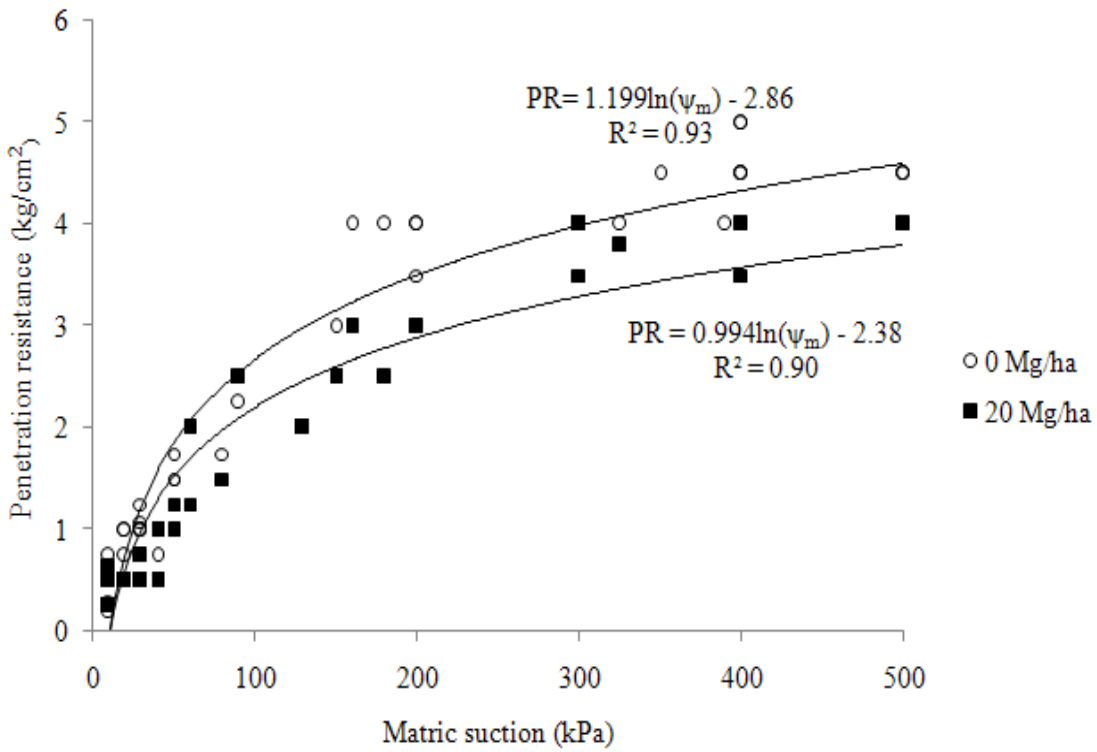

Fig 4.1a Effect of soil matric suction on soil penetration resistance in scalped hardsetting soils amended with 0 and 20 Mg/ha cattle manure; PR= penetration resistance, ψ_m= matric suction, R^2 = correlation coefficient

(b)

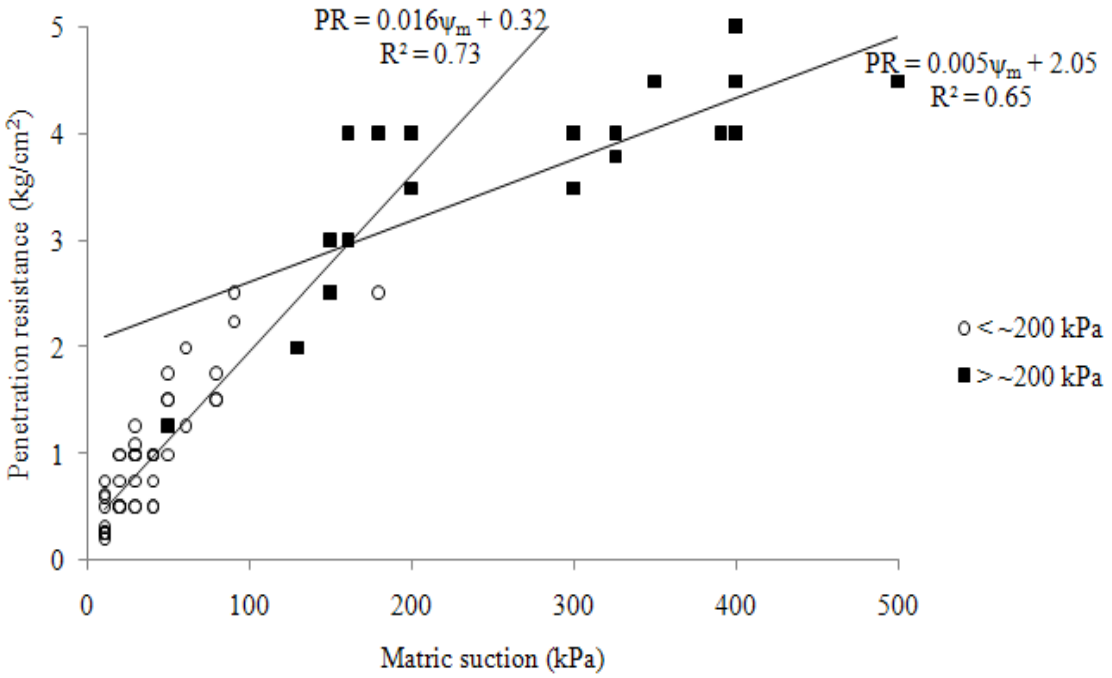

Fig 4.1b Relationship between penetration resistance and matric suction in hardsetting soils at < ~200 kPa and > ~200 kPa

4.1.3 Effect of matric suction, soil scalping and cattle manure on early maize root and shoot growth

All treatments had no significant effects on shoot dry weight but low matric suction increased root dry weight by 133% (Table 4.2). There were significant interaction effects between matric suction and cattle manure on shoot length, shoot fresh weight, root length, root surface area and root fresh weight. Cattle manure and low matric suction reduced shoot length by 6%, shoot fresh weight by 25%, root surface area by 36%, root length by 5% and root fresh weight by 29% (Fig 4.2a to 4.2d). In contrast, application of cattle manure and high matric suction increased shoot length by 37%, shoot fresh weight by 136%, root surface area by 159%, root length by 94% and root fresh weight by 119% (Fig 4.2a to 4.2d). Table 4.2 shows the *P* values for the main and interaction effects whilst Fig 4.2 shows the interaction trends where statistical significance was observed.

Table 4.2 Effects of soil scalping, cattle manure and matric suction on early maize growth in hardsetting soil

Treatment	Shoot length	Shoot fresh weight	Shoot dry weight	Root length	Root surface area	Root fresh weight	Root dry weight
	cm	g		cm	cm^2	g	
Scalped surface, cm							
0	39.08[a]	2.54[a]	0.32[a]	97.92[a]	16.64[a]	2.06[a]	0.04[a]
10	42.09[a]	2.32[a]	0.32[a]	110.31[a]	14.26[a]	2.30[a]	0.04[a]
20	46.50[a]	2.60[a]	0.33[a]	110.32[a]	14.03[a]	1.94[a]	0.06[a]
Cattle manure, Mg/ha							
0	40.42[a]	2.35[a]	0.32[a]	95.81[a]	13.35[a]	1.90[a]	0.05[a]
20	44.69[a]	2.66[b]	0.33[a]	120.62[a]	16.60[a]	2.30[a]	0.04[a]
Matric suction, kPa							
30	49.26[a]	3.33[a]	0.34[a]	113.43[a]	16.80[a]	2.37[a]	0.03[a]
400	35.86[a]	1.68[b]	0.31[a]	98.00[a]	13.10[b]	1.83[a]	0.07[b]
ANOVA							
Water potential (W)	0.0002	0.0022	ns	ns	ns	ns	0.001
Scalping (S)	ns	ns	ns	ns	ns	ns	ns
Manure (M)	ns	ns	ns	ns	ns	ns	ns
W × M	0.0274	0.0379	ns	0.0362	0.0362	0.0079	ns

[#] Means followed by different superscript letters indicate significant difference, $P \leq 0.05$, ns: not significant

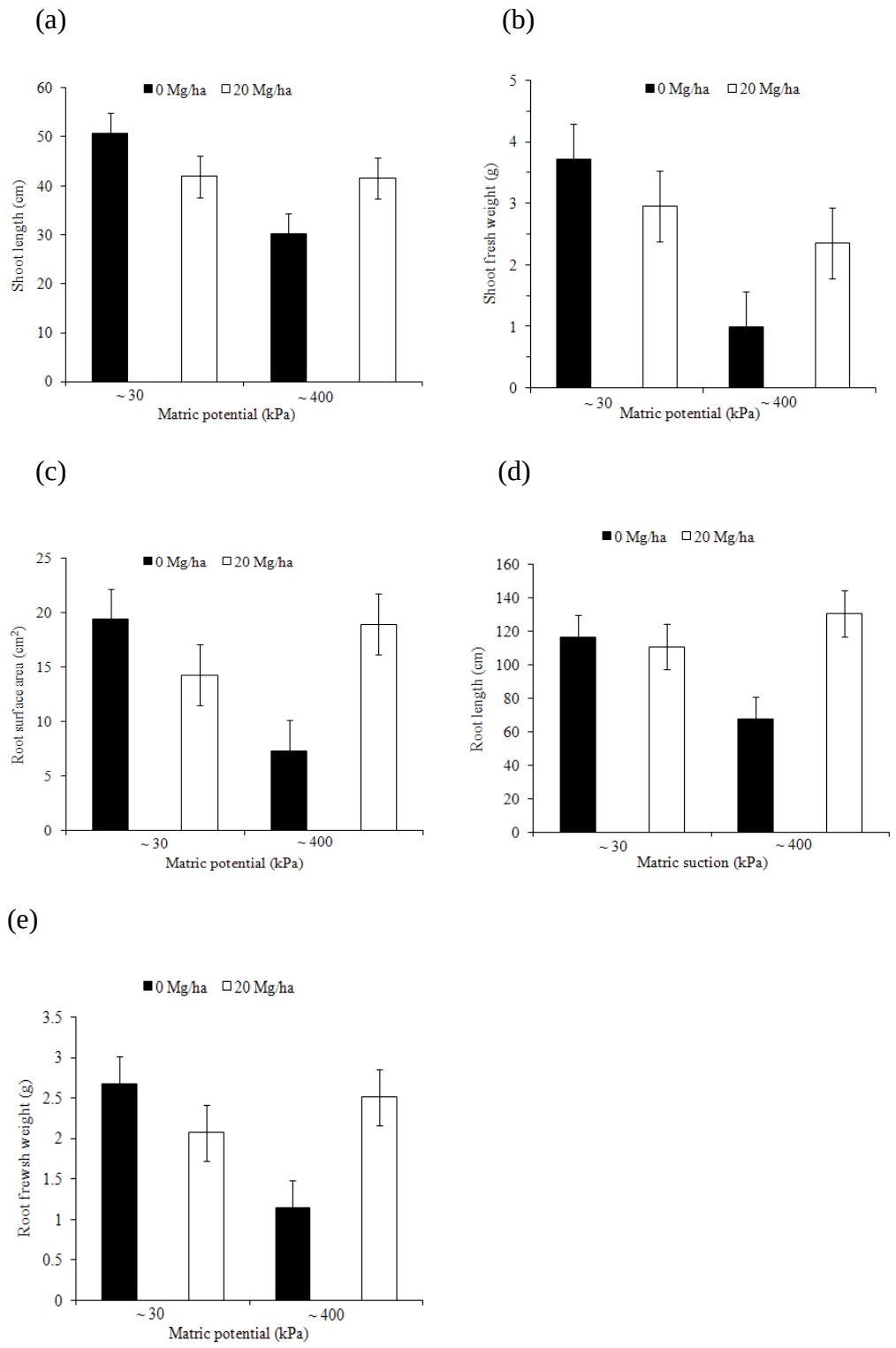

Fig. 4.2 Interaction effects of cattle manure and matric suction on (a) shoot length, (b) shoot fresh weight, (c) root surface area, (d) root length and (e) root fresh weight. Vertical bars are standard errors of means.

4.1.4 Relationship between maize root, shoot growth parameters and soil penetration resistance

All measured plant parameters showed negative linear relationships with soil penetration resistance (Table 4.3). The highest correlation coefficient (-0.50) was observed between shoot length and soil penetration resistance whilst the least (-0.22) was between root length and penetration resistance.

Table 4.3 Correlation coefficients estimated between soil penetration resistance and maize yield components

	Shoot length	Shoot fresh weight	Shoot dry weight	Root surface area	Root length	Root fresh weight	Penetration resistance
	cm	g		cm^2	cm	g	kg/cm^2
Shoot length	1.0000	0.9054	0.4355	0.6988	0.5757	0.7236	-0.5012
Shoot fresh weight		1.0000	0.5338	0.7430	0.5070	0.7361	-0.4919
Shoot dry weight			1.0000	0.3545	0.2137	0.3137	-0.0341
Root surface area				1.0000	0.7292	0.8718	-0.3236
Root length					1.0000	0.7332	-0.2243
Root fresh weight						1.0000	-0.3716
Penetration resistance							1.0000

4.2 Field experiment

4.2.1Mean weight diameter as affected by scalping and cattle manure application

Scalping had no significant effect on the MWD values for all three mechanisms of breakdown (Table 4.4). Cattle manure increased the MWD by 18% and 33% when the soil was fast wetted and slowly wetted respectively. However, addition of cattle manure reduced the MWD by 16% under mechanical shaking. There were no significant interaction effects between soil scalping and cattle manure application.

Table 4.4 Effects of soil scalping and cattle manure on mean weight diameter under field conditions #

Treatment	Fast wetting	Slow wetting	Shaking
Scalping, cm			
0	0.32[a]	0.40[a]	0.44[a]
10	0.24[a]	0.43[a]	0.43[a]
20	0.34[a]	0.53[a]	0.42[a]
Cattle manure, Mg/ha			
0	0.28[a]	0.39[a]	0.49[a]
20	0.33[b]	0.52[b]	0.41[b]
Analysis of variance			
Scalping	ns	ns	ns
Cattle manure	0.0120	0.0499	0.0281

#values followed by different superscript letters within a column in a treatment indicate a significant difference, $P \leq 0.05$; ns, not significant.

4.2.2 Effect of soil wetness on soil penetration resistance in scalped hardsetting soil amended with cattle manure

Both scalping and cattle manure did not have any significant effect on the soil's penetration resistance. However, penetration resistance in this hardsetting soil decreased linearly with increase in matric suction for both cattle manure amended soils and the control ($R^2 = 0.92$) (Fig 4.3). The soil at 0 Mg/ha had higher penetration resistance than the 20 Mg/ha at lower soil wetness. Penetration resistance decreased with an increase in soil wetness until 23 cm^3/cm^3 where the effect of manure was overridden by soil wetness.

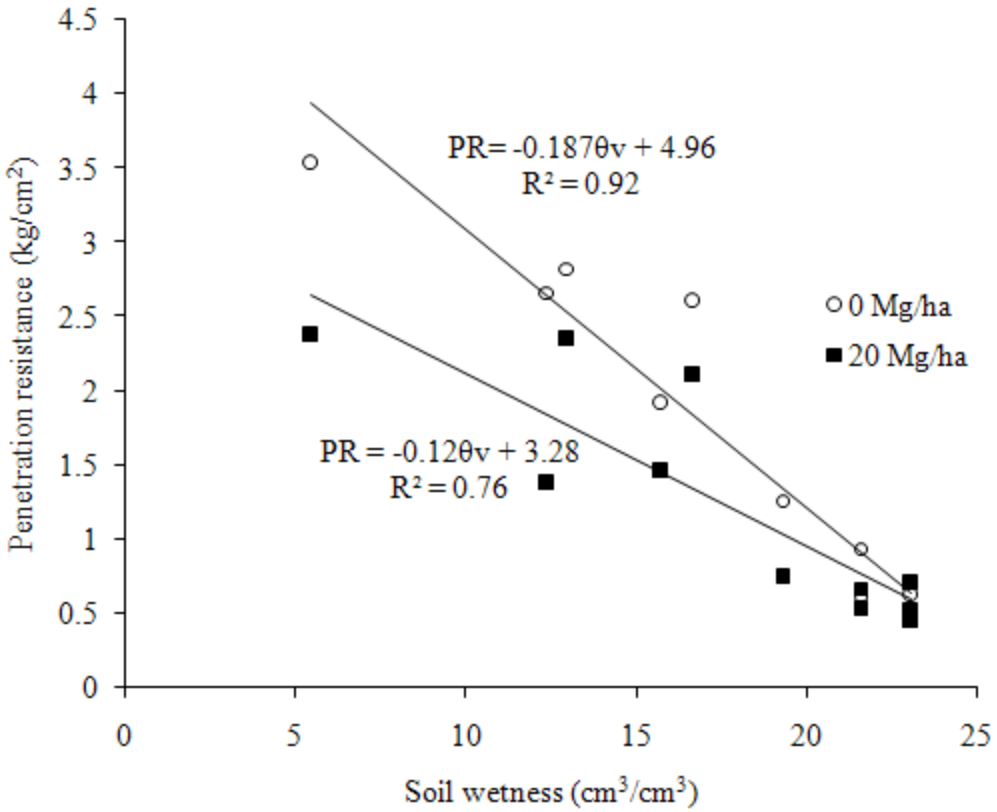

Fig. 4.3 Effect of soil wetness on the soil penetration resistance in a hardsetting soil amended with cattle manure under filed conditions. PR = penetration resistance; θ_v = volumetric soil wetness; R^2 = correlation coefficient

4.2.3 Effect of soil scalping and cattle manure on early maize root and shoot growth

There were no interaction effects of cattle manure and scalping depth on all measured parameters (Table 4.5). Soil scalping had no significant effects on all parameters. Application of 20 Mg/ha cattle manure had no significant effects on plant height, days to emergence and days to flowering. However, cattle manure application increased root length density (RLD) and shoot dry matter by 26% and 30% respectively.

Table 4.5 Effects of soil scalping and cattle manure on early maize root and shoot growth parameters..

Treatment	Days to emergence	Days to flowering	Plant height	Root Length Density	Shoot Dry Matter
	days		M	cm/cm^3	g
Scalped surface, cm					
0	8.30^a	63.17^a	2.53^a	1.18^a	138.52^a
10	9.50^a	63.17^a	2.61^a	1.47^a	132.59^b
20	9.00^a	62.67^a	2.60^a	1.67^a	156.71^a
Cattle manure, Mg/ha					
0	8.77^a	62.67^a	2.60^a	1.26^a	124.17^a
20	9.11^a	63.33^a	2.56^a	1.60^b	161.04^b
Analysis of variance					
Scalping	ns	ns	ns	ns	ns
Manure	ns	ns	ns	0.0446	0.0157

[#] Means followed by different superscript letters indicate a significant difference, $P \leq 0.05$, ns: not significant

4.2.4 The relationship between root length density and soil penetration resistance

There was a negative linear relationship between RLD and PR values for the cattle manure treatment (R^2 = 0.63) and for the control (R^2 = 0.89) (Fig 4.4). Root length density values in cattle manure amended plots were generally higher than in the control plots.

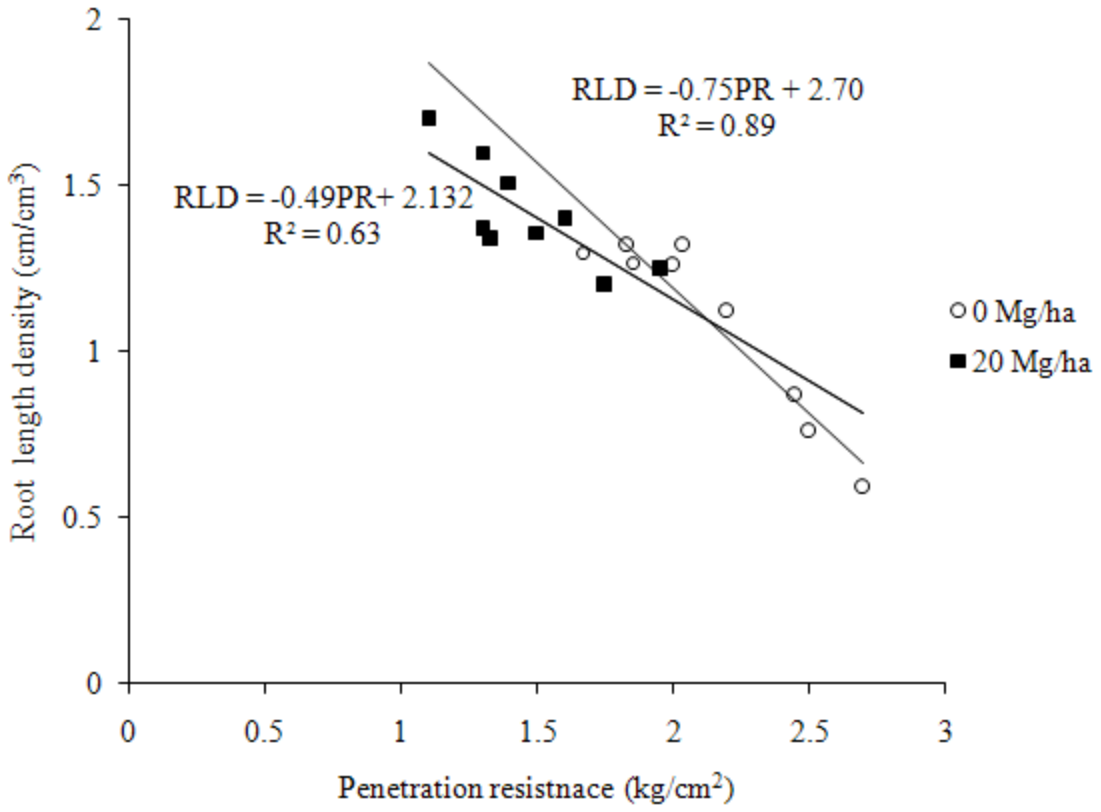

Fig 4.4 Response of early maize root length density to increasing soil penetration resistance in a hardsetting soil with and without cattle manure; RLD = root length density, PR = penetration resistance; R^2 = correlation coefficient.

4.2.5 The relationship between shoot dry matter and soil penetration resistance

Shoot dry matter decreased linearly, with increasing PR for both the amended and non-amended soils (R^2 = 0.30) and the control (R^2 = 0.20) as shown in Fig. 4.5.

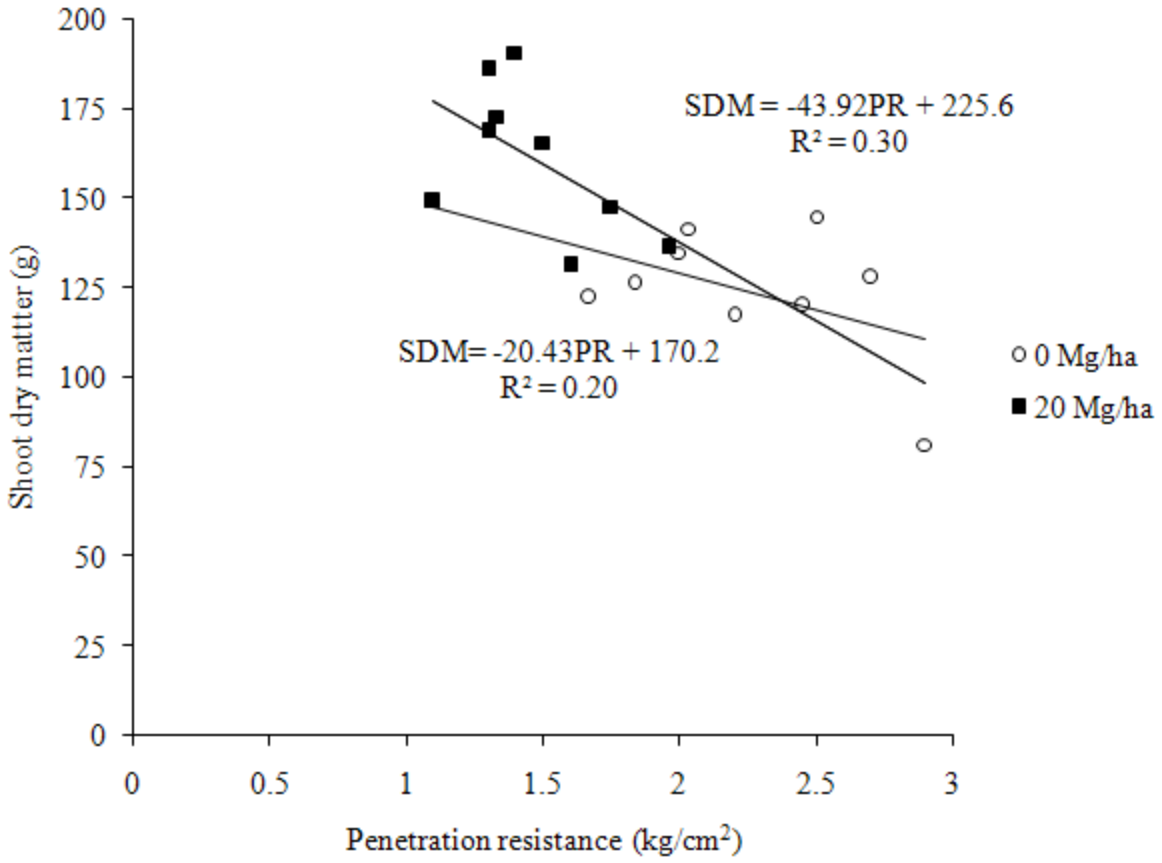

Fig. 4.5 Response of early maize shoot dry matter to increasing soil penetration resistance in a hardsetting soil amended with cattle manure and a non-amended hardsetting soil. SDM = shoot dry matter; PR = penetration resistance; R^2 = correlation coefficient.

4.2.6 Relationship between root length density and maize dry matter yield

Root length density had a positive linear relationship with shoot dry matter for the cattle manure amended treatment (R^2 = 0.68) and the control (R^2 = 0.55) (Fig 4.6).

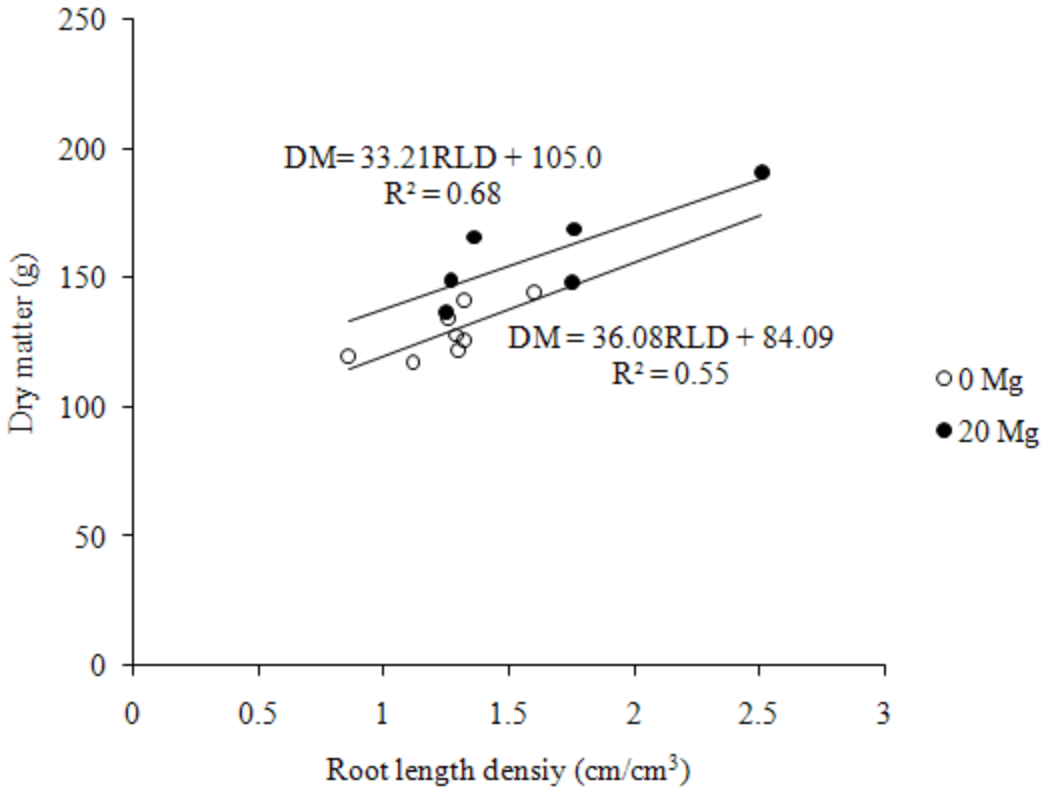

Fig. 4.6 Relationship between root length density (RLD) and shoot dry matter (DM). R^2 = Correlation coefficient.

CHAPTER FIVE

5.0 DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 DISCUSSION

5.1.1 Glasshouse experiment

Mean weight diameter of hardsetting soil as affected by cattle manure application

The MWD is related to aggregate stability (Nimmo and Perkins, 2002), and higher MWD values correspond to higher aggregate stability (Le Bissonais, 1996). In this experiment, application of 20 Mg/ha cattle manure increased MWD by between 48% and 71%. Therefore amendment of the hardsetting soils with 20 Mg/ha cattle manure increased aggregate stability by stabilizing the soil aggregates against disruptive forces. Similar results were observed by Materechera (2009), the author observed increased MWD after applying 5 Mg/ha cattle manure on a hardsetting soil. However, in addition to cattle manure, Materechera (2009) also used several soil amending materials: mulch, gypsum and polymer gel and found similar results. Interparticle hydrophobicity and cohesion are known to be the main reasons responsible for aggregates stabilization (Abiven *et al.*, 2009). These processes are mainly determined by SOM and texture. Besides the SOM input through the cattle manure, the soils contained ~ 50% silt plus clay fraction (Table 3.1) which could have enhanced interparticle cohesion within the aggregates (Chan, 1995).

Mean weight diameter of hardsetting soil as affected by matric suction

Soil structural stability varies with soil water content and suction at the time of sampling (Nimmo and Perkins, 2002) due to increased swelling forces like slaking. In this study, the effect of soil wetness and matric suction on MWD depended on the aggregate breakdown treatment (Le Bissonnais 1996). Lower matric suction increased aggregate stability under slow wetting but decreased MWD under shaking (Table 4.1). Slow wetting, which corresponds to field conditions of wetting under gentle rain, could have reduced swelling forces and slaking and hence increased aggregate stability. The main mechanism of breakdown under slow wetting is dispersion (Le Bissonnais, 1996). Dispersion is affected by the electrolyte concentration of the soil solution. However, it appears that there was no dispersion in the soils because the electrical conductivity and Na in the soil were low (Table 3.1). Aggregate stability under shaking was lower when the soils had been maintained at low matric suction compared with high matric suction. This result was attributed to increased slaking as a result of relatively high ~ 50% silt plus clay content (Table 3.1).

Soil penetration resistance

Cattle manure prevented aggregates from slaking upon wetting (Table 4.1), thereby ameliorating the hardsetting tendency on drying. Consequently, application of cattle manure would be expected to reduce soil penetration resistance but this was not the case in the present study. However, Sui *et al.* (2009) have shown that the effectiveness of cattle manure as a soil ameliorant depends on many other factors especially the nature of soil and the extent of degradation. In this experiment, rapid increase in soil penetration resistance occurred at a matric

suction below 200 kPa reaching a soil penetration resistance of ~2.5 kg/cm^2. Beyond 200 kPa the rate of increase in penetration resistance significantly decreased (Fig. 4.1). Earlier studies have shown that hardsetting soils are characterized by a marked increase in soil strength within narrow water content changes upon drying (Chan, 1995; Ley *et al.*, 1995). Strength development in such soils is caused by an increase in effective stress which results from the increase in matric suction as the soil dries. 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 two-stage increase in penetration resistance was attributed to the silt plus clay content which was ~ 50% (Table 3.1), the main material responsible for hardsetting. These results compared well with those of Ley *et al*. (1995), who worked with soils containing ~ 41% silt plus clay. However, Chan (1995) worked with soils containing 28% silt plus clay and showed that strength development extended over a much wider range of matric suction.

Early maize growth as affected by cattle manure and matric suction

Cattle manure and matric suction interactions significantly influenced shoot length, shoot fresh weight, root surface area, root length and root fresh weight. Values for the growth parameters were higher in the soils amended with cattle manure and subjected to high matric suction (~ 400 kPa) compared to low matric suction (~ 30 kPa). The results from this study suggest that the effectiveness of cattle manure as a soil ameliorant in hardsetting soils depends on the matric suction of the soil and is most effective at higher matric suction. Therefore, application of cattle

manure delayed the deleterious effects of hardsetting phenomenon on crop growth as the soil dried up as reported earlier by Rey *et al.* (2004). However the results of this study showed a negative linear correlation between all measured maize growth parameters and penetration resistance. A reduction in root length due to mechanical impedance has been reported in earlier studies (Cook *et al.,* 1996; Young *et al.,* 1997). However, in this present studya higher correlation coefficient between penetration resistance and shoot length than between penetration resistance and root length was observed. This indicated that penetration resistance exerted more influence on shoot length than root length. Some authors have attributed the reduction in shoot growth in hardsetting soils to reduced water and nutrient uptake due to poor root growth and distribution (Mullins, 2000). In this study maize plants subjected to ~ 400 kPa did not show signs of wilting although their height was reduced thus indicating that other factors besides water also contributed to the observed height reduction. This could suggest that an increase in mechanical impedance in hardsetting soils directly limits shoot growth. Some authors have shown the existence of shoot-inhibiting signals generated by roots growing in a medium of large mechanical impedance (Masle and Passioura, 1987; Young *et al.,* 1997). It has been established that high mechanical impedance releases hormones to the shoots which inhibit leaf expansion and induces stomatal closure before a change in the water and nutrient status of the leaves is observed (Bingham, 2001).

5.1.2 Field experiment

Mean weight diameter as affected by cattle manure application

The increase in MWD after amending the soils with cattle manure when the soil was fast and slow-wetted indicated a reduction in slaking and dispersion respectively. Fast wetting resembles high rainfall intensity whilst slow wetting resembles gentle rain (Le Bissonais, 1996). These results thus highlight the benefits of cattle manure in maintaining aggregate stability in hardsetting soils under rapid or gentle water intake from rain or irrigation. Conversely, SOM acts as a deflocculant and reduce aggregate stability when the soil is subjected to conditions like shaking that break organic bonds (Mullins *et al.,* 1990). Shaking the soil that was amended with cattle manure reduced its aggregate stability (Table 4.4). Shaking forces the fine organic and inorganic soil particles apart and therefore SOM acted as dispersing rather than as flocculating agent (Abiven *et al.,* 2009).

Early maize growth as affected by cattle manure application

Root length density (RLD) is an important indicator of root growth and is directly related to both amount and rate of water and nutrient uptake (Zhuang *et al.,* 2001). Hardsetting soils are characterized by rapid increases in soil penetration resistance to beyond 2 MPa as the soil dries and this is sufficient to halt root growth (Mullins, 2000). In this study, root length density decreased linearly with an increase in soil penetration resistance (Fig 4.4). Soil organic matter plays an important role in improving crop growth and yield under such circumstances by supplying nutrients and modifying soil physical properties (Miller *et al.,* 2009). Therefore, application of cattle manure is expected to reduce soil penetration resistance and increase root

growth and hence increase RLD. Application of cattle manure increased RLD by 26% most likely through the improvement of soil physical properties. For example, there was a reduction in soil penetration resistance with application of 20 Mg/ha cattle manure (Fig 4.3). Similar results were reported by Mossadhegi *et al.* (2009), who reported significant increases in maize RLD after applying 60 Mg/ha of cattle manure on a top-crusted soil. Therefore, these results confirm the benefits of increased SOM inputs in hardsetting soils. Nonetheless, this study showed a high negative linear relationship between soil penetration resistance and RLD. An increase in soil penetration resistance has been shown to prevent root elongation due to lack of oxygen and reduced pore size (Bengough *et al.*, 2006). Mossaddeghi *et al.* (2009) also reported a significant negative linear relation between RLD and penetration resistance. Similar to the glasshouse study, increases in penetration resistance had negative influences on shoot growth. This indicated that an increase in mechanical impedance due to hardsetting directly limits shoot growth. In contrast to the glasshouse, the correlation coefficient between penetration resistance and shoot dry matter was lower than between RLD and penetration resistance. Under field conditions, root growth can be slowed by a combination of soil stresses which may vary depending on the location of the root in the soil profile, prevailing soil water conditions and the degree of compaction (Bengough *et al.*, 2006). In addition, under field conditions, a greater diversity of soil organisms interact with roots influencing root morphology, nutrient uptake and loss of organic matter (Bingham, 2001). Decreases in RLD result in reduced water and nutrient uptake and this leads to a reduction in shoot growth (Bingham, 2001). This study showed high positive correlation coefficients between RLD and shoot dry matter for both cattle manure amended soils and the control. It should be noted that higher values were observed for the cattle amended soils thus indicating the importance of increasing SOM in improving soil productivity.

5.2 CONCLUSIONS

1. Cattle manure improved the stability of aggregates of the hardsetting soil under rapid or slow water intake conditions experienced during rainfall or irrigation. Conversely, under field conditions stability of aggregates to mechanical stress commonly associated with conventional tillage decreased.

2. Application of cattle manure under field conditions increased RLD and shoot dry matter, but these parameters were negatively correlated with soil penetration resistance. Under glasshouse conditions, the effectiveness of cattle manure in improving maize growth in the hardsetting soils was determined by the matric suction. Cattle manure improved maize growth at the higher matric suction.

3. The effect of cattle manure on soil penetration resistance was overridden by soil moisture under both glasshouse and field conditions. However, under glasshouse conditions, soil penetration resistance increased with an increase in matric suction in two stages; initial rapid rate of increase and a second slow rate of increase. The critical matric suction value dividing the two stages was ~ 200 kPa.

4. Aggregate stability, penetration resistance and early maize growth in the studied soils were not affected by the thickness of the hardsetting layer.

5.3 RECOMMENDATIONS FOR FURTHER STUDIES

1. It is necessary to establish the optimum cattle manure quantity and quality that produces the optimum improvement on both maize growth and soil physical properties in such hardsetting soils.

2 There is need to study the effect of matric suction on soil penetration resistance in hardsetting soils of various texture especially silt plus clay with respect to clay and silt content.

3 There is also need to determine the effects of cattle manure on aggregate stability under different tillage systems.

4 The effect of cattle manure on early maize growth was affected by soil matric suction under glasshouse conditions. Therefore, there is a need to determine the effectiveness of cattle manure in improving early maize growth under both dryland and irrigated conditions.

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