The impact of different land use types on selected soil quality parameters in northern KwaZulu-Natal

Vusi Erick Mbanjwa

Submitted in fulfilment of the academic requirements for the degree of Master of Science in Agriculture

Discipline of Soil Science

School of Agricultural, Earth and Environmental Sciences

College of Agriculture, Engineering and Science

University of KwaZulu-Natal

Pietermaritzburg

November 2015

DECLARATION

I hereby certify that the research reported in this dissertation is the result of my own investigation, except where otherwise indicated, and that it has not been submitted for a higher degree at any other university or institution.

Signed: __________ Date: 25/2/2016

Candidate: Vusumuzi Erick Mbanjwa

As the candidate's supervisor I have/~~have not~~ approved this dissertation for submission

Signed: JCHughes Date: 25/2/16.

Name: Prof Jeffrey C. Hughes

As the candidate's co-supervisor I have/~~have not~~ approved this dissertation for submission

Signed: __________ Date: 25/02/2016

Name: Prof Pardon Muchaonyerwa

DECLARATION: PLAGIARISM

I, Vusumuzi Erick Mbanjwa, declare that:

1. The research reported in this dissertation, except where otherwise indicated is my original research.

2. This dissertation has not been submitted for any degree or examination at any other university.

3. This dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.

4. This dissertation does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

    (a) Their words have been re-written but the general information attributed to them has been referenced.
    (b) Where their exact words have been used, then their writing has been placed in italics and inside quotation marks, and referenced.
    (c) This dissertation does not contain text, graphics or tables copied and pasted from the internet, unless specifically acknowledged, and the source being detailed in the dissertation and in the references section.

Signed: ______________________ Date: 2016 - 02 - 25.

Candidate: Vusumuzi Erick Mbanjwa

ACKNOWLEDGEMENTS

I would like to express my most sincere thanks and appreciation to:

- God Almighty for giving me strength and courage throughout the study;
- Prof. Jeffrey C. Hughes for his advice, patience, encouragement and guidance throughout this study. I'm so grateful that our paths crossed and could not ask for more than that in life.
- My co-supervisor, Prof. Pardon Muchaonyerwa for his constructive suggestions, guidance, time and patience throughout this study.
- OSCA management for funding this study especially Mrs Q.G Mhlongo who did the approval in the beginning.
- OSCA second year students (2012 class) who helped me with sample collection.
- Dr P. Dlamini who helped in organising the data on excel and gave me general support, constructive suggestions and friendship.
- Ms Cathy Stevens from Cedara who helped with the statistical analysis.
- Soil Science technical staff, Mr Rajiv Singh, Mr Jothan Buthelezi, and Ms Tezi Nala.
- Mr Sandile Mthimkhulu and Mr Siphamandla Madikizela who helped with the aggregate stability analysis in the laboratory.
- Ms Ziyanda Makatini for being my source of strength throughout this study.
- My family, for their encouragement and support, in particular my mother, Mrs N.E Mbanjwa, who has been a source of courage throughout my academic progress and life's struggles in general.

ABSTRACT

Soil is a natural resource that must be sustainably managed for the future of humankind. Maintaining soil resources in the long term is of primary necessity since sustainable agriculture is a global issue that has received special attention by the scientific community, policymakers and the agricultural community over the past few years. Agriculture should involve the successful management of the soil resource to satisfy changing human needs while maintaining or enhancing its quality. Therefore, land use change that might impact on soil quality parameters continues to be a focus for researchers. Land use changes such as conversion of native grasslands to cultivated mixed croplands or pasture are known to result in changes to soil physical, chemical and biological properties. However, the direction and magnitude of these changes vary with soil type, land cover and management. The objective of this study was to investigate the effects of land use change from undisturbed grassland to pasture and crop farming on selected properties of four contrasting soils.

The study was conducted at Owen Sitole College of Agriculture (OSCA), which is located at Kwesaka-Mthethwa, KwaZulu-Natal Province, South Africa, about 12.5 km north of Empangeni and 163 km north of Durban. Nine different soil forms are found on the College land of which Inhoek and Mayo are the most common. Shortlands and Westleigh each cover approximately 6% of the area and Oakleaf is common on the low-lying areas along the Cwaka and Enseleni Rivers. The land uses studied were undisturbed native grassland, irrigated pasture, and cropland on Shortlands, Westleigh, Inhoek and Oakleaf soil forms. Due to the absence of any areas of undisturbed Oakleaf in the study site, only pasture and arable land use systems were compared on this soil form. The impact of these different land use types were evaluated through their effects on some soil chemical and physical characteristics.

Samples were collected from each of the soil forms under each of the available land use types by digging mini-pits (90 cm wide, 120 cm long and 30 cm deep). Four bulk samples were systematically collected from each soil form at depths of 0-1, 1-5, 5-10, 10-20 and 20-30 cm using a spade. For soil aggregate stability determinations, samples were air dried and sieved to collect sufficient aggregates between 2.8 and 5 mm. The aggregate size distribution under the different land use management systems was assessed by three different treatments namely WT: water treatment, ET: ethanol treatment and SCWET: slow capillary wetting ethanol

treatment. The rest of the bulk samples were crushed with a pestle and mortar and passed through a 2 mm sieve for the analysis of soil organic carbon (SOC), particulate organic matter (POM), pH (H_2O and KCl). Samples for effective cation exchange capacity (ECEC), available phosphorus (P), base cations and particle size distribution were bulked to three depths of 0-10, 10-20 and 20-30 cm prior to analysis.

The results revealed that some soil properties significantly ($p < 0.05$) changed following the conversion of undisturbed grassland to pasture and arable land use systems. Soil pH (H_2O and KCl) was significantly affected by land use in the Shortlands soil. The interaction between land use and soil depth was only significant in the Inhoek soil form. The mean pH (H_2O) values were 6.31 for the soils under the arable land use and 6.50 under pasture and undisturbed systems. In KCl the mean pH values were 5.10 for arable and 5.43 for both pasture and undisturbed soils. The concentration of SOC significantly followed the order: pasture > undisturbed > arable with mean values across all depths and for all soils. Significant interactions between land use and soil type were observed for POM in the Westleigh and Inhoek soil forms. Inhoek soils under pasture had significantly higher POM than the other land uses in the 0-1, 1-5 and 5-10 cm depths, while only 0-1 and 1-5 cm depths had higher POM in the Westleigh soil under pasture. The Oakleaf form under pasture had significantly higher POM than the arable soil at all depths. Mean POM values were in the order of pasture (0.608%) > undisturbed (0.223%) > arable (0.118%).

Pasture soils had lower available P in the 0-10 and 10-20 cm depths than the other land uses in the Shortlands, while in the Westleigh pasture and undisturbed land uses were similar and higher than the arable soil. In the Oakleaf, the arable soil had higher P (18.6 mg kg^{-1}) than pasture (7.0 mg kg^{-1}) in the 0-10 cm depth, while both land uses were similar at the other depths. There were no significant effects of land use on ECEC in the Shortlands, Westleigh and Inhoek. The overall ECEC mean values ($cmol_c$ kg^{-1}) for the Shortlands, Westleigh and Inhoek soils were in the order of arable (24.12) > pasture (19.29) > undisturbed (16.11). However, in the Oakleaf, mean ECEC values ($cmol_c$ kg^{-1}) were in the order of pasture (14.9) > arable (7.40). Arable soils had higher amounts of Ca in the 20-30 cm depth of both Shortlands and Westleigh soils and in the 0-20 cm depth of the Inhoek soil form. The overall mean values of exchangeable Ca were 23.6 $cmol_c$ kg^{-1} (arable), 19.0 $cmol_c$ kg^{-1} (pasture) and 18.9 $cmol_c$ kg^{-1} (undisturbed grassland). The overall mean values for exchangeable Mg were 10.0 $cmol_c$ kg^{-1} (arable), 9.29 $cmol_c$ kg^{-1} (undisturbed grassland) and 8.21 $cmol_c$ kg^{-1}

(pasture). In the Oakleaf, the mean values (cmol$_c$ kg^{-1}) of Ca were 19.1 (arable) and 9.58 (pasture) while those for Mg were 2.76 (arable) and 5.89 (pasture). The mean K values (cmol$_c$ kg^{-1}) were 3.33 under arable, 2.55 for pasture and 1.95 for the undisturbed land use system. The soils under undisturbed and pasture land uses showed significantly higher mean weight diameter (MWD) values than under the arable land use system in all the treatments. The mean values of MWD for the undisturbed, pasture and arable land use systems were 2.99 mm, and 2.95 mm and 1.92 mm, respectively.

The 38 years of continuous cultivation of undisturbed grassland has led to changes of the measured physical and chemical properties of the soils at OSCA. The pasture soils showed similar trends in the measured parameters to those of the undisturbed soils and values were higher than those found in the arable soils. The soil characteristics negatively affected by cultivation practises were SOC, POM, pH and aggregate stability. These results showed the need to improve agricultural practices at OSCA to limit degradation of some vital soil properties. This can be achieved by long term monitoring of soils at the College so as to measure changes in soil attributes and link them to a land management plan.

TABLE OF CONTENTS

LIST FIGURES

LIST OF TABLES

LIST OF APPENDICES

CHAPTER ONE
INTRODUCTION

Most areas of previously undisturbed land in South Africa have been degraded by loss of soil fertility due to land mismanagement (du Preez *et al.*, 2011). High population densities and favourable agro-climatic conditions have led to a large variety of land use types of which mixed-crop fields, improved pasture and perennial plantations are most widespread. Change in land use, such as from undisturbed grassland to arable agriculture or improved pasture can have significant and long lasting effects on soil quality and productivity. These effects are largely a result of changes in both plant and microbial diversity associated with management practices across land use types (Haynes and Beare, 1994). Some research findings have suggested that soil type, rather than management practice, is the key determinant of the extent to which soil quality is affected (Dominy and Haynes, 2002).

There is a considerable amount of literature on the changes to soil quality following deforestation and cultivation (e.g. du Preez and Claassens, 1999; Whitbread *et al.*, 2003; Aghasi *et al.*, 2010). However, relatively little is known, especially in South Africa, of the effects of conversion of natural areas (undisturbed) to other land use types such as forestry, pasture and mixed cropping. Soil organic carbon (SOC) has been the most widely used soil quality parameter for monitoring effects of land use change and cover patterns as it plays a crucial role in the biogeochemical cycles of key nutrients (Cambardella and Elliot, 1992; du Preez and Claassens, 1999; Whitbread *et al.*, 2003). These observed changes in SOC could have effects on soil physical, chemical and biological quality, which are all related to soil organic matter (SOM).

Organic matter is well known for reducing soil erosion and improving soil porosity, faunal activity, water infiltration and soil fertility (Alvarez and Alvarez, 2000). The SOM has strong interactions with land use, farming system and soil/crop management systems (Schlesinger and Pilmanis, 1998). Native grasslands and forest have the potential to build-up large amounts of organic matter whereas conversion of natural ecosystems to croplands can result in high rates of turnover leading to declining levels of organic matter and hence a decrease in soil fertility (Six *et al.*, 2000b ; Lutzow *et al.*, 2002; Aucamp, 2008).

Soil fertility is an important indicator of soil quality and is defined as the ability of the soil to supply the nutrients essential for plant growth (Elliot, 1986). Thus phosphorus, cation exchange capacity, individual cations such as calcium, magnesium, potassium and sodium are often quantified to evaluate changes in soil fertility. Soil organic carbon and pH are other important indicators of fertility since changes in carbon concentration and pH values will affect aggregate stability, nutrient supply, buffer capacity and nutrient availability.

In northern KwaZulu-Natal, the extent of natural grassland conversion to low-input arable agricultural systems has been considerable. These changes are driven by a complex interaction of a multitude of factors and have resulted in changes of land use and soil management practices that affect some vital soil properties such as pH, available P and organic matter. A study conducted by van Antwerpen and Meyer (1996) of 16 soil types in KwaZulu-Natal showed a significant decline of organic matter following conversion of virgin grassland to pasture and sugarcane plantation. While this study documented important information regarding the effects of land use change on SOM, much remains to be established about land use change effects on other soil properties such as particle size distribution, pH, available P, effective cation exchange capacity, base cations and aggregate stability.

The primary objective of the present study was to investigate the effect of land use change from undisturbed land to arable agriculture and improved pasture on selected soil properties in northern KwaZulu-Natal. In order to achieve this objective the following key questions were formulated:

1. **How does a given change in land use or management affect soil quality?**
2. **How are the land use effects affected by soil type?**

The thesis is structured as follows:

Current knowledge of land use induced changes on soil properties is reviewed in Chapter Two. The methodology is presented in Chapter Three. Chapter Four outlines the results. Chapter Five contains a discussion of the comparative study of undisturbed, pasture and arable land use types on some properties of the four soil forms. Chapter Six contains conclusions and recommendations for future studies.

CHAPTER TWO
IMPACT OF LAND USE ON SOME SOIL QUALITY INDICATORS
A LITERATURE REVIEW

2.1 Introduction

Soil is a vital natural resource which performs key environmental, economic and social functions. It is essentially a non-renewable resource and thus constant monitoring of its quality is of great importance. Soil quality has been defined by Doran and Jones (1996) as "the capacity of the soil to function within ecosystem and land use boundaries, to sustain biological productivity, maintain environmental quality and promote plant, animal and human health". High quality soils not only produce better food and fibre, but also help establish natural ecosystems and enhance air and water quality (Griffiths *et al.,* 2010). The physical quality of soils relates to the status of those physical properties that influence biomass productivity and environment (Franzluebbers *et al*., 1994). Soil fertility quality varies from within field to larger scale and is controlled by both land use and soil management practices (Haynes and Williams, 1993). Assessment of the quality of a particular soil therefore involves evaluating numerous properties including texture, bulk density, aggregation, microbial biomass carbon, available phosphorus, organic matter, exchangeable bases, pH and electrical conductivity. The key properties that determine soil quality differ between soils and across ecological regions (Doran and Parkin, 1994).

Land use practices and changes in soil management affect the distribution and supply of soil nutrients by directly altering soil properties and by influencing biological transformations in the rooting zone (Majaliwa *et al*., 2010). Destruction of vegetative cover can promote soil erosion that eventually increases the degree of soil-related constraints to crop production (Haynes and Francis, 1990). However, increasing population and lack of new land worldwide for cultivation have forced people to transform former virgin grasslands to both cultivated pastures and cropped lands (Hartemink, 1998). Establishing the effects of land use and land cover changes on soil properties has implications for devising land management strategies for sustainable use (Bekwet and Stroosnijder, 2003). Hence, "understanding the basic processes of soil degradation in relation to land use and crop management must be allocated a high research priority" (du Preez *et al*., 2011).

This review is aimed at understanding how land use practices have led to changes in both physical and chemical properties of soils. Although the focus is on South African research, this review refers to work done in other parts of the world in order to put the local research into a wider perspective.

2.2 Common land use management practices

Zhang (1998) defines land use as the way in which humans use and modify the land. In a similar vein, FAO (1995) defines land use as the number of operations performed on land, caused by humans to generate benefits from natural resources. In South Africa, common land uses include grasslands, improved pastures and arable agriculture.

2.2.1 Natural grassland

Natural grassland is defined as "land covered with grassland and that may have between 10 and 40% tree or shrub cover" (FAO, 1995). In contrast, Aucamp (2008) allowed the tree percentage cover to range anywhere between 15 and 50% as long as the ground has a more or less continuous grass cover. In general, spatial adjacency of grasslands and shrublands is very common in nature and, in many settings, grasslands tend to have scattered shrubs from dwarf to mid-size (Zhang, 1998). These grasslands are not sown or planted and the component species have evolved from competition with other species in harmony with the prevailing soil and climate conditions. In the climax stage, the floral composition has been relatively undisturbed by human agency or interference apart from probably, control of grazing animals, generally by herding, and more or less frequent annual burning (Van der Linden, 2004). The species patterns vary from open grassland with patches of scrub forest to bushed grassland and bushland thicket depending on the environmental conditions. Dominant grass species in South Africa may include: *Eragrostis capensis, E racemosa, Tristachya leucothrix, Heteropogon contortus* and *Panicum maximum* while *Acacia karoo, A. nilotica* and *Dichrostachys cinerea* are common trees. The main forage resource for livestock in South Africa is natural rangeland grazing (Mills and Fey, 2003). Cultivated pastures also contribute to forage resources.

2.2.2 Cultivated pasture

Cultivated pastures are defined as improved grazing lands comprising of introduced or planted grasses or legumes for temporary or permanent grazing (Van der Linden, 2004). They may be established by improvement of native or naturalized grasslands by some form of grass disturbance, fertilization and introduction of new species through sowing or transplanting (Aucamp, 2008). Many studies have reported a substantial loss of soil organic matter, microbial activity and aggregate stability under pastures tilled annually compared with those under a permanent system (Haynes and Swift, 1990; Lal, 1994; Dominy and Haynes, 2002; Mills and Fey, 2003). In general, when native vegetation is replaced by improved, permanent, grazed pasture there is often an increase in soil organic matter content. This is due to the very large inputs of organic matter mainly as root turnover, but also as above-ground litter and animal dung, which occur under grazed pasture (Mills and Fey, 2003). In addition, pasture yield differences increase with age and tend to be greatest in the first two years after pastures are ploughed (Haynes and Beare, 1994).

2.2.3 Arable agriculture

Cultivation or tillage of any undisturbed land diminishes the soil carbon within a few years of initial conversion (Majaliwa *et al.*, 2010) and substantially lowers mineralisable phosphorus (Haynes and Beare, 1994). About 12% of South Africa's land surface can be used for crop production. High potential arable land comprises only 22% of the total arable land of which 1.3 million ha are under irrigation (FAO, 1995). Agricultural activities range from intensive mixed cropping to animal production farming in the more arid regions of the country. Mixed cropping is a major arable land use in South Africa. Traditionally, arable crops of approximately similar growing periods (3-4 months) are grown and soil organic matter is maintained at relatively constant levels.

2.3. Impact of land use change on selected soil quality indicators

Soil properties may differ depending on management practices and land use and they vary naturally according to soil formation factors such as parent material, topography, time and climate. Land use change and changes in soil management practices often occur together and have a profound influence on the soil physical (texture, aggregation and bulk density), chemical (pH,cation exchange capacity, salinity and sodicity) and biological (organic matter, microbial biomass and diversity, mesofauna) environment (Six *et al.*, 2000a).

2.3.1 Soil physical properties

2.3.1.1 Soil texture

Soil texture is considered to be amongst the most important factors that play a crucial role in the development and maintenance of soil structure. A study by Bronick and Lal (2005) indicated that clay soils tend to have more developed structure than sandy soils. They further speculated that the poor structure in the sandy soils was due to lower organic carbon content accompanied by low negativity on the edges of the sand particles as compared to clay particles. As a result sandy soils suffered greater losses of organic carbon. In similar vein, Puget and Lal (2005) reported higher organic carbon concentration in the < 2 µm particle size fraction than in the 2-20 µm fraction of an agricultural Mollisol in central Ohio.

When organic matter concentration is very low or absent in the soil, promotion of soil particle aggregation by high clay content has been reported in several studies (Haynes *et al.,* 1991; Lutzow *et al.,* 2002). In an attempt to confirm these findings, Tayel *et al.* (2010) analysed topsoils from three different Egyptian soil profiles to determine the soil aggregation percentage and particle size distribution (Table 2.1). They concluded that soils with higher clay content were more strongly aggregated than soils with lower clay content. In a similar study, Simansky (2012) observed that the role of soil organic carbon as an aggregating agent diminishes in the presence of other dominating aggregating agents, such as polyvalent metals and silicate clay.

Table 2.1: The influence of different texture classes on soil aggregation in some topsoils in Egypt (modified from Tayel *et al.*, 2010)

Profile number	Depth (cm)	Aggregation (%)	Coarse sand	Fine sand	Silt	Clay
			……………………...... **(%)**	**...........**	**...........**	**...........**
1	0-25	63.86	7.35	35.67	23.02	33.96
2	0-30	81.45	1.55	16.37	31.36	50.71
3	0-20	80.50	1.23	3.85	24.65	70.28

2.3.1.2 Aggregate stability

Soil aggregation refers to the process whereby aggregates are formed through the joining of sand, silt and clay particles (Amezketa, 1999). Soil organic matter is considered a major binding agent that stabilizes soil aggregates (Tisdall and Oades, 1982). As a consequence, soils consist of aggregates of different sizes with pores between and within the aggregates. Many studies have reported that aggregates physically protect soil organic matter, influence soil tilth, regulate water flow, determine microbial biomass and nutrient reserves and reduce run-off (Tisdall and Oades, 1982; Lal, 1994; Amezketa, 1999; Six *et al.*, 2000a; Six *et al*., 2000b; Carter *et al*, 2002; Bronick and Lal, 2005; Covaleda *et al.*, 2006).

Though several theories of soil aggregate formation exist, the aggregate hierarchy concept is the most commonly accepted (Bronick and Lal, 2005). The model is based upon the hypothesis that macroaggregates (> 250 μm) are collections of smaller microaggregates (< 250 μm) held together by temporary and transient organic binding agents (Tisdall and Oades, 1982). These consist of plant roots, fungal hyphae, microbial or plant exudates, and humic material (Lal, 1994). More recently, the heat-stable protein glomalin which is produced by arbuscular mychorrizae has also been shown to cause soil aggregation (Covaleda *et al.*, 2006). Glomalin promotes soil aggregation especially in coarse textured soils and its content in soils decreases with duration of arable use of the soils (Chevallier *et al.*, 2004).The arrangement of minerals, amorphous material, organic matter, and biota in aggregates of diameter < 20, 20-53, 53-250, and 250-2000 μm is highly dependent on aggregate size (Six *et al*., 2000b). The hierarchical model of aggregation proposes that the bonds within microaggregates are stronger than the bonds between microaggregates. This aggregate hierarchy theory has been used in several studies to explain correlations between reduction of aggregation and loss of soil organic matter (Six *et al*., 2002; Bronick and Lal, 2005; Covaleda *et al.*, 2006).

Tillage is one of many agricultural management practices that have a profound effect on soil aggregate stability (Six *et al*., 2000a; Dominy and Haynes, 2002; Bronick and Lal, 2005). Aggregate dynamics generally differ between cultivated and uncultivated (no-tillage) conditions (Pulleman and Marinissen, 2004) with soils that are subjected to frequent and intensive cultivation generally suffering decline in structure, which is reflected by a decrease in stability of aggregates (Amezketa, 1999). Soil tillage indirectly affects stability mainly through its influence on soil moisture, redistribution of organic matter, microbial activity, soil solution and population of soil fauna (Angers, 1992; Beare *et al*., 1994). During tillage, aggregates are broken down exposing organic matter to microbial attack (Six *et al*., 2000a). Consequently organic matter is lost resulting in weakly bonded aggregates, which are subject to degradation (Six *et al*., 2000b). The effects of cultivation on aggregate stability have been extensively researched (e.g. Ashman *et al*., 2003; Bongiovanni and Lobartini 2006; Spohn and Giani, 2010). The study conducted by Spohn and Giani (2010) showed that the mean weight diameter (MWD) of the water stable aggregates was reduced during the first 46 years after the conversion from pasture to cropland. They concluded that the decrease in MWD was caused by a breakdown of macroaggregates (>200 µm), which resulted in an increase in the proportion of microaggregates (63-200 µm) as a result of cultivation. Similarly, Bongiovanni and Lobartini (2006) reported that the content of macroaggregates was 1.7 times lower after nearly 50 years of cropland use than at a natural forest site in Artland, Germany (Figure 2.1).

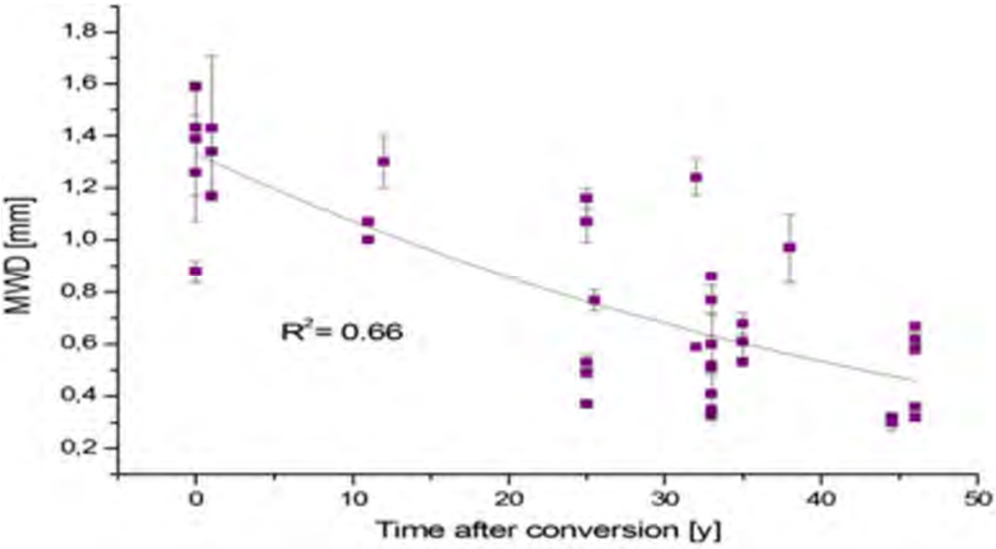

Figure 2.1: Relationship between the mean weight diameter (MWD) of the water-stable aggregates and the time after conversion of soils from pasture to cropland from 0 to 46 years in Artland, Germany (Bongiovanni and Lobartini, 2006).

In contrast, the lack of tillage in native grasslands reduces soil mixing and soil disturbance which allows soil organic matter to accumulate. This land use is also characterised by promotion of fungal growths which contribute to the formation and stabilisation of macroaggregates (Tisdall and Oades, 1982). A study conducted by Six *et al.* (2000b) indicated a significant increase in the mass of macroaggregates and a decrease in microaggregates with no-tillage compared with conventional tillage.

Furthermore, different crops have different effects on soil aggregation and this is strongly influenced by the amount of carbon accumulated (Powers and Schlesinger, 2002). A number of studies have showed that annual crops are less efficient in soil aggregation improvement than perennial grasses (Tisdall and Oades, 1982; Dominy and Haynes, 2002; Ashman *et al.*, 2003). These studies further indicated that aggregates (200-2000 µm) in pasture soils are significantly richer in monosaccharides than those in cultivated soils and, in turn, these aggregates account for most of the soil carbohydrates. In fact, xylose which is highly decreased within macroaggregates after cultivation, is responsible for the management-induced changes in aggregate stability (Pulleman and Marinissen, 2004). Roots have also been found to play a crucial role in the stability of aggregates. This is through their ability to increase the percentage of small sized aggregates, organic carbon, tensile strength and stability of aggregates. Shepherd *et al.* (2001) observed high aggregate stability in high organic matter soils under pasture and this was attributed to the presence of a protective water-repellent lattice of long-chain polymethylene compounds around the soil aggregates. Similarly, Carter (2002) concluded that changes in aggregate size distribution and properties are related to root length density. Root length density was in the order of ryegrass > pea> wheat. These results are consistent with those obtained by a number of other researchers (e.g. Haynes *et al*., 1991; Beare *et al.*, 1994; Aghasi *et al*., 2010).

In addition, soil texture and cover crops may possibly influence soil aggregation and associated carbon pools, thereby affecting soil quality and productivity. In the study conducted by Shepherd *et al.* (2001), mica-rich, fine textured soils high in organic matter showed the greatest increase in MWD compared to sesquioxide-rich, allophanic soils as a result of differences in clay content. A long period of annual cropping with intensive tillage without a cover crop has also been considered to decrease soil organic carbon stocks and therefore aggregation (Feller and Beare, 1997). These conditions might result in a potential increase in erosion accompanied by a decrease in productivity of a given area due to the removal of the fertile top-soil (Chevalier *et al*., 2004).

2.3.2 Soil chemical properties

2.3.2.1 Organic matter and organic carbon

Organic matter can be described as “the total complement of organic substances present in the soil, including living organisms of various sizes, organic residues in various stages of decomposition and dark-coloured humus consisting of non-humic and humic substances”(du Preez *et al*., 2011). Organic carbon and total nitrogen are used as measures of organic matter content in many studies (e.g. Pulleman and Marinissen, 2004; Snyman and du Preez, 2004; Bongiovanni and Lobartini, 2006). Soil organic matter is a vital constituent of the soil–plant ecosystem and its depletion causes a loss in water holding capacity, poor aggregation, acceleration of soil erosion, poor retention of applied nutrients and reduced soil biological and enzymatic activities (Tisdall and Oades, 1982; Hillel, 1998; Puget *et al.*, 2000; Mills and Fey, 2003). A combination of these factors causes loss of productivity. Therefore maintenance and improvement of soil organic matter in agricultural soils is essential to land sustainability (Campbell *et al.*, 1991; Doran and Parkins, 1994). Soil organic matter content is determined naturally mainly by climate, vegetation cover and, to a lesser extent, by topography, parent material and time. However, land use change or agricultural management practices may lead to changes in, and often loss of, soil organic matter content. The largest of these changes results from the conversion of native grasslands to arable agricultural activities such as crop and stock farming (du Preez *et al.*, 2011). Tillage is often highlighted as the main cause of soil organic matter decline especially in the particulate organic matter fraction (Mills and Fey, 2003).

Particulate organic matter is a labile intermediary in the soil organic matter continuum from fresh organic materials to humified soil organic carbon. The size of particulate organic matter is strongly influenced by soil management and has been used as an early indicator of trends in soil organic matter managed soils (Cambardella and Elliott, 1992; Cambardella *et al.*, 2001; Covaleda *et al.*, 2011). van Antwerpen and Meyer (1996) compared organic matter content of native grasslands and adjoining cultivated fields at 29 sites in KwaZulu-Natal 15 of which were from dryland and 14 from irrigated sugarcane. Cultivated fields had been under sugarcane production for between 2 and 50 years. These 29 sites represented 16 soil forms including Shortlands, Westleigh, Oakleaf and Inhoek (Soil Classification Working Group, 1991), the soils used in the present study. The sampling depths were 0-15, 15-30 and 30-45 cm. The soil organic matter content decreased with depth in all the soils and the depletion was higher in the irrigated than in the dryland areas (Table 2.2).

Table 2.1: Average depletion of organic matter in dryland and irrigated soils (modified from van Antwerpen and Meyer, 1996)

	Dryland			**Irrigated**		
Depth (cm)	initial mass	final mass		initial mass	final mass	
	……………….................. (g C 100 g^{-1} soil)..					
0-15	3.87	3.31	($p<0.05$)	2.40	1.88	($p<0.05$)
15-30	3.33	3.19	($p<0.05$)	2.08	1.69	($p<0.05$)
30-45	3.16	3.04	($p<0.05$)	1.46	1.39	($p<0.05$)

In similar vein, Dominy *et al*. (2001) showed a decline in soil organic matter from 4.6% under undisturbed grassland to 3.4 and 1.3% for Hutton and Glenrosa soil forms, respectively, after 30-50 years of cropping in the KwaZulu-Natal Midlands. The higher percentage of organic matter maintained by the Hutton soil was attributed to its higher clay content (62%) compared to 18% in the Glenrosa. These results are consistent with those obtained by Qongqo and van Antwerpen (2000) where organic matter declined from 4.7% under native grasslands to 2.4% over 50 years of dryland sugarcane cropping. In general, cultivation decreases the amount of soil organic matter by (i) reducing organic matter inputs via roots and leaf litter and (ii) accelerating erosion (Mills and Fey, 2003; Bongiovanni and Lobartini, 2006).

Removal of vegetation during ploughing may result in oxidation of organic matter and the formation of nitrates. These nitrates are normally subjected to loss through leaching and denitrification processes (van Antwepen and Meyer, 1996). Nitrogen can also be transferred by livestock from the veld into the kraal and this may lead to unbalanced C : N ratios resulting in a net loss of soil carbon (Mills and Fey, 2003). The loss of nitrogen is accompanied by loss of carbon and these losses are accompanied by a gradual deterioration of soil structure. The weakly structured aggregates on the surface are exposed to the force of raindrops and dispersed clay blocks soil pores and run-off takes place resulting in a net loss of topsoil. The first few centimetres of top soil generally holds more humus, nutrients and salts than the underlying layers, therefore not much soil loss is needed for soil organic matter decline to take place (Mills and Fey, 2003). In addition, soil organic matter tends to be positively correlated with precipitation and negatively correlated with temperature (Feller and Beare, 1997). Warm areas and semi-deserts tends to have low soil organic matter contents, typically in the range of 0.2 -1.7% C in surface soils (du Preez *et al*., 2011).

Loss of soil organic matter has also been linked to a reduction of N, P and K in most South African studies. Wiltshire and du Preez (1993) showed that cultivation in the Free State resulted in the loss of 30-50% of the total N. Prinsloo *et al*. (1990) similarly found that cultivation reduced N in the top 15 cm of soil from 1.8 to 0.5 t ha^{-1}. They further speculated that soil N loss was due to the removal of crops especially where no organic manure or fertilizer had been added. In general, crop production leads to removal of plant nutrients from the soil unless these nutrients are returned as fertilizers. Fertilization can, however, increase nutrient levels above that of virgin soils and potentially improve soil quality (Mills and Fey, 2004b). The effect of crop production on soil nutrients therefore varies widely and is a function of soil type, crop type and management (Carter, 2002). Wiltshire and du Preez (1993), for example, found that K decreased while P levels increased under dryland cultivation in the central region of South Africa. In another study conducted by Miles and Hardy (1999) at Cedara in the KwaZulu-Natal Midlands, it was found that Italian ryegrass production removed 518 kg of K ha^{-1}.

Reduction in labile P has also been closely associated with soil organic matter losses in South Africa. A study conducted by du Preez and Snyman (1993) on the South African Highveld indicated a 30% loss of labile P as a result of cultivation. They, however, pointed out that inorganic P fertilizers are converted to stable soil P forms and can be viewed as a long term P pool for plants. van Zyl and du Preez (1997) showed that the concentration of inorganic P was greater than organic P in cultivated fields, while the reverse was true for undisturbed native soils. Similar findings have been obtained by Milne and Haynes (2002) who found a lower total P concentration in native pasture than cultivated soil at Tsitsikamma, southern Cape. Such low P concentration was attributed to the removal of vegetation by grazing animals over a long period. After comparing conventional tillage with native savannah soils, Lilienfein *et al.* (2000) found that conventionally tilled soils were 28% higher in total P than native savannah soils due to regular fertilization. Research in other parts of the world has also indicated that nutrients such as P can be depleted in grassland soils due to their removal with dairy products where animals are grazed (Jobbagy and Jackson, 2004).

The main effects of land use practices can be observed by changes in the distribution of soil organic carbon within particle-size classes (Covaleda *et al.*, 2011). Mills and Fey (2004a) indicated that vegetated soils tend to have more carbon than exposed soils because plants recycle carbon and they may suppress mineralization by releasing antibacterial exudates. Plants can also reduce mineralization through wetting and drying of the soil and by shading and cooling accompanied by rainfall interception (Covaleda *et al.*, 2011).

Dominy *et al.* (2001) investigated the effects of the main agricultural land uses on soil organic carbon in the Midlands of KwaZulu-Natal. Undisturbed native grasslands were found to have higher soil organic carbon than improved pasture (kikuyu) and cultivated fields of maize and sugarcane. Du Toit *et al.* (1994) found that 5-90 years of cultivation in the Free State resulted in a loss of 10-73% of the soil organic carbon relative to natural grasslands. Nel *et al*. (1996) conducted a study on a Hutton soil at Pretoria and they found a 50% decline of soil organic carbon after 50 years of cropping. Lobe *et al*. (2001) recorded a 50% decline in soil organic carbon after only 3.5 years of cropping in the Free State. In a similar study by Covaleda *et al*. (2011), the soil under cropland contained 45% less carbon than the grassland soil. Grassland in the study area included shrub and herbaceous vegetation which resulted in a higher litter input compared with agricultural land where crop residues and harvested crops were removed. In grassland soils, much of the litter input is from root biomass (Dominy and Haynes, 2002).

Soil carbon has been found to decline with depth by a number of researchers worldwide (du Toit *et al*., 1994; Six *et al*., 2000a; Mills and Fey, 2003; Covaleda *et al*., 2006; du Preez *et al*., 2011). In a study conducted by du Preez *et al*. (2011) to examine the overall organic carbon distribution in different soil profiles, the A horizon had the highest organic carbon at 1.21%, decreasing to 0.54% in the B and 0.40% in the C horizon. The organic carbon in the E horizon (0.40%) was lower than in the B, C and G horizons. Mills and Fey (2004b) studied the impact of transforming thicket to savanna on soil quality in the Eastern Cape region. Total carbon was amongst other soil quality indicators that were measured and its concentration decreased with change of land use and with depth (Figure 2.2).

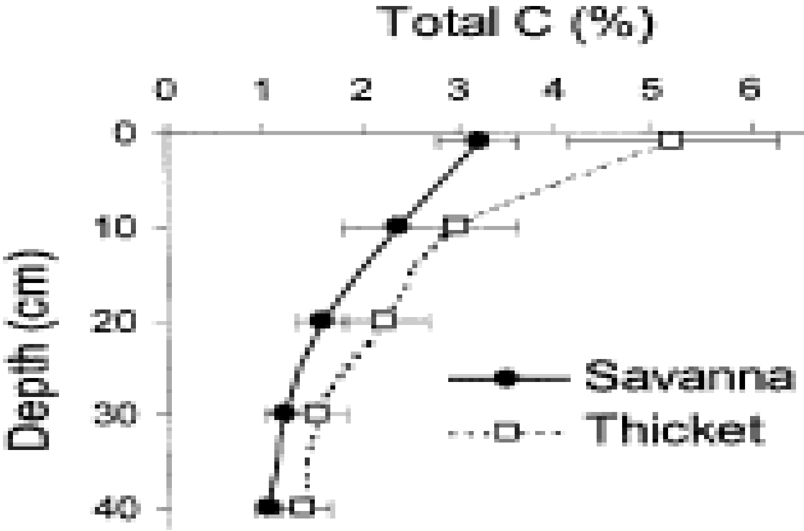

Figure 2 2: The change in total carbon with depth (0-40 cm) in a xeric succulent thicket that was transformed to savanna in the Eastern Cape region (Mills and Fey, 2004b).

Moreover, land use changes or agricultural management practices that lead to changes in soil organic carbon content often occur gradually and are therefore difficult to detect in the short or medium-term (Campbell *et al.*, 1991). From an environmental perspective, short-term sensitivity of a measurement is desirable for its use as an indicator. Soil microbial biomass has been shown to be sensitive to short-term changes in soil management (Doran and Jones 1996). However, the determination of soil microbial biomass is a time-consuming process. Also, in most cases, soil microbial biomass has to be measured at field-moist conditions or pre-incubated at a certain moisture and temperature for a fixed period (Puget *et al.*, 1995). This creates further delays in analysis.

2.3.2.2 Soil pH

Soil pH influences plant growth directly, via the effect of the hydrogen ions, and indirectly, via its effect on nutrient availability (Bouajila and Gallali, 2010). Increased soil acidity may result in lower rates of nitrification and higher nitrate leaching (Geissen *et al.*, 2009). Soil pH affects the decomposition of organic matter by influencing microbial activity, hydrolysis and protonation processes (Aghasi, 1981). Protonation in particular, regulates many soil processes including complexation and solubilisation that affect the stability of soil organic matter by controlling sorption and desorption of organic carbon on mineral surfaces (Anderson, 1988).

It also affects the microorganism population by increasing the availability of biologically toxic Al with decreasing pH. A decrease in microbial activity is commonly associated with a change in soil structural stability. Acidity decreases microbial activity as microbes do not function properly in soils with low pH (Bekwet, and Stroosnijder, 2003). Many studies have indicated that large aggregates generally form in soils of high pH (Bronick and Lal, 2005; Geissen *et al.*, 2009; Bouajila and Gallali, 2010). Conversion of native grasslands to arable agriculture involves, in most cases, the use of fertilizers to supplement nutrients lost when crops are removed. However, a long-term effect of fertilizer application, particularly nitrogenous fertilizers, is to decrease soil pH by increasing the concentration of hydrogen and aluminium ions in soil solution (Anderson and Nilsson, 2001; Falkengren-Grerup and Diekmann, 2003). Roberts *et al.* (1990) investigated the impact of cultivation on pH. It was found that when native grassland was brought into crop production, soil pH significantly increased after eight years of cultivation. Increasing years of cultivation caused further pH rise and this was attributed to loss of topsoil by erosion with cultivation, so that subsoil with higher pH was brought up and mixed into the plough layer.

2.3.2.3 Cation exchange capacity and exchangeable cations

Cation exchange capacity (CEC) refers to the capacity of soil to hold and exchange cations (Jobbagy and Jackson, 2004). It provides a buffering effect to changes in pH, available nutrients and soil structural changes. As such it is a major controlling agent of soil structural stability, nutrient availability for plant growth, soil pH and reaction to fertilizers and other amendments. A low CEC means that the soil has a low resistance to changes in chemistry that are caused by land use (Johnson, 1992).

The cultivation of native grassland can have a marked effect on the distribution of materials and cations within aggregates of different sizes. Emadi *et al.* (2000) conducted a study to determine the distribution of exchangeable cations and nitrogen within different water stable aggregate (WSA) fractions of soils under different land uses i.e. virgin grassland, cultivated pasture and forest in the Alborz Mountains of northern Iran. The selected aggregate fraction ranges were macroaggregates (4.75 - 0.25 mm) and microaggregates (< 0.25mm). Figure 2.3 shows the distribution of the exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) within WSA for soils under virgin grassland and cultivated pasture. Cultivation of virgin soil generally led to a reduction in the concentration of total exchangeable cations in the macroaggregate fractions, but an increase in concentration of these cations in the <0.25 mm fraction. A similar trend was obtained under forest. These results are consistent with those obtained by Adesodun *et al*. (2007) who reported that cultivation induced redistribution of exchangeable nutrients into the smaller aggregates.

Small aggregates (< 0.25 mm) are, however, subject to erosion under most cultivated conditions resulting in the net removal of exchangeable cations from the soil (Emadi *et al*., 2000). Saikh *et al.* (1998) also reported significant decreases in exchangeable Ca and Mg after conversion of forest into cultivated fields. The removal of exchangeable cations can also have effects on soil structure. Calcium, for example, is an aggregating force in many soils and its loss due to erosion could reduce soil structural stability (Mills and Fey, 2003). Haynes and Francis (1990) indicated that low Ca:Mg ratios enhance dispersivity of clays and cause structural instability. In addition removal of exchangeable cations from the soil may affect the salinity status and this might impact on soil structural stability (Emadi *et al.*, 2000).

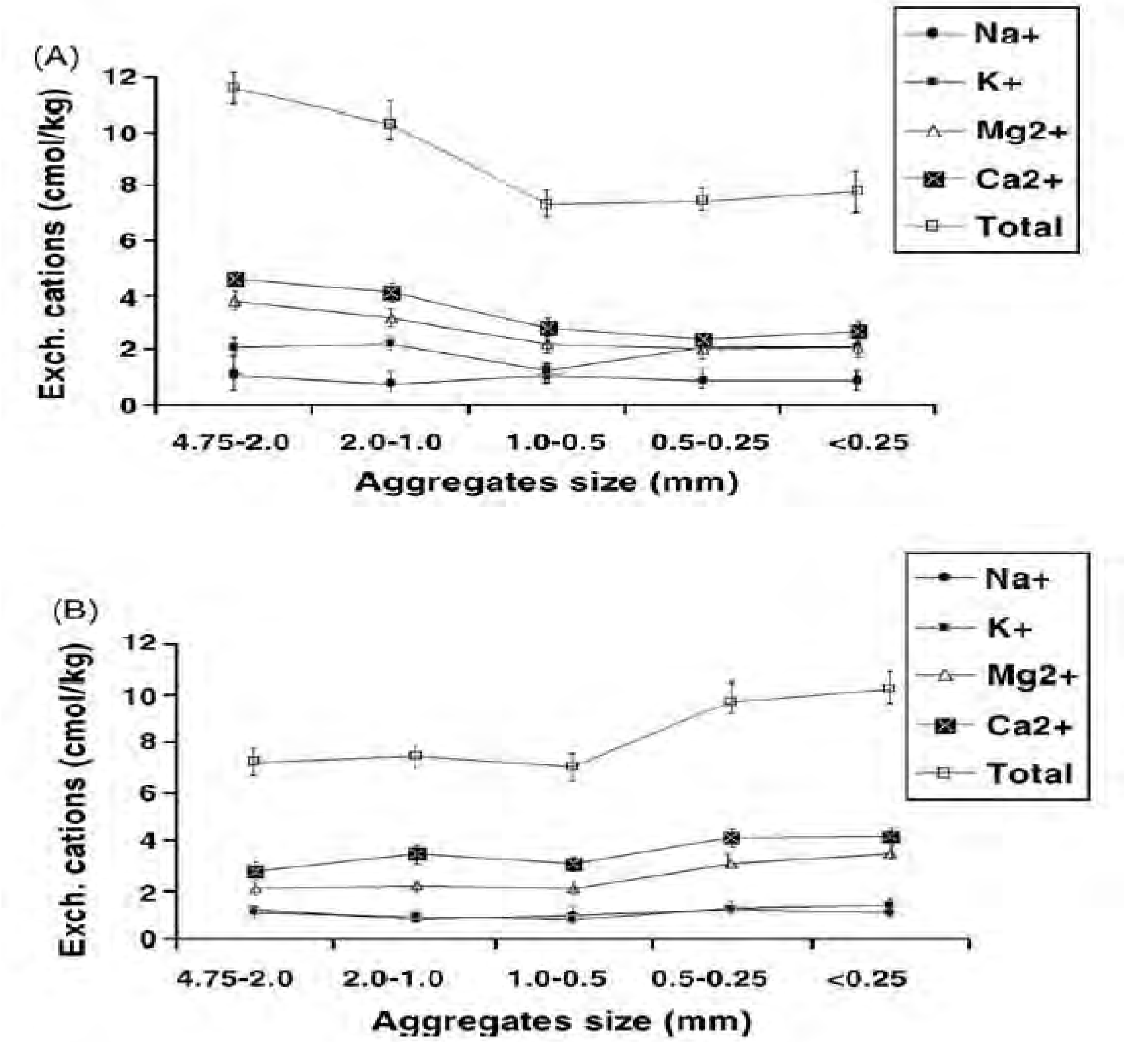

Figure 2 3: Distribution of exchangeable cations in water stable aggregates of pasture soils in northern Iran. (A) virgin grassland, (B) cultivated pasture (Emadi *et al*., 2000).

2.4 Conclusions

The conversion of native grasslands to arable land has been associated with reduction in organic matter content of the topsoil and subsequently a decline in productivity, since organic matter is a major factor responsible for the productivity of soils (Haynes and Beare, 1994). The loss of particulate organic matter after the removal of vegetation accounts for much of the total organic matter depletion in soils. The mechanisms resulting in the binding of primary soil particles into stable aggregates vary with vegetation and management practices among other factors. Plant residues through microbial processes generate complex substances that serve as a framework for linking soil particles into aggregates. Plant roots and residues are the primary organic skeleton in the formation of both macro- and microaggregates.

Therefore, loss of soil organic matter following cultivation results in the formation of weakly structured aggregates which are susceptible to erosion through raindrop impact. Vegetation or soil cover plays a crucial role in diminishing soil erosion.

Soil total organic carbon and total N, P and K are major fertility elements. Cultivation tends to destroy the macroaggregate structure of native grassland soils with a concomitant reduction in soil C and N. The soil organic matter possesses a great capacity to absorb cations such as Ca and Mg but its reduction following cultivation results in redistribution of these cations such that their content increases in microaggregates (< 0.25 mm) which are more susceptible to erosion. The more years of cultivation, the less total organic carbon and N remain. The forms and dynamics of soil P are affected by agricultural management practices which often involve dramatic changes in vegetation cover and biomass production. It is reported that differences in fertilization and cropping systems following cultivation of native grassland may lead to higher total P levels in arable fields. pH is also sensitive to environment and soil management practices. Its value will affect nutrient supply, buffer capacity and nutrient availability.

Changes in land use, such as from undisturbed grassland to arable agriculture or improved pastures can have significant and long lasting effects on some soil quality parameters and hence productivity. Research into these impacts on the soil is important to determine how soil fertility can be maintained and the land use system improved. In this present study, the effects of land use systems are evaluated on the following soil properties: particle size distribution, pH, organic C, available P, particulate organic matter content and exchangeable bases in some soils from northern KwaZulu-Natal.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Site description

This study was conducted at Owen Sitole College of Agriculture (OSCA) (28° 57' 45"S and 31° 55' 31"E) located at Kwesaka-Mthethwa about 12.5 km north of Empangeni and 163 km north of Durban, KwaZulu-Natal Province, South Africa (Figure 3.1). The eastern boundary is formed by the old Mtubatuba road and the southwestern boundary by the Nseleni River. Altitude ranges from 23 m a.s.l. in the river valley to 120 m a.s.l. on the north-western portion of the farm. The College farm is approximately 672 ha in extent and the climate is subtropical with hot, humid summers and cooler, drier winters. The mean annual rainfall is 867 mm (Van der Linden, 2004), with a third falling between October and March and most of the remainder between April and September. Mean daytime temperatures range from 19°C in winter to 33°C in summer. The mean annual temperature is 26°C (Camp, 1994) and frost occurs only rarely.

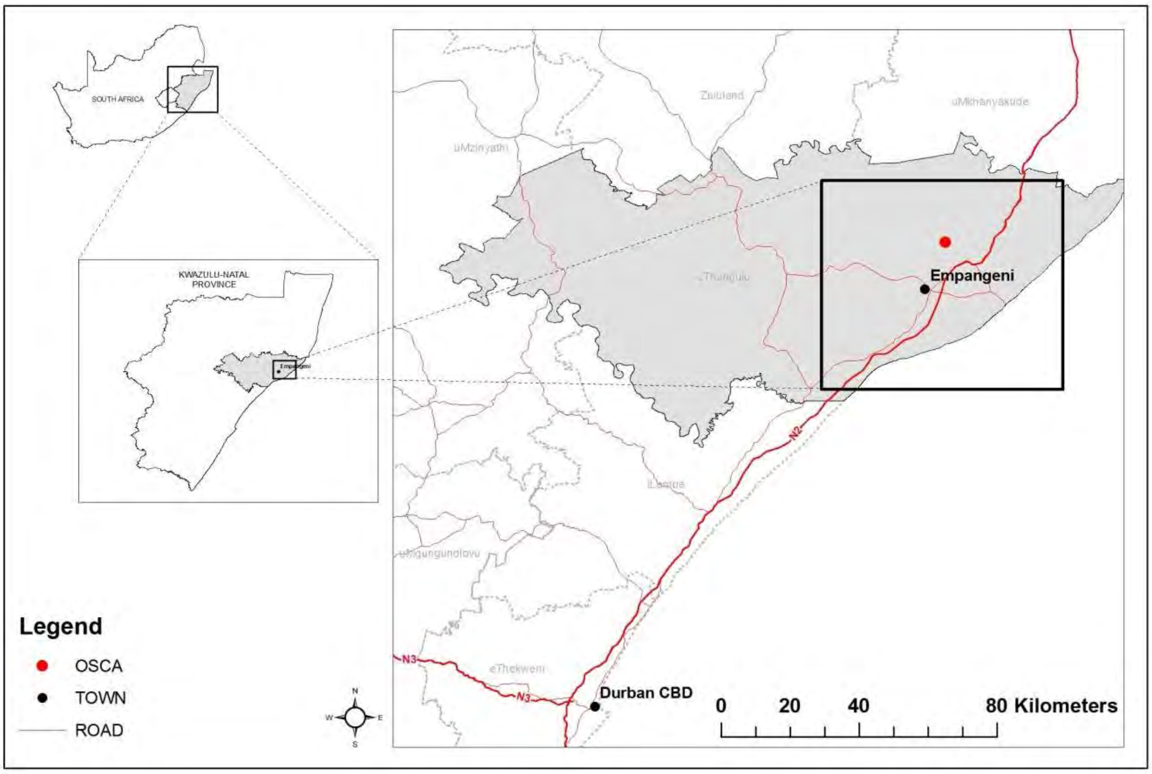

Figure 3.1**:** The location of Owen Sitole College of Agriculture (OSCA) in KwaZulu Natal Province, South Africa.

The OSCA land area is underlain by volcanic basalts that belong to the Letaba Formation of the Lebombo Group (Van der Linden, 2004). Nine different soil forms (Soil Classification Working Group, 1991) are found within the College grounds of which Mayo and Inhoek are the most common types (Figure 3.2). Soil classification and description of OSCA were done by Drennan, Maud and Partners (1986). Camp (1994), with a project planning group of the Department of Agriculture and Forestry confirmed the soil forms occurring within the area.

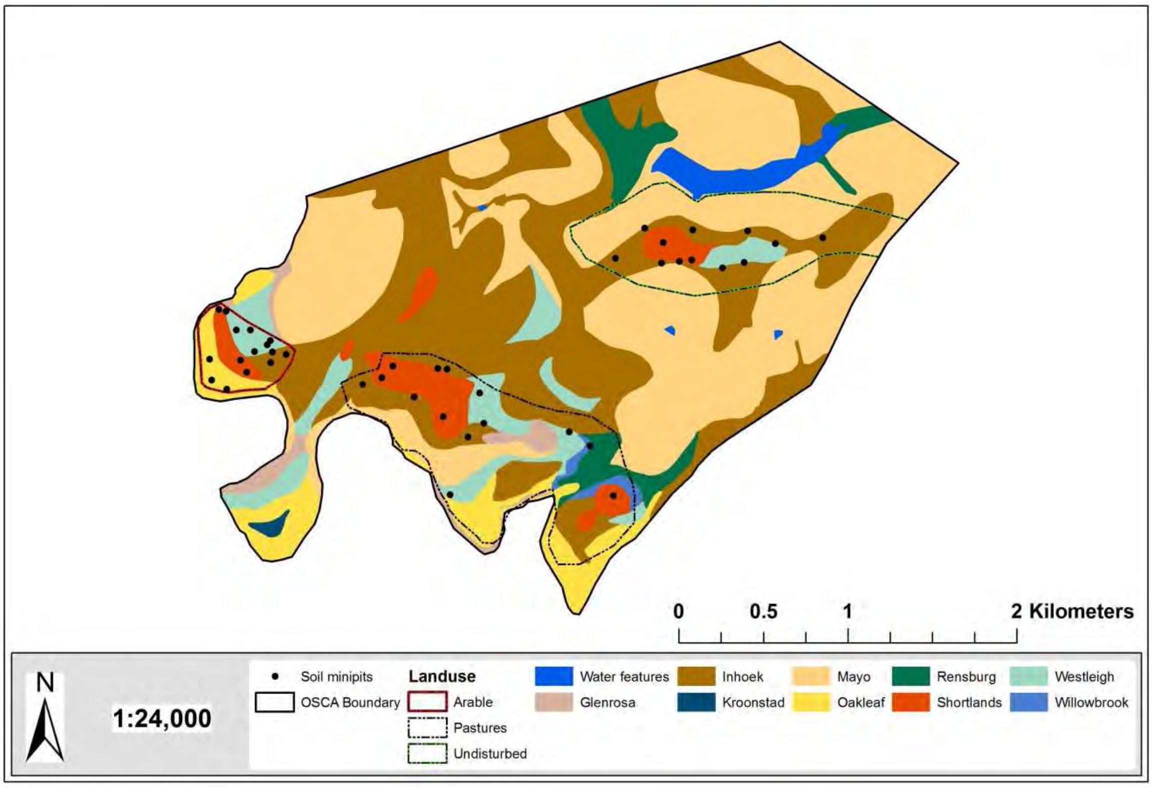

Figure 3.2: Soil map of the Owen Sitole College of Agriculture showing the study areas under undisturbed grassland, pasture and arable land use systems and the soil sampling points (Camp, 1994).

3.2 Land use history

Based on interpretation of aerial photographs, this area was under settlement with a typical mixed crop–livestock system at subsistence scale between 1937 and 1968. Most parts of the farm were cultivated and overgrazed and the veld was burned by frequent fires. From 1968, after all the subsistence farmers were removed and the area fenced, the area reverted to the original vegetation of natural grassland.

The undisturbed grassland has not been cultivated for the past 45 years and the area is very patchy due to the wide range of treatments given in the past. The common grass species include *Themeda trianda, Tristachya leucothrix, Hyparrhenia filipendula* and *Chloris gayana*. Other vegetation under this land use comprise a variety of forbs and small to tall bushes such as *Hypoestes aristata, Hewittia sublobata* and *Cassia mimosodes*. *Acacia karroo, Phoenix reclinata* and *A. nilotica* are among other trees common in this area. Undisturbed areas close to rivers and drainage lines consist of a dense woodland/forest that become more open savanna with distance from the waterways (Van der Linden, 2004).

The pasture is a mix of weeping love grass (*Eragrostis curvula*), Italian ryegrass (*Lolium multiflorum*) and kikuyu (*Pennisetum clandestinum*). The approximate area under pasture is six hectares. All the pastures have been tilled with a rotary parlour every 2-3 years for 38 years to a depth of about 15 cm in spring (September to November), prior to resowing the pasture with the exception of the kikuyu which has been untilled for 38 years. Limestone ammonium nitrate (LAN) is the most common fertiliser applied when resowing. The pasture is rotationally grazed by cattle and goats, fertilised (75 kg N; 15 kg P and 5 kg K ha^{-1} yr^{-1}) and irrigated using a sprinkler irrigation system. Wheeled travel over the area at other times of the year consists of occasional movement of tractors for livestock management. The College also rears pigs, poultry, dairy as well as Nguni cattle.

The arable land has been under cultivation for 38 years and mostly used for vegetables (spinach, carrot, butternut, green pepper, tomatoes and cabbage) and field crops (sugarcane, potatoes, maize, sweet potatoes, dry-beans and madumbe). This field has a history of annual applications of fertilizer (LAN, monoammonium phosphate, potassium chloride and lime ($CaCO_3$) at commercially recommended rates. Typical annual rates are: 2 t lime ha$^{-1(}$, 250 kg N ha^{-1}, 75 kg K ha^{-1} and 25 kg P ha^{-1}.

Currently bananas, mangos, macadamias and oranges are the most common tree crops grown. Common field crops include sugarcane, maize and butternut while tomatoes, spinach, cabbage and carrots are the most important vegetables. The fruits, vegetables and some agronomic crops are produced mainly under irrigation.

3.3 Soil sampling and preparation

In the absence of prior information for this study area, changes in soil properties induced by land use dynamics were evaluated by taking soil samples from plots of land under different land use systems (pasture and arable) and comparing their physicochemical properties with soils under natural or semi-natural vegetation (grassland) that has been less disturbed in its history. A prerequisite for this method was that the reference undisturbed grassland and the land use treatments were located such that differences in geology, topography and climate were negligible. Given this condition, any differences in soil properties could then be attributed to the differences in land use.

A preliminary soil survey was carried out to ensure that land use types at each site were on soils of the same type. The sampling (Figure 3.2) was done as two investigations. In the first investigation, sampling was carried out from the Shortlands, Westleigh and Inhoek soil forms under the undisturbed, pasture and arable land use systems. In the second investigation, sampling was carried out on the Oakleaf soil form under the pasture and arable land use systems due to the absence of this soil form under undisturbed grassland.

Soil samples were collected by digging mini-pits (90 cm wide, 120 cm long and 30 cm deep). Four bulk samples were carefully collected from each soil form at 0-1, 1-5, 5-10, 10-20 and 20-30 cm depths using a spade to ensure natural aggregates were not broken during sampling. All the samples were transferred in labelled plastic bags to the laboratory for analysis. For soil aggregate stability determinations, samples from the upper four sampled depths were air dried and sieved to collect sufficient aggregates between 2.8 and 5 mm for aggregate stability measurements. The bulk of each sample was crushed with a pestle and mortar and passed through a 2 mm sieve for the analysis of pH, organic carbon and particulate organic matter. For the analysis of soil fertility and particle size distribution samples were bulked to three depths of 0-10; 10-20 and 20-30 cm.

3.4 Laboratory analysis

3.4.1 Aggregate stability

Aggregate stability was measured on separated 2.8-5 mm aggregates according to the French AFNOR norm NF X 31-515 (AFNOR, 2005). This method uses three disruptive tests having a range of different wetting conditions and energies namely fast wetting (water treatment-WT), slow wetting (ethanol treatment-ET) and mechanical breakdown after prewetting (slow capillary wetting-ethanol treatment-SCWET). The WT mimics rainfall with > 50 mm h^{-1} intensity on dry soil (representing the effect of rapid slaking); ET mimics rainfall with about 10 mm h^{-1} intensity on dry soil to represent slow (less aggressive) wetting of soils; SCWET represents the situation when rainfall is deposited on aggregates that are already saturated with water (least aggressive) (AFNOR, 2005). Aggregates were oven dried at 40^{o}C for 24 hours prior to analysis.

In the WT test, a known mass of aggregates between 5 and 10 g were immersed in 50 ml of deionised water for 10 minutes before the water was extracted by pipetting. For the ET test, a similar amount of aggregates was immersed in 50 mL of ethanol for 30 minutes. After 30 minutes, ethanol was removed with a pipette and aggregates transferred into a 200ml Erlenmeyer flask containing 50 ml of distilled water. The solution was adjusted to 200 ml with distilled water, stoppered and gently agitated end-over-end by hand for 20 times. The suspension was left to stand for 2-3 hours for sedimentation of coarse fragments, after which the excess water was removed with a pipette. For the SCWET test, a similar amount of aggregates was capillary wetted using filter papers for 60 minutes. Each treatment was replicated four times. After each test, residual aggregates were collected and transferred onto a 50 µm sieve previously immersed in ethanol for the measurement of aggregate size distribution. The remaining aggregates were collected, dried at 105^{o}C and sieved using a nest of six sieves: 2000, 1000, 500, 200, 106 and 50 µm. The mass of each fraction of stable aggregates was measured. Results were expressed as mean weight diameter (MWD) corresponding to the sum of the mass fraction remaining on each sieve (Equation 3.1).

$$\mathbf{MWD} = \frac{[(3.5xPa)+(1.5xPa)+(0.75xPa)+(0.35xPa)+(0.15xPa)+(0.075xPa)+(0.025xPa)]}{100} \quad \text{..........Equation 3.1}$$

Pa = mass of aggregates as percentage aggregates per sieve (using the mean sieve size (mm)

3.4.2 Particle size distribution

Particle size distribution was measured in bulked samples (< 2 mm) from the 0-10, 10-20 and 20-30 cm depths using the pipette method (Gee and Bauder, 1986). Suspended clay and fine silt were determined after dispersion and sedimentation while sand fractions were determined by sieving (Day, 1965). Silt (0.002-0.05mm) was estimated by difference (Manson and Roberts, 2000). Once the particle size distribution was known, the textural class was determined from the texture triangle (Soil Classification Working Group, 1991).

3.4.3 Particulate organic matter and organic carbon

Particulate organic matter (POM) was determined using the wet sieving method of Cambardella and Elliot (1992). Soil (20 g) was dispersed in 60 ml of a 0.5% (w/v) solution of sodium hexametaphosphate by shaking for 15 hours on a reciprocal mechanical shaker. After shaking, the sand material was allowed to settle for about five minutes and decanted. The suspension was then passed through a 106 µm sieve that retained the flocculated material, defined as POM. This material was transferred to a glass beaker and dried in an oven at 40 ^{o}C for 24 hours. The mass of the oven dried material was weighed and POM was calculated and expressed as a percentage of the original soil sample mass used.

For the analysis of soil organic carbon (SOC), soil samples were bulked into depths of 0-5, 5-10 and 10-20 cm before analyzing by the dichromate oxidation method (Walkley, 1947). This method measures the readily oxidizable organic carbon. The organic matter is oxidized by potassium dichromate in a sulphuric acid medium. The excess dichromate was determined by titration with ferrous ammonium sulphate solution.

3.4.4 Extractable phosphorus, exchangeable potassium, zinc, copper and manganese

Available phosphorus and micronutrients were measured in bulked samples from the 0-10, 10-20 and 20-30cm depths using the Ambic-2 extractant as described by Manson and Roberts (2000). The Ambic-2 extracting solution consists of 0.25M NH_4CO_3 + 0.01M Na_2EDTA + 0.01M NH_4F + 0.05 g L^{-1} Superfloc (N100), adjusted to pH 8 with a concentrated ammonia solution. This solution (25 mL) was added to 2.5 mL soil, and the suspension was stirred at 400 r.p.m. for 10 min using a multiple stirrer. The extracts were filtered through a Whatman No.1 paper. Phosphorus was determined on a 2 mL aliquot of filtrate using a modification of the Murphy and Riley (1962) molybdenum blue procedure (Hunter, 1975). Potassium was determined by atomic absorption spectrophotometry (Varian 2600) on a 5 mL aliquot of the filtrate after dilution with 20 mL deionised water. Zinc, Cu and Mn were determined by atomic absorption spectrophotometry on the remaining undiluted filtrate.

3.4.5 pH, exchangeable calcium and magnesium and effective cation exchange capacity

Soil pH in 1 M KCl and deionised water (1:2.5 soil: solution) was determined electrometrically using a standard glass electrode (MetrohmHersiau E396B). Ten ml of soil was scooped into a 50 mL plastic beaker before addition of 25 mL of solution. The suspension was stirred and allowed to stand for 30 minutes before the pH was measured.

Exchangeable Ca and Mg were measured in bulked samples from the 0-10, 10-20 and 20-30 cm depths following methods described by Manson and Roberts (2000). Approximately 2.5 mL of soil was scooped into sample cups. 1*M* KCl solution (25 mL) was added and the suspension stirred at 400 r.p.m. for 10 minutes using a multiple stirrer. The extracts were filtered through a Whatman No.1 paper. Five mL of the filtrate was diluted with 20 mL of 0.0356*M* $SrCl_2$, and Ca and Mg determined by atomic absorption spectrophotometry (Varian 2600). To determine extractable acidity, 10 mL of the filtrate was diluted with 10 mL of deionised water containing 2-4 drops of phenolphthalein, and titrated with 0.005*M* NaOH. Effective cation exchange capacity (ECEC) was calculated as the sum of KCl-extractable Ca, Mg, and acidity and Ambic-2 extractable K.

3.4.6 Data analysis

A separate analysis of variance (ANOVA) was performed to compare land use types and soil depth on each of the soil quality indicators measured for each soil using GENSTAT 14 (Payne *et al*., 2011). The Least Significant Difference (LSD) at both 0.1 % (highly significant) and 5% (moderately significant) were used to indicate treatment differences. Correlation matrices were calculated for the main variables measured to determine significant relationships between the soils.

CHAPTER FOUR
RESULTS

4.1 Introduction

Soil quality decline is one of the most crucial problems facing agriculture (Doran and Parkin, 1994; Puget and Lal 2005). This chapter reports the results of the effects of the three different land use types (undisturbed natural grassland, irrigated pasture and arable) on some selected soil quality properties in four contrasting soils.

4.2 General description of the soils and particle size distribution

The four soil forms and their families were classified as Shortlands 1210 (Empangeni), Westleigh 2000 (Mareetsane), Inhoek 1100 (Oatlands) and Oakleaf 2110 (Cooper) (Soil Classification Working Group, 1991). From the World Reference Base for Soil Resources (IUSS Working Group WRB, 2014), the Shortlands, Westleigh, Inhoek and Oakleaf are classified as Nitisol, Acrisol, Fluvisol and Arenosol respectively. The Shortlands was a dark reddish brown (2.5YR 3/3) clay (Tables 4.1 to 4.3) at the surface and was mostly found on the upper to middle slopes of the study site. Westleigh was a dark greyish brown (10YR 4/3) clay loam at the surface and mostly found on the middle slopes. The Inhoek soil form was a black (10Y 2.5/2.5) clay loam at the surface and was generally found on the lower to middle slopes. The Oakleaf was a deep soil derived from alluvium on Cwaka river terraces and lower slopes. It had a dark reddish grey (2.5YR 4/1) colour at the surface with sandy loam texture overall. Although sampling from the mini-pits was limited to 30 cm depth, an auger investigation to allow full classification showed that the soils were deep (> 1 m) with the exception of Westleigh which had a much shallower effective rooting depth (< 0.4 m). Brief soil profile information for each of the soil forms is given in Appendix 4.1. Shortlands and Inhoek had higher clay content that increased with depth (0-30 cm) in all land uses with the exception of the arable Inhoek where the clay decreased with depth. In the Westleigh and Oakleaf soil forms, clay content initially decreased in the 10-20 cm depth and then increased in the 20-30 cm depth. The 10-20 and 20-30 cm depths of Westleigh, Inhoek and Oakleaf soil forms under the pasture and arable land use systems had higher clay contents than those under the undisturbed land use.

Table 4.1: The average particle size distribution (±SD; n = 4) of the 0-10 cm depth of the Shortlands, Westleigh, Inhoek and Oakleaf under undisturbed, irrigated pasture and arable land use systems

Soil form	Land Use	Clay (> 0.002mm)	Silt (0.002- 0.05mm)	Sand (0.05-2 mm)	Texture class
		……………………….(%)…………………………..			
Shortlands	Undisturbed	57±5.8	13±5.3	28±4.1	Clay
	Pasture	65±1.1	16±6.3	20±4.1	Clay
	Arable	54±4.7	11±3.6	36±4.3	Clay
Westleigh	Undisturbed	34±4.1	14±2.0	53±3.8	Clay
	Pasture	44±2.1	13±4.1	43±8.1	Clay
	Arable	52±7.0	17±6.1	31±7.8	Clay
Inhoek	Undisturbed	34±3.6	11±3.1	54±3.0	Sandy loam
	Pasture	47±1.0	16±4.1	37±5.1	Clay
	Arable	60±2.3	17±2.9	23±1.2	Clay
Oakleaf	Pasture	16±5.9	7±3.1	77±4.0	Sandy loam
	Arable	16±2.0	9±3.3	75±4.4	Sandy loam

Table 4.2: The average particle size distribution (±SD; n = 4) of the 10-20 cm depth of the Shortlands, Westleigh, Inhoek and Oakleaf under undisturbed, irrigated pasture and arable land use systems

Soil form	Land Use	Clay (< 0.002mm)	Silt (0.002- 0.05mm)	Sand (0.05-2 mm)	Texture class
		……………………….(%)…………………………..			
Shortlands	Undisturbed	60±3.1	15±2.6	25±1.4	Clay
	Pasture	65±5.2	18±1.6	17±2.4	Clay
	Arable	55±4.1	8±2.3	37±7.0	Sandy clay
Westleigh	Undisturbed	38±6.1	11±2.1	51±4.1	Sandy clay
	Pasture	40±7.3	10±1.7	50±2.6	Sandy clay
	Arable	49±3.0	16±1.9	35±3.0	Clay
Inhoek	Undisturbed	41±1.0	16±4.1	43±7.0	Sandy clay
	Pasture	63±3.0	14±2.0	23±1.8	Clay
	Arable	57±5.0	10±7.7	33±2.5	Clay
Oakleaf	Pasture	13±1.0	5±1.6	83±2.0	Loamy sand
	Arable	13±1.1	2±1.6	85±3.7	Loamy sand

Table 4.3: The average particle size distribution (±SD; n = 4) of the 20-30 cm depth of the Shortlands, Westleigh, Inhoek and Oakleaf under undisturbed, irrigated pasture and arable land use systems

Soil form	Land Use	Clay (< 0.002mm)	Silt (0.002- 0.05mm)	Sand (0.05-2 mm)	Texture class
		……………………….(%)…………………………..			
Shortlands	Undisturbed	66±5.8	12±3.2	22±3.8	Clay
	Pasture	71±1.1	16±1.9	13±2.5	Clay
	Arable	56±5.0	10±2.2	35±3.7	Clay
Westleigh	Undisturbed	26±2.1	6±4.8	68±1.3	Sandy clay
	Pasture	42±1.2	15±6.0	43±5.3	Sandy clay
	Arable	56±4.8	9±5.2	35±6.1	Clay
Inhoek	Undisturbed	42±1.0	12±6.5	46±6.0	Sandy clay
	Pasture	66±5.0	16±4.4	19±7.1	Clay
	Arable	53±3.2	13±2.9	34±1.1	Clay
Oakleaf	Pasture	17±2.2	6±4.5	78±3.9	Sandy loam
	Arable	23±3.1	5±6.3	73±2.2	Sandy loam

4.3 Soil pH and exchangeable acidity

The mean pH (H_2O and KCl) values for Shortlands, Westleigh, Inhoek and Oakleaf are shown in Appendices 4.2 to 4.5, respectively. Soil pH (H_2O) was significantly ($p < 0.001$) affected by land use in the Shortlands and the interaction between land use and soil depth was only significant in the Inhoek soil form (Appendix 4.6). The pH (KCl) was also significantly ($p < 0.001$) affected by land use in both the Shortlands and Westleigh and the interaction between land use and soil depth was significant in the Inhoek soil form (Appendix 4.7). Arable land generally had lower pH values, which were not affected by soil depth whereas soil pH under pasture declined with depth in all soil forms. The undisturbed grassland on the other hand, showed an initial decline of pH with depth (0-20 cm) and then a slight increase at the 20-30 cm depth in all the soils. The mean pH (H_2O) values were 6.31 for the arable soil and 6.50 for both pasture and undisturbed soils. In KCl, the mean pH values were 5.10 for arable and 5.43 for both pasture and undisturbed soils. The Oakleaf soil under the arable land use tended to be more acidic compared to that under pasture at all depths even though this was only significant ($p < 0.001$) in the pH (KCl) treatment (Appendices 4.8 to 4.10). Both land use systems were less acidic in the top 0-5 cm and the acidity status increased with depth (10-30 cm). There were no significant interactions between land use and soil depth in the

Oakleaf soil form (Appendix 4.11). In the Oakleaf soil the mean pH (KCl) values were 5.04 (arable) and 5.61 (pasture). The pH (H_2O) mean values were 6.21 (arable) and 6.50 (pasture).

4.4 Organic carbon

The soil organic carbon (SOC) showed significant ($p < 0.001$) change with land use in all the soils (Appendix 4.12). However, the interaction between land use and soil depth was only significant in the Oakleaf soil form (Appendix 4.13). The 0-5 cm depth had a higher SOC than the 5-10 and 10-20 cm depths under in the pasture whereas there were no significant depth effects under arable in the Oakleaf soil form (Figure 4.1D). The pasture soils had similar SOC with undisturbed soil for all soils (which had undisturbed soil) at all depths except in the 5-10 cm depth of Westleigh where it had higher levels. At all depths and for all soils the arable land had lower SOC (Figure 4.1A to D). In all the land uses and soil types, SOC decreased with depth. The concentration of SOC followed the order: pasture > undisturbed > arable (Figure 4.1) with mean values at all depths and for all soils of 3.52, 3.37 and 1.85%, respectively.

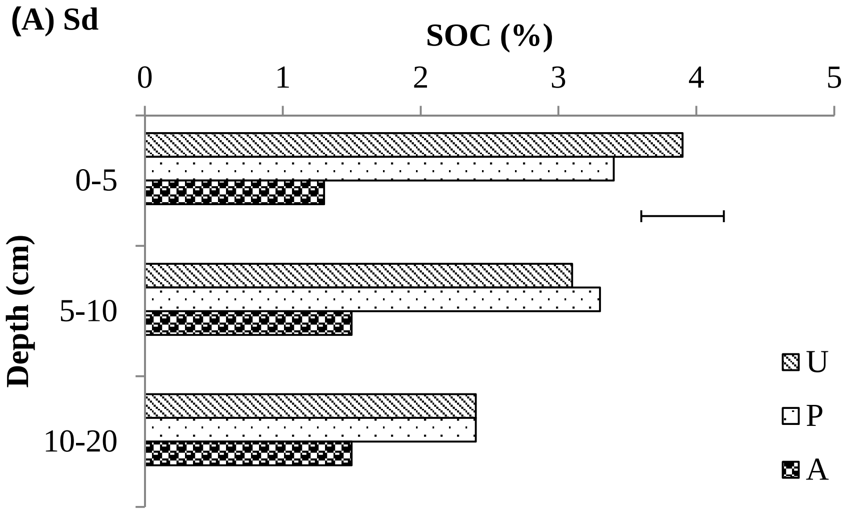

Figure 4.1A: The change in soil organic carbon (SOC) concentration in Sd: Shortlands soil form with depth (0-20 cm) under U: undisturbed; P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at $p = 0.05$.

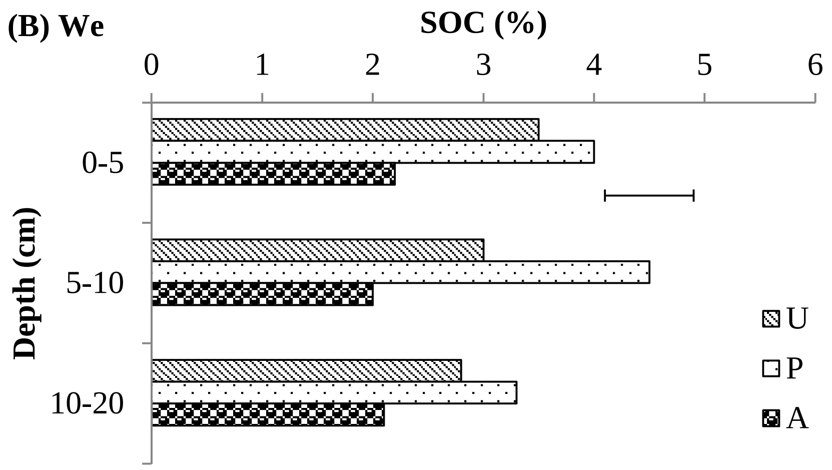

Figure 4.1B: The change in soil organic carbon (SOC) concentration in We: Westleigh soil form with depth (0-20 cm) under U: undisturbed; P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

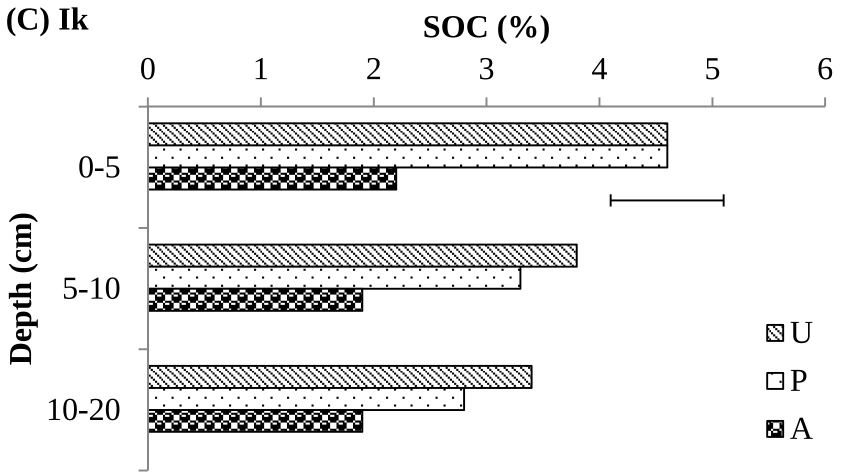

Figure 4.1C: The change in soil organic carbon (SOC) concentration in Ik: Inhoek soil form with depth (0-20 cm) under U: undisturbed; P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

(D) Oa

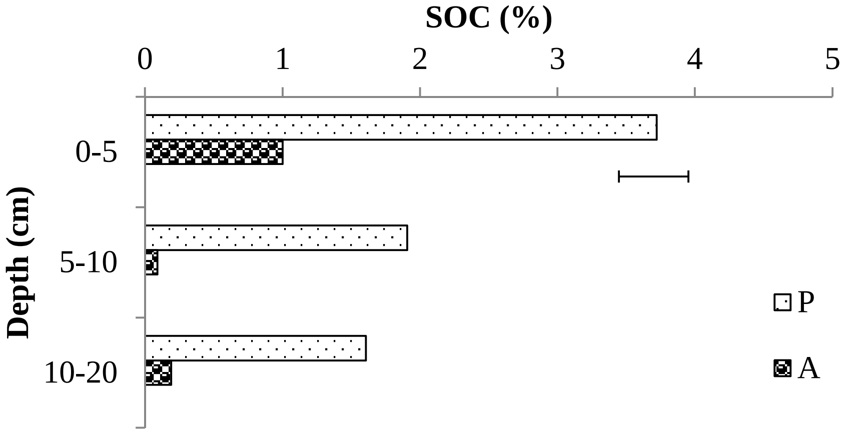

Figure 4.1D: The change in soil organic carbon (SOC) concentration in Oa: Oakleaf soil form with depth (0-20 cm) under U: undisturbed; P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

4.5 Particulate organic matter

Significant interactions between land use and soil type were observed for particulate organic matter (POM) in the Westleigh and Inhoek soil forms (Figure 4.2B and C; Appendix 4.14). Levels of POM in the different land uses were similar for each of the depths. In the Inhoek soil form, pasture soils had significantly ($p < 0.001$) higher POM than the other land uses in the 0-1, 1-5, 5-10 cm depths, while in the Westleigh pasture was only higher in the 0-1 and 1-5 cm depths. Mean POM values were in the order of pasture (0.608%) > undisturbed (0.223%) > arable (0.118%). In the Oakleaf soil form, pasture soils had significantly ($p < 0.05$) higher POM than arable soils at all depths (Appendix 4.15; Figure 4.2D).

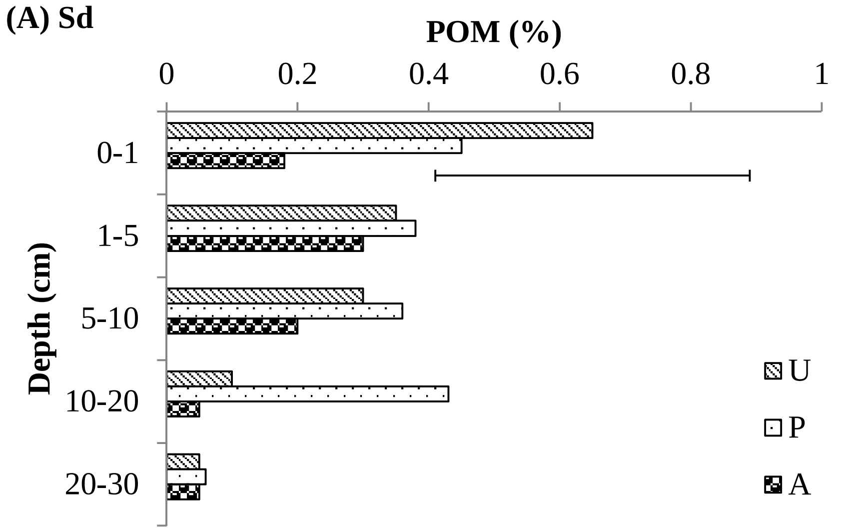

Figure 4.2A: The change in particulate organic matter (POM) in Sd: Shortlands soil form with depth (0-30 cm) under the U: undisturbed; P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

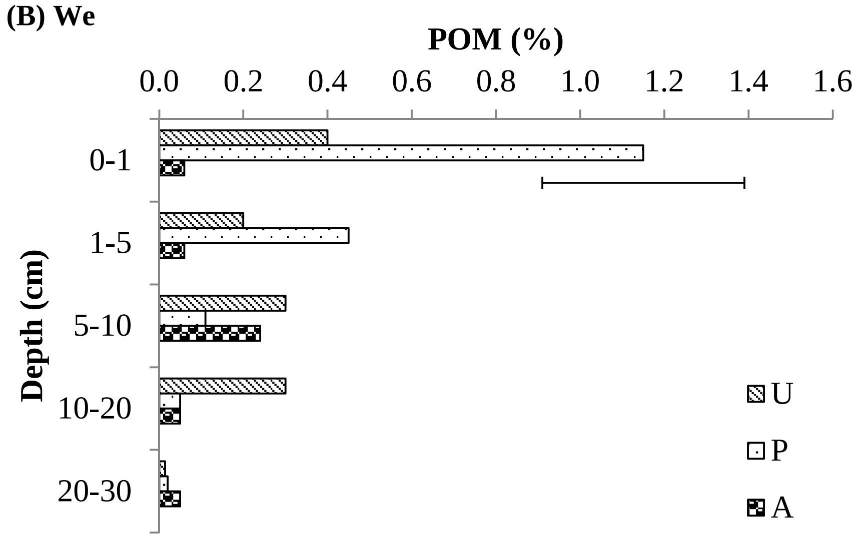

Figure 4.2B: The change in particulate organic matter (POM) in We: Westleigh soil form with depth (0-30 cm) under the U: undisturbed; P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

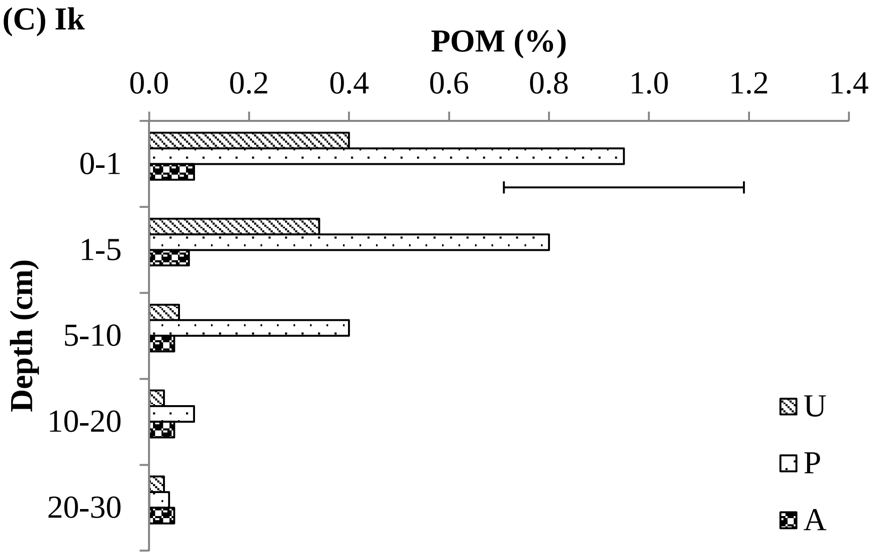

Figure 4.2C: The change in particulate organic matter (POM) in Ik: Inhoek soil form with depth (0-30 cm) under the U: undisturbed; P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

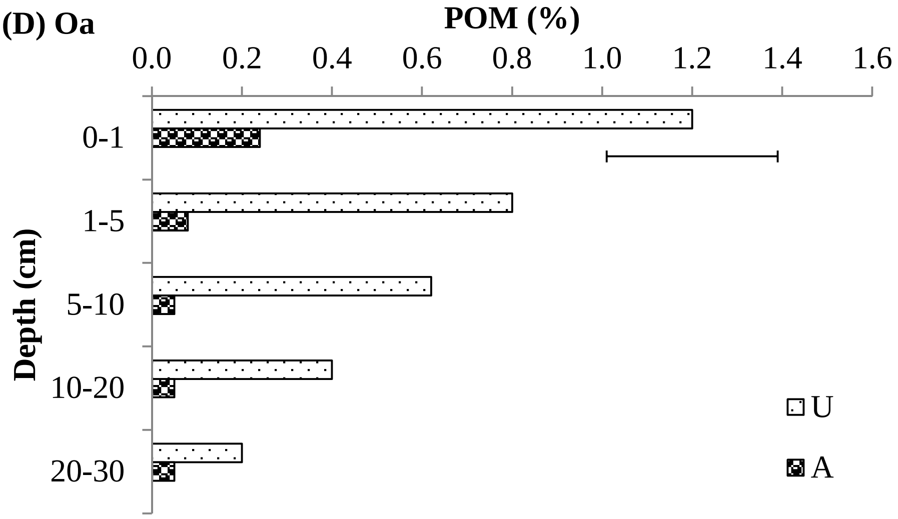

Figure 4.2D: The change in particulate organic matter (POM) in Oa: Oakleaf soil form with depth (0-30 cm) under the U: undisturbed; P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

4.6 Phosphorus

Although there were no interaction effects of soil depth and land use on soil P in the Shortlands, Westleigh and Oakleaf soil forms, these interaction effects were significant in the

Inhoek soil form (Appendices 4.16 and 4.17). In the 0-10 and 10-20 cm depths, pasture soils had lower P than the other land uses in the Shortlands, while in the Westleigh pasture and undisturbed were similar and higher than under arable (Figure 4.3 A and B). In the Oakleaf, the 0-10 cm depth under arable had higher P (18.6 mg kg^{-1}) than pasture (7.0 mg kg^{-1}) while the other depths for both land uses were similar (Figure 4.3D). There was a notable decline in soil P with depth for all soils across all land uses and there were no land use effects on soil P in any soil at the 20-30 cm depth. Available P was highly correlated to SOC in the undisturbed (r = 0.92), pasture (r = 0.72) and arable (r = 0.71) in the Shortlands soil (Appendices 4.28 and 4.29) than in the undisturbed Inhoek (r = 0.42) (Appendix 4.34).

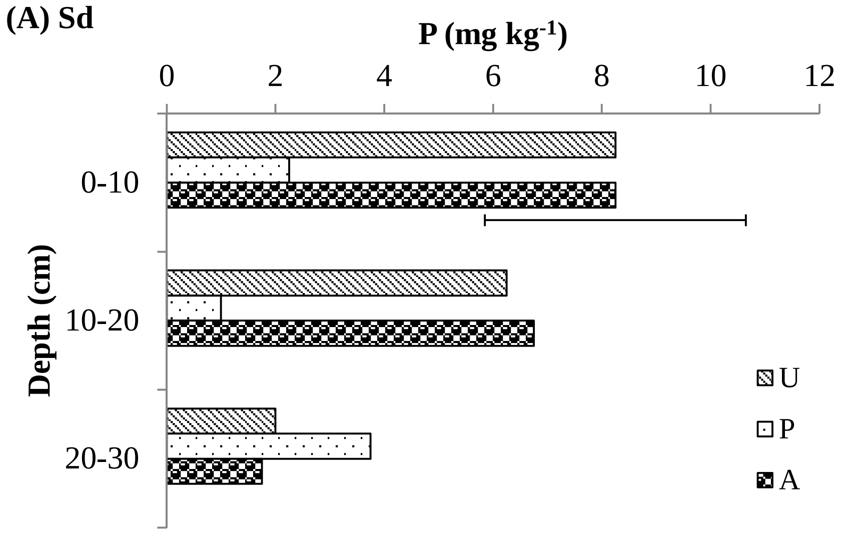

Figure 4.3A: The change in available phosphorus (P) concentration in Sd: Shortlands soil form with depth (0-30 cm) under U: undisturbed; P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

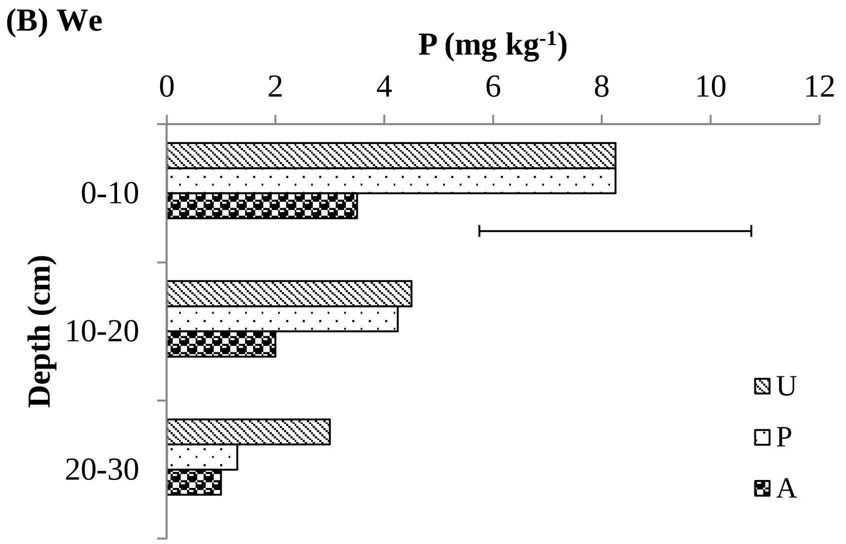

Figure 4.3B: The change in available phosphorus (P) concentration in We: Westleigh soil form with depth (0-30 cm) under U: undisturbed; P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

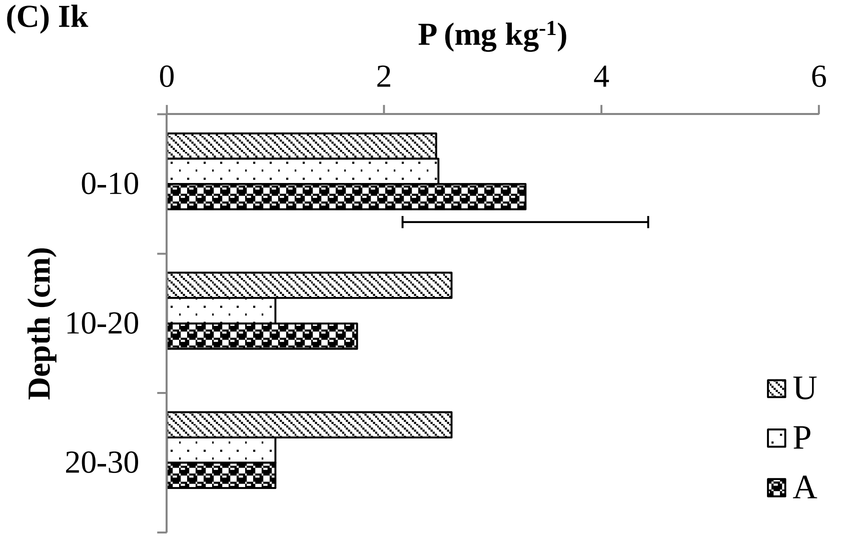

Figure 4.3C: The change in available phosphorus (P) concentration in Ik: Inhoek soil form with depth (0-30 cm) under U: undisturbed; P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

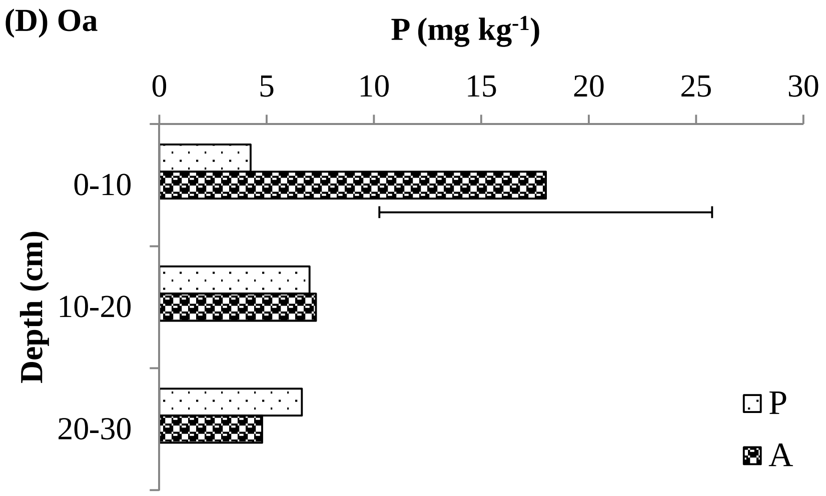

Figure 4.3D: The change in available phosphorus (P) concentration in Oa: Oakleaf soil form with depth (0-30 cm) under U: undisturbed; P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

4.7 Effective cation exchange capacity and base cations

There were no significant effects of land use on effective cation exchange capacity (ECEC) in the Shortlands, Westleigh and Inhoek (Appendix 4.18). However, pasture had significantly higher ECEC than the arable land use system in the Oakleaf soil form and under both land uses the distribution of cations was not significantly affected by soil depth (Appendix 4.19). For each land use the mean ECEC values (cmol$_c$ kg^{-1}) were in the order of arable (24.12) > pasture (19.29) > undisturbed (16.11) in the Shortlands, Westleigh and Inhoek (Figure 4.4A to C). However, in the Oakleaf for the two land uses the mean ECEC values (cmol$_c$ kg^{-1}) were pasture (14.9) > arable (7.40) (Figure 4.4D). No significant correlation was observed between ECEC and SOC in all land use systems. The ECEC was nevertheless correlated to clay in the undisturbed Shortlands (r = 0.80) (Appendix 4.27) and under pasture (r = 0.71) and arable (r = 0.72) in the Inhoek soil form (Appendices 4.35 and 4.36).

(A) Sd

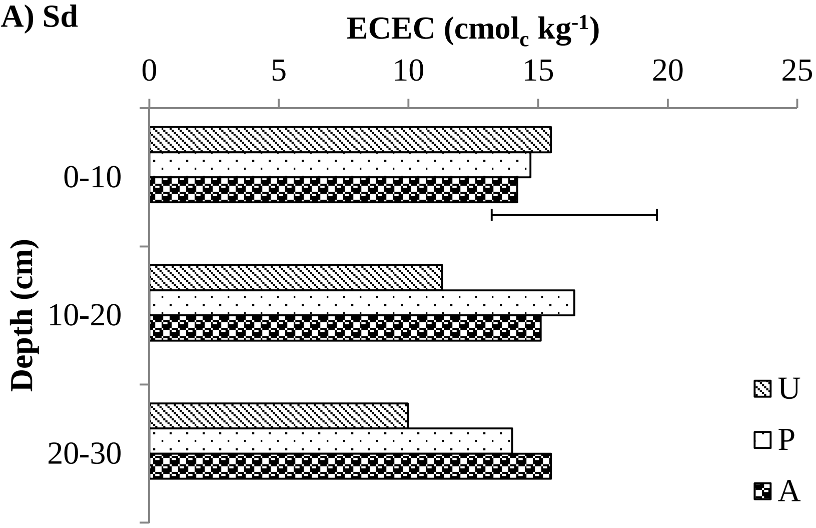

Figure 4.4A: The change in effective cation exchange capacity (ECEC) in soil forms Sd: Shortlands with depth (0-30 cm) under the U: undisturbed, P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

(B) We

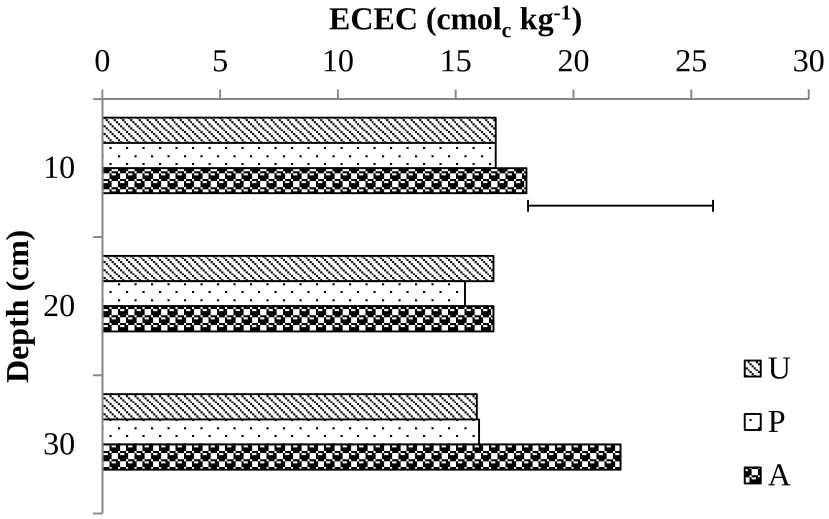

Figure 4.4B: The change in effective cation exchange capacity (ECEC) in We: Westleigh soil form with depth (0-30 cm) under the U: undisturbed, P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

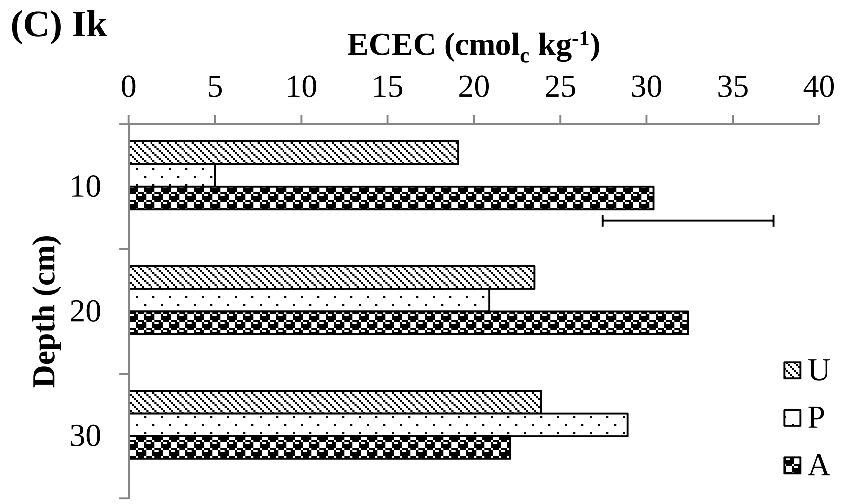

Figure 4.4C: The change in effective cation exchange capacity (ECEC) in Ik: Inhoek soil form with depth (0-30 cm) under the U: undisturbed, P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

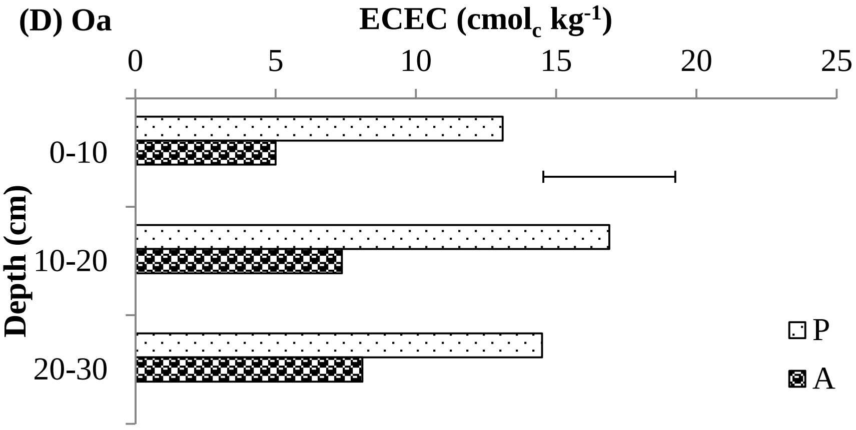

Figure 4.4D: The change in effective cation exchange capacity (ECEC) in Oa: Oakleaf soil form with depth (0-30 cm) under the U: undisturbed, P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

Because the dominant cations in all four soils were calcium (Ca) and magnesium (Mg) it is not surprising that the observed differences in Ca and Mg content related well to the ECEC under all the land use systems and that the ECEC was positively correlated to Ca and Mg in all the soil forms and land use systems (Appendices 4.28 to 4.38). As for ECEC, both these cations were not affected by land use and soil depth (Appendices 4.20 and 4.22). The highest exchangeable Ca and Mg values were recorded in the Inhoek soil form across all land use systems (Figures 4.5 and 4.6). Arable soils had higher amounts of Ca in the 20-30 cm depth of both the Shortlands and Westleigh soils and in the 0-20 cm depth of the Inhoek soil form. The overall mean values (cmol$_c$ kg^{-1}) of Ca were 11.8 (arable), 9.5 (pasture) and 9.4 (undisturbed grassland). Undisturbed grassland had the lowest Mg content which increased markedly with depth. The overall mean values (cmol$_c$ kg^{-1}) for exchangeable Mg were 8.3 (arable), 7.7 (undisturbed grassland) and 6.8 (pasture). In the Oakleaf soil form, the arable land use soil contained significantly more Ca (Figure 4.5D) and lower Mg (Figure 4.6D) than under pasture. The interaction of land use and soil depth was significant for Ca but not for Mg in the Oakleaf soil form (Appendices 4.21 and 4.23). The mean values (cmol$_c$ kg^{-1}) of Ca were 9.55 (arable) and 4.8 (pasture) while those for Mg were 2.3 (arable) and 4.9 (pasture).

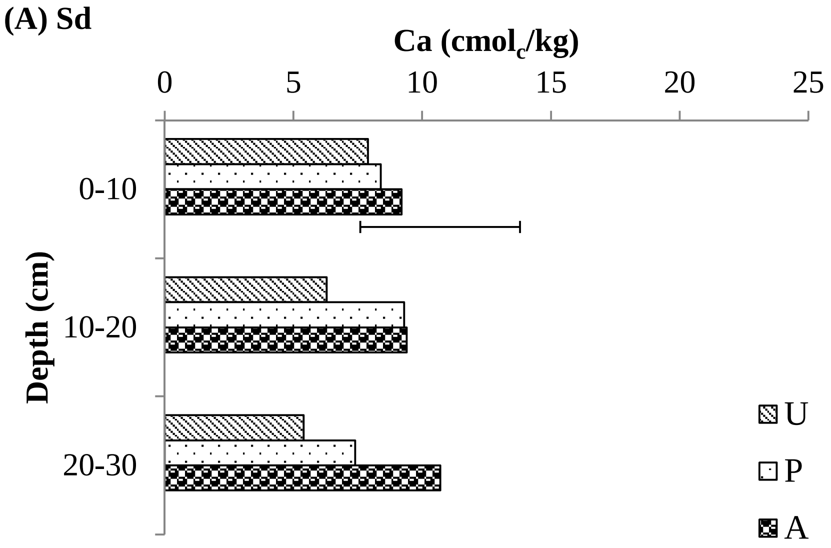

Figure 4.5A: The change in exchangeable calcium (Ca) concentration in Sd: Shortlands soil form with depth (0-30 cm) under the U: undisturbed, P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

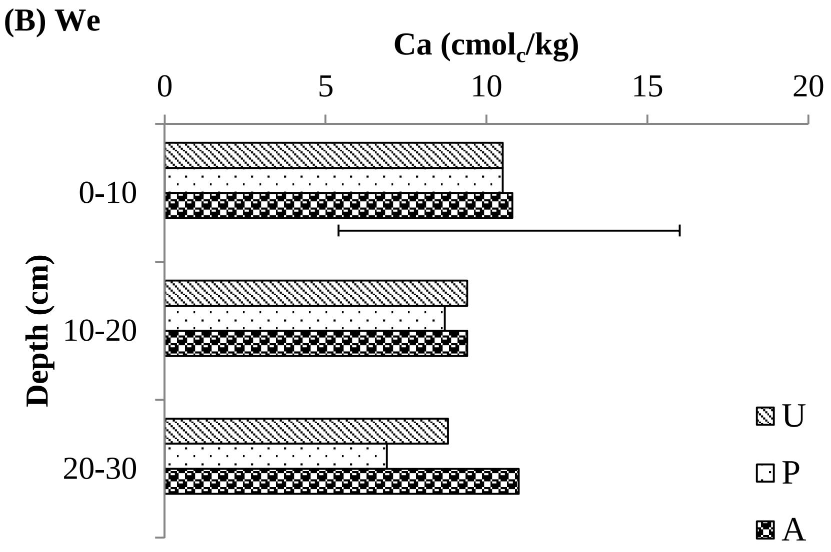

Figure 4.5B: The change in exchangeable calcium (Ca) concentration in We: Westleigh soil form with depth (0-30 cm) under the U: undisturbed, P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

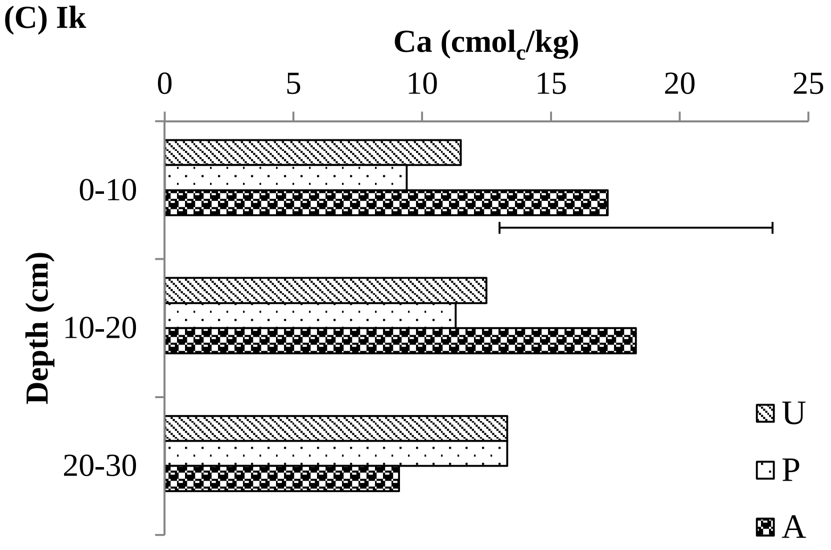

Figure 4.5C: The change in exchangeable calcium (Ca) concentration in Ik: Inhoek soil form with depth (0-30 cm) under the U: undisturbed, P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

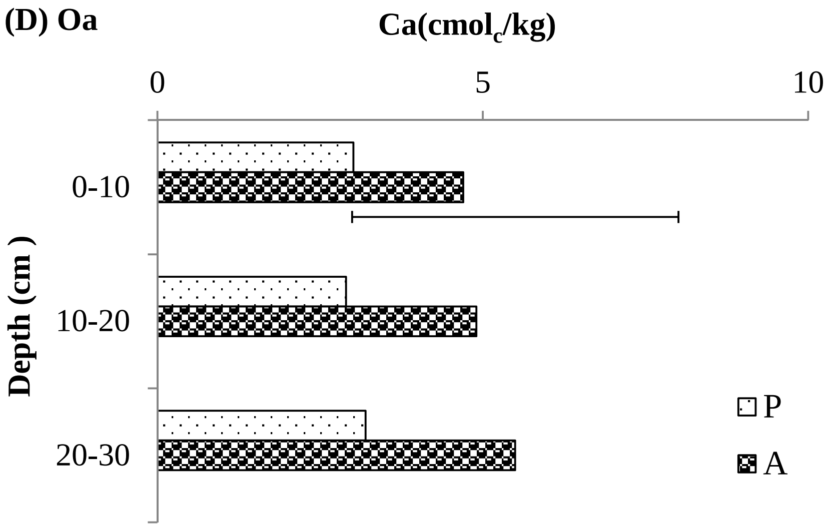

Figure 4.5D: The change in exchangeable calcium (Ca) concentration in Oa: Oakleaf soil form with depth (0-30 cm) under the U: undisturbed, P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

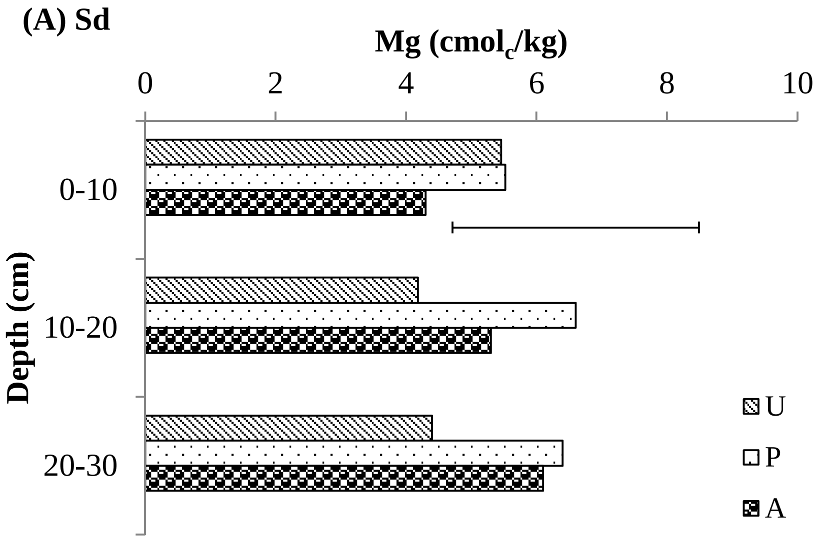

Figure 4.6A: The change in exchangeable magnesium (Mg) concentration in Sd: Shortlands soil form with depth (0-30 cm) under the U: undisturbed, P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

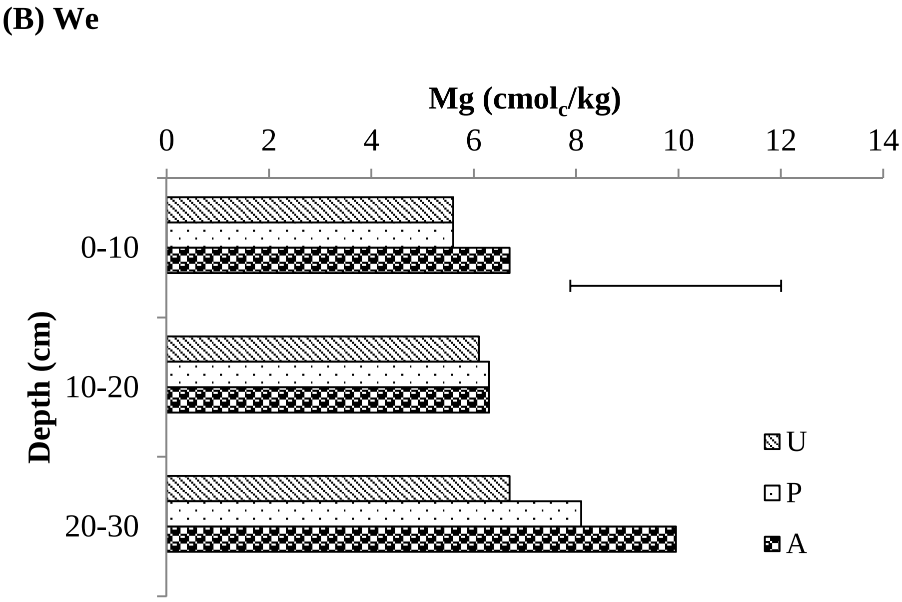

Figure 4.6B: The change in exchangeable magnesium (Mg) concentration in We: Westleigh soil form with depth (0-30 cm) under the U: undisturbed, P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

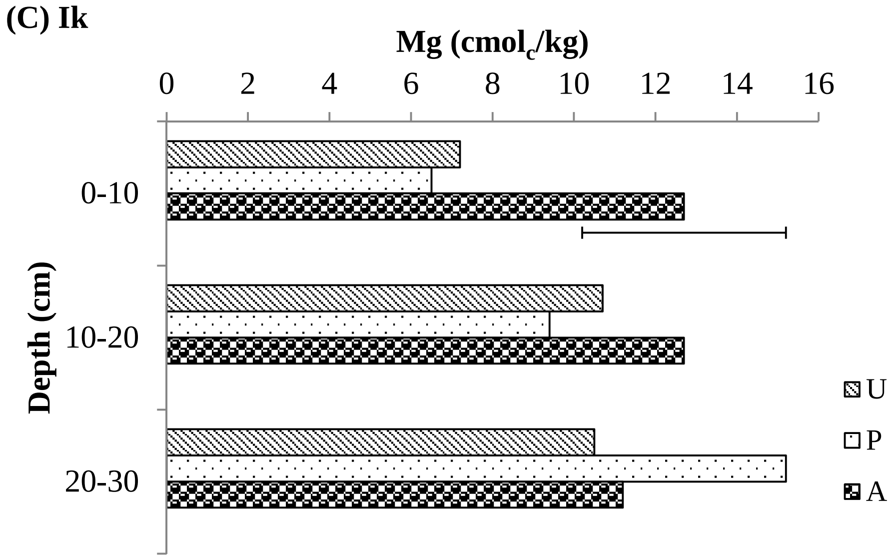

Figure 4.6C: The change in exchangeable magnesium (Mg) concentration in Ik: Inhoek soil form with depth (0-30 cm) under the U: undisturbed, P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

(D) Oa

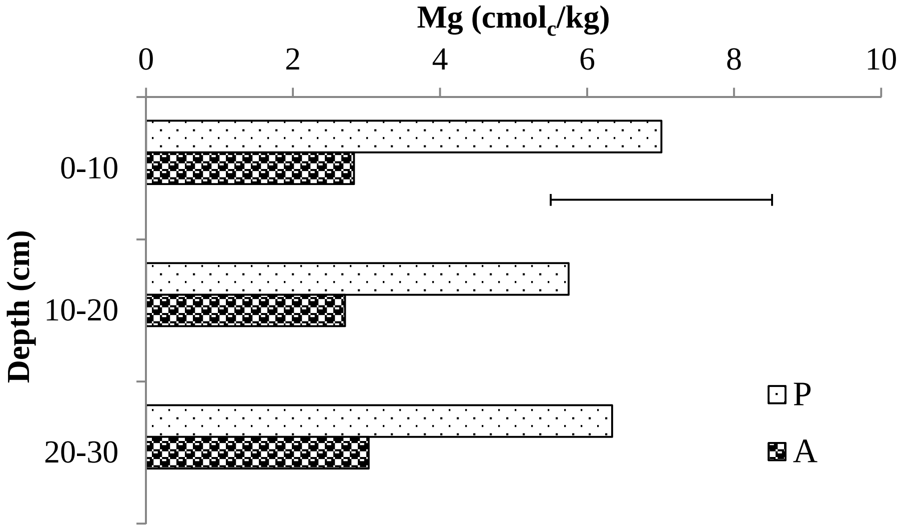

Figure 4.6D: The change in exchangeable magnesium (Mg) concentration in Oa: Oakleaf soil form with depth (0-30 cm) under the U: undisturbed, P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

The K content was significantly affected by land use and soil depth in the Shortlands soil form (Appendix 4.24). The mean K values (cmol$_c$ kg^{-1}) were 0.85 (arable), 0.65 (pasture) and 0.5 (undisturbed). Unlike Ca and Mg, the Westleigh contained more K under the arable and pasture land use systems even though the results were not significant. The Inhoek on the other hand had lower K values which were not affected by land use with the exception of the 20-30 cm depth for the undisturbed grassland (Figure 4.7A to C). In the Oakleaf, the interaction between land use and soil depth on K concentration was statistically significant ($p < 0.001$) (Appendix 4.25). While the K concentration in the 10-20 cm depth was lower than at 0-10 cm under the arable land use, under pasture, the 10-20 cm depth had higher K concentrations (Figure 4.7D).

In addition to K, soils under irrigated pasture had higher mean extractable Zn, Mn and Cu contents. The concentration of these nutrients also declined significantly with depth ($p < 0.001$). The effect of land use on Zn (mg kg^{-1}) follows the order: pasture (2.04) > arable (1.74) > undisturbed (0.82). Copper (mg kg^{-1}) followed the same order i.e., pasture (16.4) > arable (13.9) > undisturbed (13.8). Manganese (mg kg^{-1}), on the other hand showed a trend of pasture (24.0) > undisturbed (19.3) > arable (18.6). These observations were all statistically significant ($p < 0.001$). Higher concentrations (mg kg^{-1}) of Zn (2.33) and Mn (30.0) were obtained in the Shortlands soil form under the arable land use system. The Inhoek soils on the other hand, tended to have the lowest mean concentrations (mg kg^{-1}) of both Zn (0.60) and Mn (10.8) under native grassland and arable land uses, respectively. In the Shortlands under pasture the Cu content significantly ($p < 0.001$) increased with depth from 20.9 to 26.3 mg kg^{-1}.

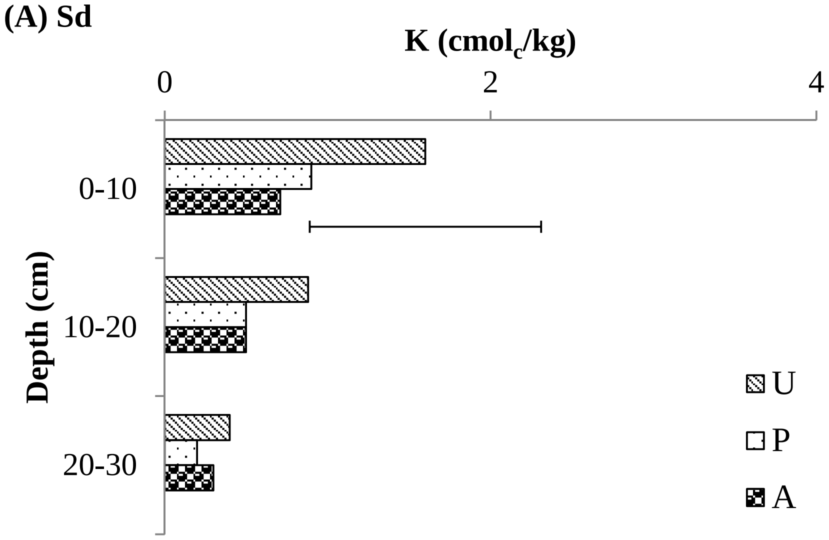

Figure 4.7A: The exchangeable potassium (K) in Sd: Shortlands soil form with depth (0-30 cm) under the U: undisturbed, P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

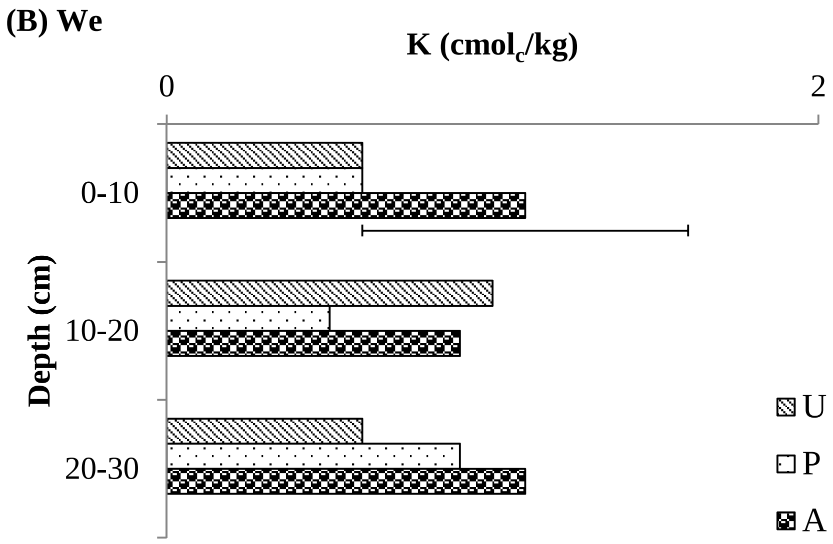

Figure 4.7B: The exchangeable potassium (K) in We: Westleigh soil form with depth (0-30 cm) under the U: undisturbed, P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

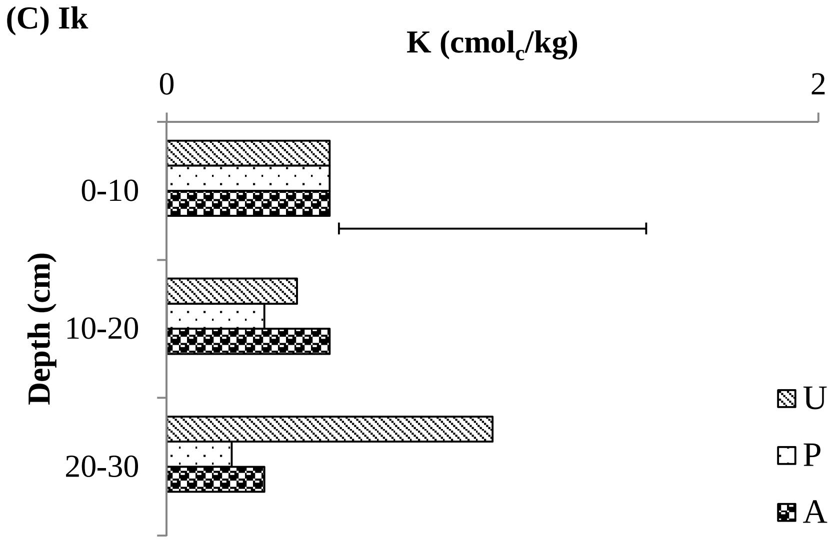

Figure 4.7C: The exchangeable potassium (K) in Ik: Inhoek soil form with depth (0-30 cm) under the U: undisturbed, P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

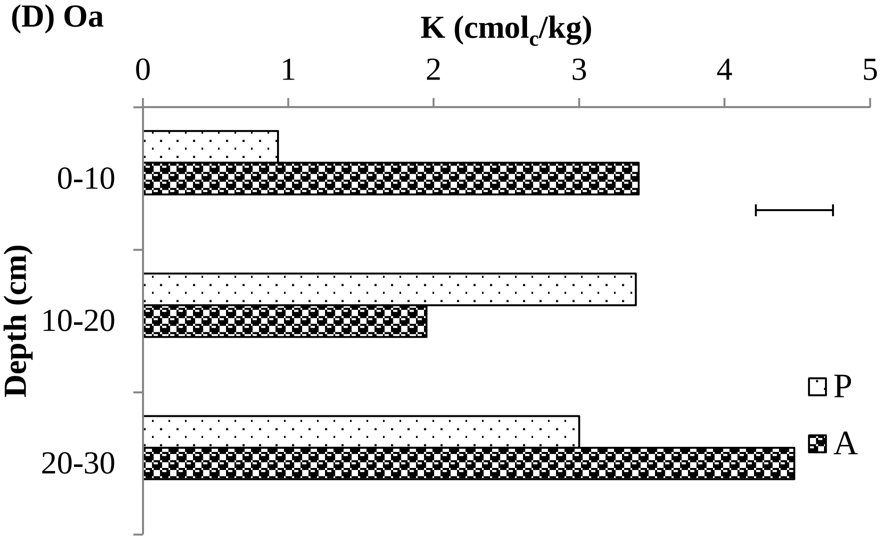

Figure 4.7D: The exchangeable potassium (K) in Oa: Oakleaf soil form with depth (0-30 cm) under the U: undisturbed, P: pasture and A: arable land use systems (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

4.8 Aggregate stability

The mean weight diameters (MWD) of aggregates in the four soils under the three different land use management systems as assessed by three different treatments are shown in Figures 4.8 (WT: water treatment), 4.9 (ET: ethanol treatment) and 4.10 (SCWET: slow capillary wetting ethanol treatment). The undisturbed land use showed significantly higher MWD values than the pasture and arable land use systems in all the treatments (Appendix 4.26). The WT showed significantly lower MWD values than ET and SCWET treatments under all land use systems. In the WT, the obtained MWD values were 2.74 mm (undisturbed), 2.61 mm (pasture) and 1.43 mm (arable). In the ET, the values were 3.11 mm (undisturbed), 2.85 mm (pasture) and 2.21 mm (arable) while in the SCWET values were 3.05 mm (undisturbed), 2.85 mm (pasture) and 2.27 mm (arable). In the Oakleaf, the MWD values were significantly ($p < 0.001$) higher under pasture than the arable land use system (Appendix 4.27). The interaction between soil depth and land use on MWD was not significant in all the treatments and land use systems. The Westleigh had the lowest MWD values under both undisturbed and pasture land use systems while the highest MWD values were obtained in the undisturbed Shortlands soil after the ET (Figure 4.9A).

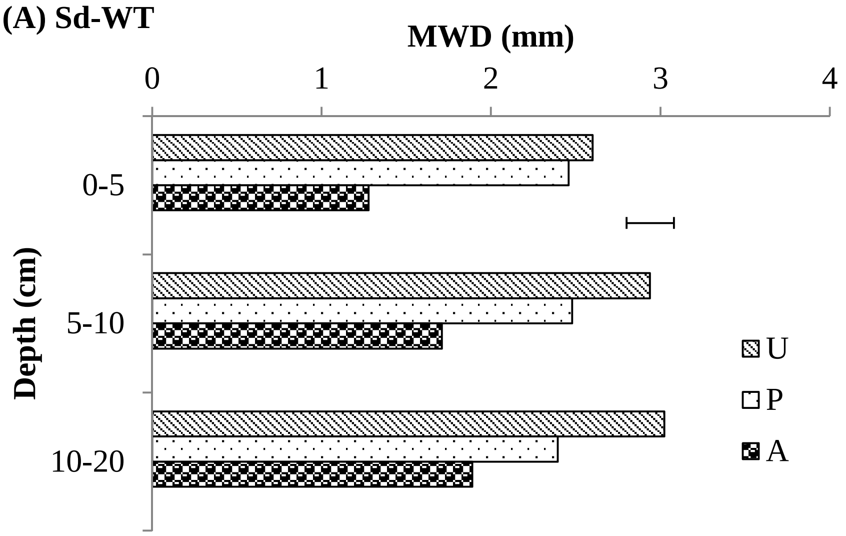

Figure 4.8A: The change in mean weight diameter (MWD) of the Sd: Shortlands soil form with depth (0-20 cm) under the U: undisturbed, P: pasture and A: arable land use systems using the water treatment (WT) (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

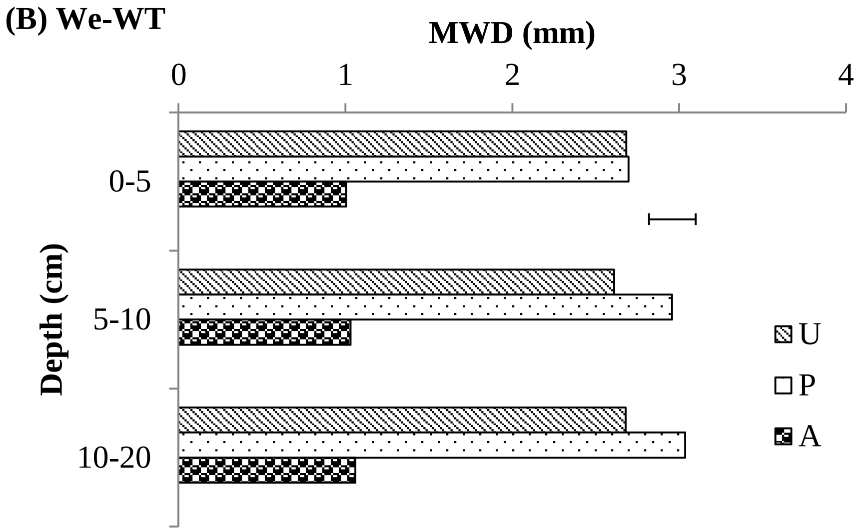

Figure 4.8B: The change in mean weight diameter (MWD) of the We: Westleigh soil form with depth (0-20 cm) under the U: undisturbed, P: pasture and A: arable land use systems using the water treatment (WT) (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

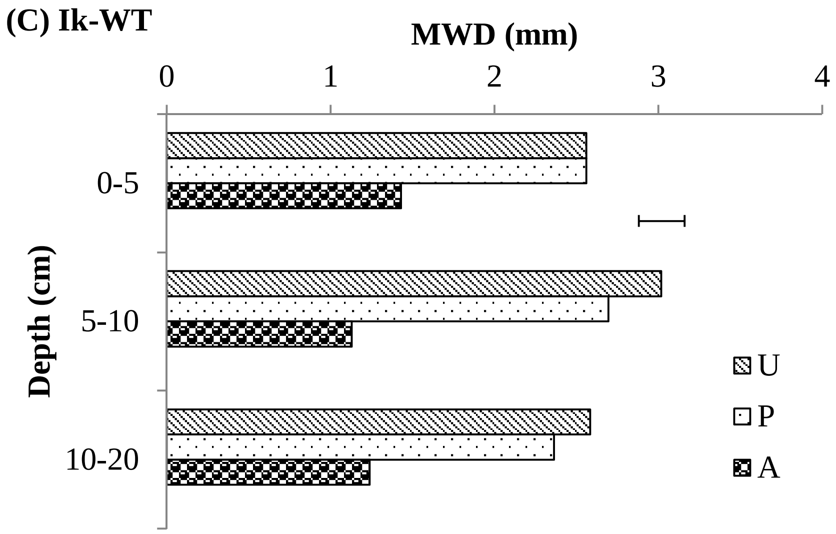

Figure 4.8C: The change in mean weight diameter (MWD) of the Ik: Inhoek soil form with depth (0-20 cm) under the U: undisturbed, P: pasture and A: arable land use systems using the water treatment (WT) (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

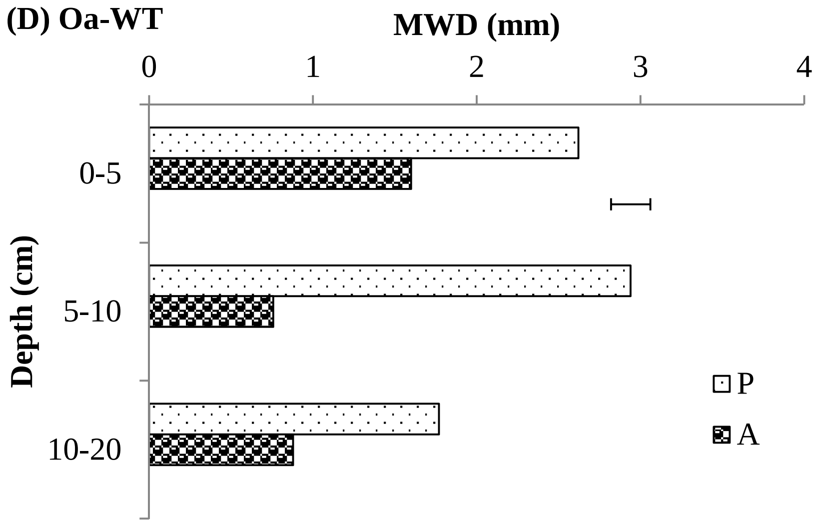

Figure 4.8D: The change in mean weight diameter (MWD) of the Oa: Oakleaf soil form with depth (0-20 cm) under the U: undisturbed, P: pasture and A: arable land use systems using the water treatment (WT) (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05

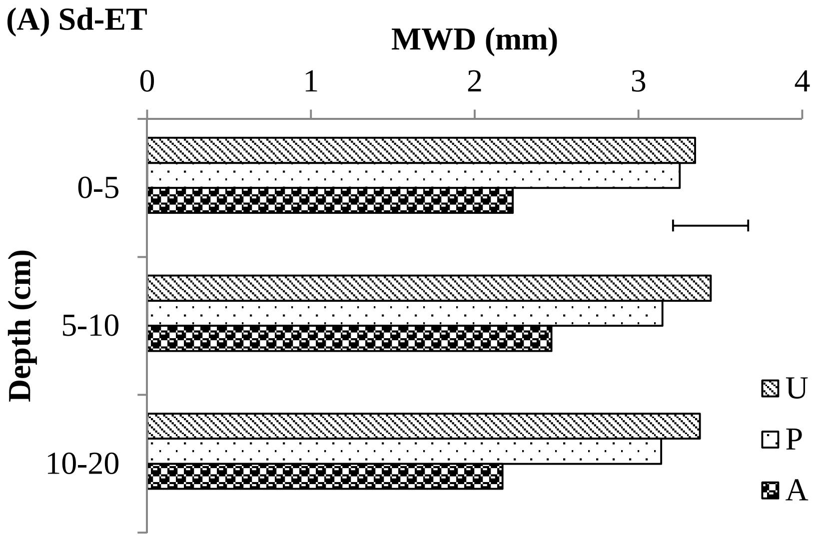

Figure 4.9A: The change in mean weight diameter (MWD) in the Sd: Shortlands soil form with depth (0-20 cm) under the U: undisturbed, P: pasture and A: arable land use systems using the ethanol treatment (ET) (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

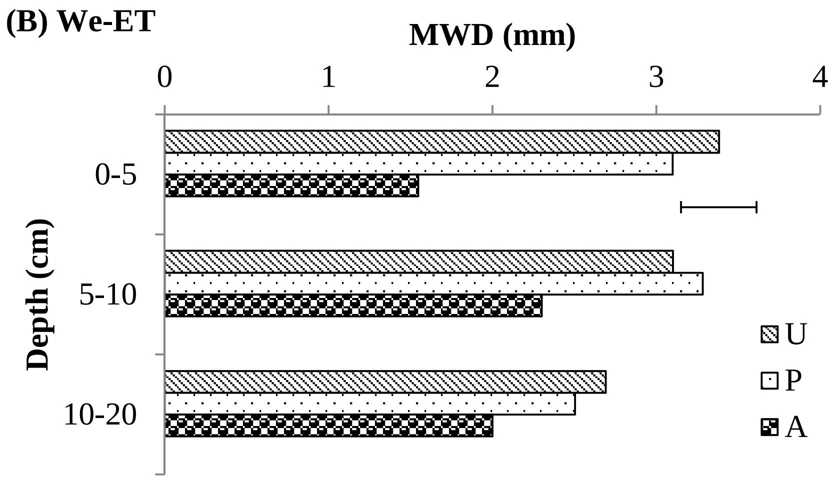

Figure 4.9B: The change in mean weight diameter (MWD) in the We: Westleigh soil form with depth (0-20 cm) under the U: undisturbed, P: pasture and A: arable land use systems using the ethanol treatment (ET) (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

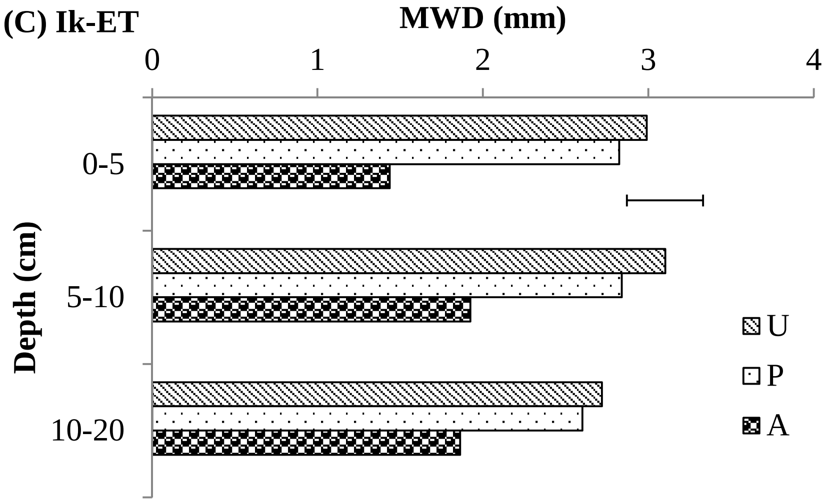

Figure 4.9C: The change in mean weight diameter (MWD) in the Ik: Inhoek soil form with depth (0-20 cm) under the U: undisturbed, P: pasture and A: arable land use systems using the ethanol treatment (ET) (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

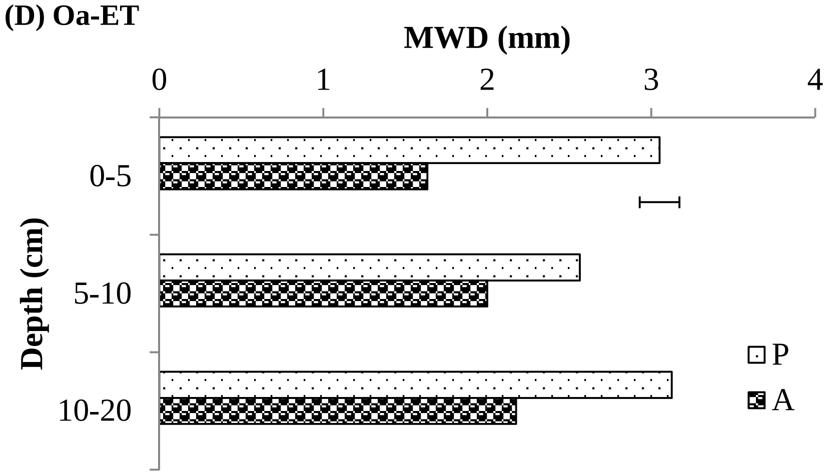

Figure 4.9D: The change in mean weight diameter (MWD) in the Oa: Oakleaf soil form with depth (0-20 cm) under the U: undisturbed, P: pasture and A: arable land use systems using the ethanol treatment (ET) (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

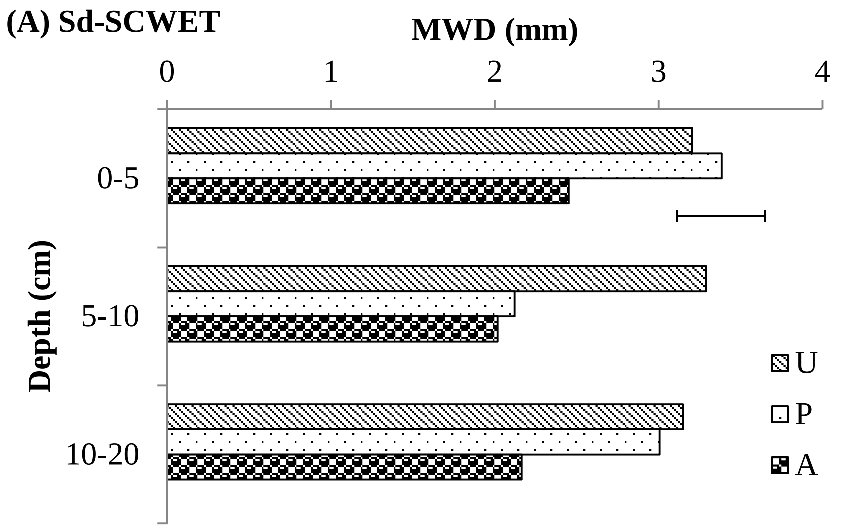

Figure 4.10A: The change in mean weight diameter (MWD) in the Sd: Shortlands with depth (0-20 cm) under the U: undisturbed, P: pasture and A: arable land use systems using the slow capillary wetting ethanol treatment (SCWET) (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

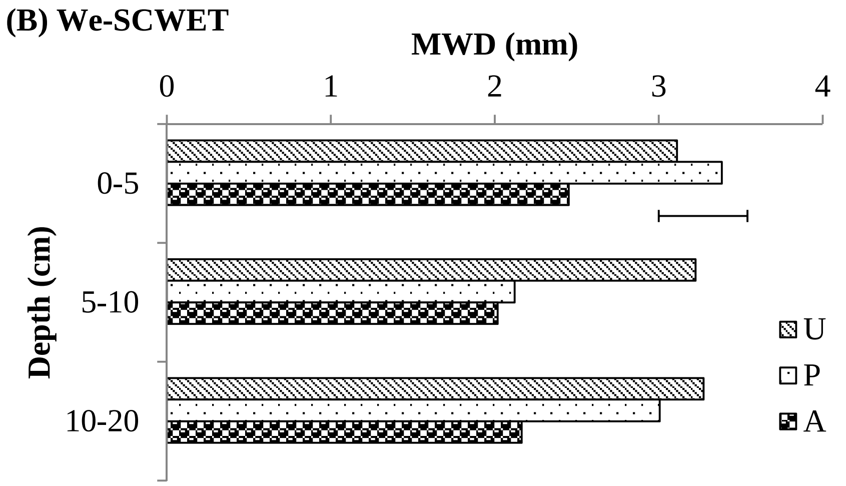

Figure 4.10B: The change in mean weight diameter (MWD) in the We: Westleigh soil form with depth (0-20 cm) under the U: undisturbed, P: pasture and A: arable land use systems using the slow capillary wetting ethanol treatment (SCWET) (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

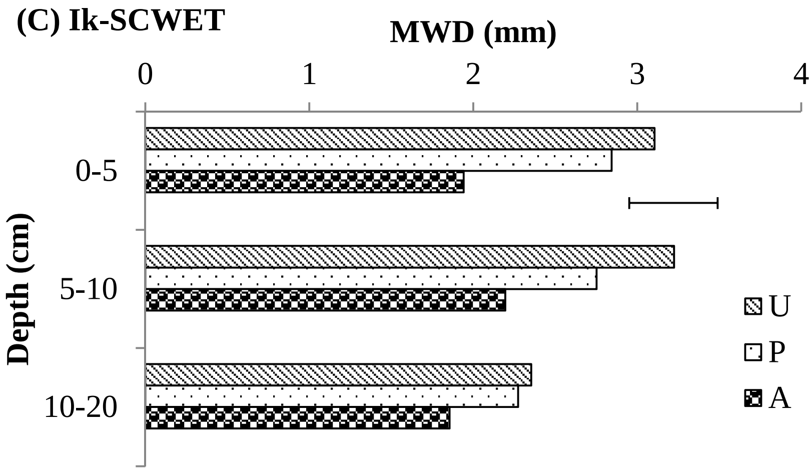

Figure 4.10C: The change in mean weight diameter (MWD) in the Ik: Inhoek soil form with depth (0-20 cm) under the U: undisturbed, P: pasture and A: arable land use systems using the slow capillary wetting ethanol treatment (SCWET) (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

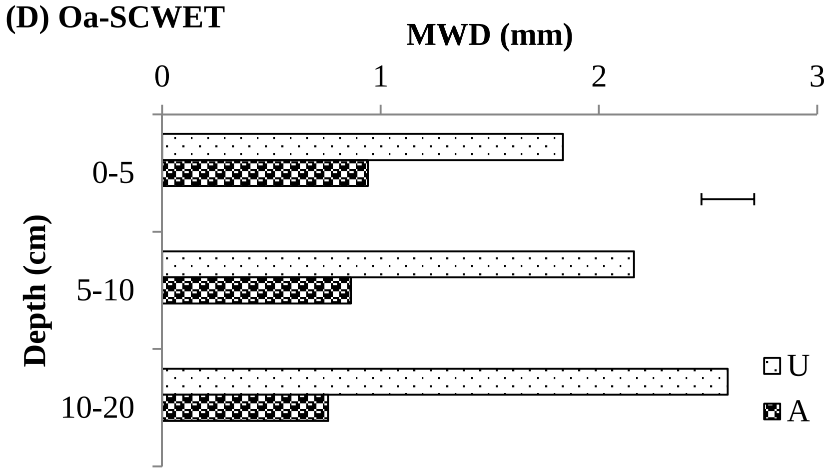

Figure 4.10D: The change in mean weight diameter (MWD) in the Oa: Oakleaf soil form with depth (0-20 cm) under the U: undisturbed, P: pasture and A: arable land use systems using the slow capillary wetting ethanol treatment (SCWET) (n = 4). The error bar represents the least significant difference (LSD) at p = 0.05.

In addition, the correlation of soil quality parameters with SOC was done through correlation matrix. The correlation between POM and SOC was only significant ($p < 0.05$) in the undisturbed Westleigh ($r = 0.62$) and pasture ($r = 0.53$) under the Inhoek soil form

(Appendices 4.31 and 4.35). Available P was highly correlated to SOC in the undisturbed (r = 0.92), pasture (r = 0.72) and arable (r = 0.71) on the Shortlands soil form (Appendices 4.28 and 4.29). No significant correlation was observed between ECEC and SOC in all land use systems. The ECEC was nevertheless correlated to clay in the undisturbed Shortlands (r = 0.80) (Appendix 4.27) and under pasture (r = 0.71) and arable (r = 0.72) in the Inhoek soil form (Appendices 4.35 and 4.36). K was highly correlated to the available P in the undisturbed (r = 0.78), pasture (r = 0.80) and arable (r = 0.50) land uses in the Shortlands soil form (Appendices 4.28 to 4.30) and in the undisturbed Westleigh (r = 0.96) (Appendix 4.31).

4.9 Summary

The conversion of native grassland into pasture and cropland affected the particle size distribution of the individual soils. In many cases, pasture and arable land use types had more clay than the undisturbed land use system with the exception of the Shortlands soil form. The clay content of the Inhoek increased with depth under the pasture and undisturbed land use systems and under all land use types in the Shortlands soil form. In the Westleigh and Oakleaf, clay initially decreased with depth and then increased markedly in the 20-30 cm depths of these soils. The SOC was lower under arable land compared to pasture and undisturbed grassland in all the soils. The POM was significantly higher under pasture than undisturbed and arable land use systems in the Westleigh, Inhoek and Oakleaf. The pH (H_2O and KCl) was affected by land use in the Shortlands and Inhoek soil forms and soils under the arable land use had slightly lower pH values than the pasture and undisturbed grassland. The exchangeable acidity on the other hand did not show much variation between land use systems. The available P did not show consistent trends between soil types and land use systems. The concentration of available P was higher in the Oakleaf under arable than pasture and in the Westleigh and Inhoek soils under the pasture and undisturbed grassland. As for pH, no clear trends were observed for ECEC between land use systems in all soil forms except for Oakleaf where values under pasture were significantly higher than under the arable land use system. The MWD determined by all three stability tests was higher in undisturbed and pasture soils compared to those under the arable land use system.

CHAPTER 5
DISCUSSION

5.1 Introduction

The need to maximise agricultural production with less environmental impact has renewed interest in assessing how land use systems and management influence soil properties and whether changes create any adverse effect on soil properties such as organic carbon, particulate organic matter, cation exchange capacity, available phosphorus and aggregate stability (Mueller *et al.*, 2009). This chapter discusses the effect of improved pasture and arable land use systems on some selected soil properties in the Shortlands, Westleigh, Inhoek and Oakleaf soil forms. The measurement of the soil properties for this study have been described in Chapter 3 and the results were outlined in Chapter 4.

5.2 Particle size distribution

Particle size distribution differed among the land use types. The higher clay fraction in soils under the pasture and arable land use systems may be due to the fact that trampling by animals and cultivation shears and pulverizes the soil to smaller particles (Nsbimana *et al*, 2004). These particles are further exposed to chemical weathering processes such as dissolution, oxidation and hydrolysis resulting in the re-arrangement of larger particles into more stable clay fraction (Kauffman *et al*., 1998; Tayel *et al*., 2010). These results are in contrast with those obtained by Adesodun *et al.* (2007) in Luvisols of the Hirmi watershed in the northern highlands of Ethopia. Their study showed lower clay contents and higher sand fractions following conversion of native grassland to pasture and cultivated land. They concluded that such results were due to the selective removal of clay particles by processes of erosion leaving behind the sand fraction. The differences in the results of these studies may therefore be attributed to the differences in climate, altitude and topography/slope of the study areas i.e. the higher altitude (1800-2500 m a.s.l.) and rainfall (1075 mm) of the Hirmi watershed result in more active erosion when compared to the much lower altitude (23-120 m a.s.l.) and rainfall (867 mm) at OSCA in northern KwaZulu-Natal.

5.3 Soil pH and exchangeable acidity

The pH (H_2O and KCl) results showed that arable land use produced slightly more acidic soils (6.31 and 5.10) than undisturbed (6.50 and 5.43) or pastoral (6.50 and 5.43) lands and although significant, the differences were generally small. The lower soil pH under the arable land use system is partly a result of excessive disturbance of the soil during seedbed preparation which causes high rates of organic matter turnover and its rapid decomposition. This view was supported by the lower organic C results in the arable soils compared to the other land uses. Through the process of decomposition, the reaction of CO_2 with H_2O forms both organic (H_2CO_3) and inorganic acids (H_2SO_4, HNO_3), which are potential suppliers of hydrogen ions in the soil encouraging the development of acidity (Esteban and Roberts, 2001). The continuous cultivation of the same land with resulting export of basic cations in harvested produce may also be another possible cause for decrease of pH in the arable fields. Additionally, nitrification of NH_4^+ originating from N fertilisers (LAN) and organic residues releases H^+ ions into the soil solution. As nitrate (NO_3) is leached down the profile Ca^{2+}, Mg^{2+} and K^+ usualy serve as counter-ions (Zhang *et al*,1996; Graham *et al*,1995; Dominy *et al.*, 2001). This leaves a higher concentration of H^+ in the surface layer, hence the pH drops. Covaleda *et al.* (2006) reported a considerable decrease of pH following conversion of virgin grassland into arable farming in Nitisols of Mexico.

The small differences in pH between land use types indicate that the soils in the study area are well buffered and is a reason why no major differences were found in exchangeable acidity in all the land use types. The low amount of exchangeable acidity in the topsoils of the study area could also be due to complexation with organic matter because it is in that layer where this is concentrated (White, 1981; Haynes and Swift, 1990). The observed increase of pH with depth in the undisturbed grassland site could be attributed to the uptake of cations by plant roots in the near surface or accumulation of basic cations from the parent material (Ashman *et al*., 2003). In the case of pasture land use, the notable decline of pH in the 10-20 cm depth may be a result of LAN fertilizer applied during the resowing period and as split dressings of 40 to 75 kg N ha^{-1} over the growing season.

5.4 Organic carbon

The results showed that soil organic carbon (SOC) concentration (%) was in the order: pasture (3.52) > undisturbed (3.37) > arable (1.85). The higher concentration of SOC under pasture may possibly be a result of less disturbance allowing more SOC build-up (Mills and Fey, 2003). Under pasture and undisturbed grassland, soil disturbance by cultivation is reduced and plant material is added to the surface (Six *et al*., 1998; Milne and Haynes, 2002; Voundi-Nkana and Tonye, 2002). This, together with the lower surface soil temperature and increased biological activity generally occurring under minimum cultivation, has been reported to increase in SOC content in the surface layer compared to those management systems where soil is cultivated (Six *et al*., 2002a; Kong *et al*.,2005; Puget and Lal, 2005; Mao and Zeng, 2010). The similarity of pasture and undisturbed grassland in the present study was in contrast to Boajilla and Gallali (2010), who reported lower SOC under pasture than the native grassland in three toposequences in Tunisia. The difference could be due to the differences in climatic conditions of the two places. The hot dry Mediterranean summers and mild winters of Tunisia generally favour less biomass production in the area (du Preez *et al*., 2011) when compared to the warm, moist conditions of the northern KwaZulu-Natal. The frequent irrigation of the pasture also favoured the rapid build-up of organic matter to a similar levels to that of the undistubed grassland. The mean SOC values for all land use types are nevertheless within the range of values reported by du Preez *et al*. (2011) for South African soils. On the other hand, the lower content of SOC in soils under arable cultivation might be due to the rapid decomposition and mineralization of organic matter subsequent to soil disturbance through cultivation (Leinweber *et al*, 1993; Dominy and Haynes, 2002). Cultivation increases soil organic matter breakdown because it aerates and disrupts soil aggregates which exposes previously protected SOC to microbial degradation (Kong *et al*., 2006; Tayel *et al*., 2010).

In the Oakleaf soil form, the SOC decreased with depth under pasture, since most inputs of organic matter under pasture occur close to the soil surface (Six *et al*., 2002b). In contrast, the 0-30 cm depth under arable land use contained relatively uniform amounts of SOC because cultivation had altered the distribution of C with depth. The results also showed different significant heterogeneity within the same land use. For example, the mean SOC (%) for pasture land use was 3.06, 3.94, 3.57 and 2.41 in the Shortlands, Inhoek, Westleigh and Oakleaf respectively. While the distribution of SOC in these soils may be related to land use effect, various horizon forming processes active in the individual soil form could have also contributed. Shortlands and Inhoek were expected to have higher SOC due to their significant natural SOC arising from intense faunal activity (Koutika *et al*., 1997; Kauffman *et al*., 1998). The higher SOC in Westleigh compared to Shortlands on the other hand was not expected since, Westleigh has poor chemical properties in nature due to its low biological activity (du Preez *et al*., 2011). The sandy texture of the Oakleaf might have played a major role in the lower concentration of SOC obtained in this soil form, directly by affecting the biomass production of the pasture (less than under the more clay rich soils) and indirectly by allowing faster decomposition of the organic matter due to greater aeration.

5.5 Particulate organic matter

Conversion of undisturbed grassland to cultivated land decreased soil organic matter and, due to its high sensitivity to management (Six *et al.*, 1999; Tornquist *et al*, 1999; Dorner *et al.*, 2009; Boajilla and Gallali, 2010), the particulate organic matter (POM) fraction decreased from 0.223% (undisturbed) to 0.118% (arable). The wider plant spacing, removal of the harvested crop and residue removal resulted in lower biomass input under arable soils hence lower POM. However, the greater accumulation of POM under pasture (0.608%) is attributed to the greater productivity of the grass sward following fertilization with LAN and hence larger returns of litter than on the undisturbed land (Mills and Fey, 2004b). The POM is a fraction of organic matter that depends on the intermediate products of the decomposition of litter as well as roots (Cambardella and Elliot, 1992). It has been reported in a number of studies (Haynes *et al.*, 1991; Six *et al.*, 1999; San Jose and Motes, 2001; Dorner *et al.*, 2009) that the SOC is usually positively correlated with POM as was observed in the undisturbed (Westleigh) and pasture (Inhoek) land uses in this study.

5.6 Phosphorus

Overall results of available P indicated no consistent change between land use systems. It would be expected that under undisturbed grassland and pasture the recycling of vegetation would increase the soil organic matter and thus the available P content in the near surface layers. Available P is also recycled during grazing periods through cattle dung under these land use systems (Naidu *et al*, 1996; Saikh *et al.*, 1998; Six *et al.*, 1999; Geissen *et al.*, 2009). By contrast, in an arable land use system, crops are harvested so P is not returned to the soil and its concentration falls as was observed in the 0-10 and 10-20 cm depths of the Westleigh soil form in this study. The higher amount of available P under the arable land use as observed in the Oakleaf, Shortlands and, to a lesser extent, the Inhoek soils may partly be due to the greater addition of P fertilizer to these soils. Lilienfein *et al.* (2000) reported significant differences between three land use systems on Brazilian red soils. Their study compared arable agriculture with native savanna soils and it showed a 28% increase of available P in soils under arable agriculture compared to native savanna soils due to regular fertilization. Many studies have reported a greater P concentration in the 0-20 cm depth (plough layer) following P fertiliser application (Paustian *et al*, 1997; Saikh *et al.*,1998; Six *et al.*, 1999; Ishaq *et al.*, 2002; Milne and Haynes, 2002; Bekwet and Stroosnijder, 2003). Hajabbasi *et al.* (1997) however, reported no significant differences in available P between virgin grassland, pasture and mixed cropping fields on the Luvisols of Broojen, Iran. Similar results were obtained by Aghasi *et al*. (2010) who investigated the decline in soil quality as a result of land use change from natural grassland to pasture and wheat production in Nitisols of Semirom, Iran.

The overall mean P values in the Oakleaf soil form varied between 7 (pasture) and 18.6 (arable) mg kg^{-1} and these results are slightly higher than the range of 5.5 (pasture) to 15.9 (arable) mg kg^{-1} reported by Geisen *et al.* (2009) in tropical soils of Mexico. The small differences in results of the two studies is most likely to be a result of higher P fertilisation rates in pasture (15 kg P ha^{-1}) and arable (25 kg P ha^{-1}) land use systems of northern KwaZulu-Natal compared to pasture (10 kg P ha^{-1}) and arable (19 kg P ha^{-1}) in Mexico. The mean available P values for the Shortlands, Westleigh and Inhoek on the other hand are too low and may partly be attributed to the higher clay contents of these soils compared to the Oakleaf soil form. Alves and Lavorenti (2004) studied the effects of clay content on available P in 15 different soils of the São Paulo State, Brazil. Nine of the soils were clayey, two very clayey and three had medium texture while one was very sandy. In their results, soils that had higher clay contents fixed more P than medium and coarse textured soils. It was concluded that available P is to some extent dependent on the clay type and content of a given soil.

The observed differences in P with depth seem to relate well with the obtained levels of SOC and POM observed per soil depth across all the land use systems. According to Zhang and Mackenzie (1997), most P exists in organic form and since P is very stable in the soil, it is a good indicator of organic matter accumulation as was shown by the positive correlation between available P and SOC in the Shortlands and undisturbed Inhoek in this study. While a positive correlation between SOC and available P has been reported by Tisdale *et al.* (1993), a significant ($p > 0.05$) negative correlation between these soil properties was observed by Sumann *et al.* (1998) in soils on the North American Great Plains. The forms and dynamics of soil P are generally affected by agricultural management practices which often involve dramatic changes to vegetation cover, biomass production, soil organic matter content and nutrient cycling in the ecosystem (Wright and Horns, 2004; Dorner *et al*., 2009). In addition, climate, land use and time also influence P dynamics (Reeves, 1997; Hartemink *et al*., 1998).

5.7 Effective cation exchange capacity and base cations

The weak correlation between effective cation exchange capacity (ECEC) and SOC in all the land use systems indicates that the organic matter did not recycle significant concentrations of base cations in these soils. The significant concentration of bases observed in these soils is rather a result of base rich parent material accompanied by low rainfall which favours less leaching of bases in the soils of the study area. The clay content seems to be a greater driving factor of the ECEC determination than SOC (Tayel *et al*., 2010) as was shown by a stronger correlation between ECEC and clay under pasture ($r = 0.71$) and arable ($r = 0.72$) land uses in the Inhoek soils as well as in the undisturbed Shortlands ($r = 0.80$). This was also shown by the lack of correlation between ECEC and SOC in the Westleigh and Oakleaf soils which were characterised by lower clay content even though these results were not significant. Therefore, the ECEC in these soils (Westleigh and Oakleaf) may possibly be a result of pH rather than SOC and clay type or content. The ECEC is crucial as an indicator of soil fertility in that it (i) affects the quantity of nutrients available to plants as exchangeable cations, and (ii) influences the degree to which hydrogen and aluminium ions occupy the exchange complex and thus affects the pH of soils (Sanchez *et al*., 2003). The overall ECEC of 16.74 to 17.66 $\text{cmol}_c\ \text{kg}^{-1}$ would be considered to be at moderate levels by Estenban and Robert (2001). Buol *et al.* (1975) noted that soils with an ECEC of 4 $\text{cmol}_c\ \text{kg}^{-1}$ or less had limited ability to retain nutrient cations.

Even though exchangeable Ca values were not significantly different between the three land use systems, a higher concentration of this cation was observed under the arable land use type. This was probably due to frequent calcium carbonate applications on the arable fields. Overall values of exchangeable Mg (in all land use types) were lower than those of Ca and this was ascribed to the higher Ca content in soils across the study area, and because it is held more strongly than Mg on the colloidal complex (Jobbagy and Jackson, 2004). These results coincide with Dominy and Haynes (2002), who described a large increase in soil Ca and Mg after conversion of undisturbed grassland into sugarcane plantations. The increase of Ca and Mg contents with soil depth (0-20 cm) suggests that the vertical distribution is influenced mostly by weathering (Jobbagy and Jackson, 2004; Muelller *et al*, 2010). The continuous supply of cations from the base rich parent material accompanied by the dry the climate of the study area are the main driving factors of Ca and Mg accumulation in these soils. Similar results were obtained by Kabrick *et al*. (2011) who concluded that parent material influenced Ca and Mg concentration through weathering which subsequently affected the ECEC in the

0-30 cm depth in Ozark forestry, Arkansas, United States of America. The overall mean Ca and Mg values obtained in the present study are higher than those reported by Raji and Ogunwole (2006) in a study to determine the effect of improved land use types on soil quality at Ibadan, Nigeria. The selected land uses included native grassland, pasture and cowpea cultivation. Such differences in results could possibly be due to the higher rainfall of Ibadan compared to OSCA and hence more leaching of bases in the Nigerian soils. As expected, Ca and Mg were correlated with the ECEC in all soil forms at OSCA.

While the higher K levels in the top 0-10 cm of the arable soils could be a result of K fertilizer application, the higher concentrations of this cation in deeper layers under pasture (and the 20-30 cm depth under arable) may be due to leaching leading to a reduction of K content in the upper layers (Shepherd, 2003; Aghasi *et al.*, 2010). The mean K values ($cmol_c$ kg^{-1}) obtained in this study are in the order of arable (3.33) > pasture (2.55) > undisturbed (1.95) and they concur with the results of Raji and Ogunwole (2006) who reported K values ($cmol_c$ kg^{-1}) of 2.23 (cowpea), 2.13 (pasture) and 2.10 (native grassland) in Nigerian soils. As for Ca and Mg, the K values for the Nigerian soils are howver lower than OSCA soils. While difference in rainfall might be the cause, the granite derived soils from Nigeria would also be expected to have lower amounts of bases.

5.8 Aggregate stability

In the WT and SCWET, the dominant breakdown mechanism is slaking, with intensities that differ according to the wetting rate of the aggregates (Le Bissonnais, 1996). The WT test corresponds to a rainfall of strong intensity (> 30 mm $h\text{-}^{1}$; Legout *et al.*, 2005), and hence more intense slaking is observed because of the greater compression of entrapped air inside the aggregates when suddenly immersed in water. The extent of aggregate breakdown is therefore reflected by a smaller mean weight diameter (MWD) of a given soil as was shown by the lower MWD values from the of the WT treatment of all the soils irrespective of the land use or soil type in this study. On the other hand, SCWET involves a weaker disruptive energy since the aggregate wetting is done gradually by capillarity. In addition, minimal or no slaking occurs during the ET since aggregate porosity is saturated with ethanol that decreases surface tension and contact angle and thus favours water penetration (Le Bissonnais, 1996). As a response to both SCWET and ET, soils subjected to these tests tend to have higher MWD values (Le Bissonnais, 1997; Boajilla and Galali, 2010) than those subjected to the WT test as was observed in the current study.

The lowest MWD value (1.43 mm) recorded in the arable land use system from the WT test indicates that these soils are generally stable with low risk of surface sealing, overland flow and interrill erosion (Le Bissonnais, 1996). On the other hand the WT, ET and SCWET tests results from the undisturbed and pasture land uses all showed MWD values greater than 2 mm indicating very stable soils such that sealing, overland flow and interrrill erosion will be very rare (Le Bissonnais, 1996). The lower MWD value under the arable land use system reflects the effect that cultivation has had on weakening soil structure. The correlation between SOC and MWD was positive but weaker in the Shortlands soils (r = 0.41) compared to the undisturbed Inhoek (r = 0.66). A positive correlation between SOC and MWD is commonly observed (Haynes and Williams, 1993; Haynes and Beare, 1994; Bouajila and Gallali, 2010) and reflects the central role of organic matter in formation and stabilization of soil aggregates (King and Campbell, 1994; Hartemink, 1997). The role of SOC in aggregate stability is, however, still a controversial issue worldwide because other workers e.g. (Carter, 2002, Madikizela, 2014) have found no correlation between aggregate stability and SOC (as observed in the Westleigh and Oakleaf soils in the present study), suggesting that some components of the organic carbon pool are more actively involved in stabilizing aggregates than others (Amezketa, 1999).

In the Shortlands soils the stability of aggregates seemed to be more dependent on clay content than SOC under all the land use systems. This was shown by stronger correlations between MWD and clay in the undisturbed (r = 0.55), pasture (r = 0.65) and arable (r = 0.51) land use systems. Clay content influences soil aggregate stability both directly and indirectly. Directly, the clay easily flocculates because of its colloidal properties and increases the soil aggregate stability. Indirectly, clay holds cations which bind the soil particles together and increase the stability of soil aggregates (Islaim and Weil, 2000; Bronick and Lal, 2005; Fey *et al*, 2006). The overall aggregate stability results nevertheless concur with those of Bouajila and Gallali (2010) who described a large decline in MWD after conversion of virgin grassland (2.79 mm) to pasture (2.10 mm) and mixed cropping (1.70 mm) land use systems.

5.9 Summary

The arable land use system had a higher clay content at all depths than other land use types mostly clearly in the Westleigh and Inhoek soil forms. Arable farming also reduced the distribution of SOC and POM while the pasture land use system increased or maintained the quantity of these soil components. The stability of aggregates was similar in the undisturbed and pasture land use systems and stronger than that of the arable land use system at all depths for all soils. No clear trend of available P was observed except for the Oakleaf soil form where arable land use had higher P than pasture. The ECEC was higher under the arable land than in soils under the undisturbed and pasture land uses soils except in the Oakleaf soil form where pasture had higher ECEC values than those of the arable land use system. The arable soils had slightly lower pH values but the exchangeable acidity results were very low indicating the absence of Al on the exchange sites.

CHAPTER SIX
CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

6.1 Introduction

A change in land use, mainly through conversion of undisturbed grasslands to pasture or cropland, influences many natural phenomena and ecological processes (Mills and Fey, 2004a) leading to considerable changes in soil properties (Six *et al.*, 1999). This study was initiated to determine the effects of converting undisturbed grassland into pasture and arable land use at Owen Sitole College of Agriculture (OSCA) in northern KwaZulu-Natal. The soil parameters measured were pH, exchangeable acidity, soil organic carbon (SOC), particulate organic matter (POM), available phosphorus (P), effective cation exchange capacity (ECEC), exchangeable bases (Ca, Mg and K) and aggregate stability. These parameters were compared under the three land use types (undisturbed, pasture and arable) in Shortlands, Westleigh, Inhoek and Oakleaf soil forms.

The findings of this study suggest that under different land uses, SOC is mainly a function of land-use. The pasture land use system significantly increased or maintained the quantity of POM, SOC, pH and aggregate stability, whereas the arable farming significantly affected these properties negatively. This implies that the use of land should be adapted to its natural conditions and that regulations must be provisioned that protect the environment. In the case of OSCA, conversion of undisturbed grassland to arable fields has not been beneficial to POM, SOC and aggregate stability. The progressive loss of POM, SOC and aggregate stability under arable agriculture, as compared to pasture and undisturbed grassland, is likely to leave the soils more susceptible to structural breakdown and surface compaction (Shepherd *et al.*, 2000; Shepherd *et al.*, 2001), and these factors may well be limiting production. Therefore, long term monitoring of soils at the College is the most reliable way to measure changes in soil attributes and link them to a land management plan. It can be concluded that conversion of undisturbed grassland to arable agriculture affected both the physical and chemical properties of the soils in the study area. This study revealed that pasture production is the most appropriate land use that can be implemented when native grasslands are converted to another agricultural land use at OSCA.

There is, however, a need to extend this research to investigate soil properties that were not measured in the present study. These may include the role of soil biological activity, hot water soluble carbon, clay mineralogy, bulk density (BD), electrical conductivity (EC) and sodicity. Soil biology strongly influences all the physical and chemical properties. The soil biological activity is regarded as a crucial indicator of changes that have occurred in the soil environment (Beare *et al*., 1994), therefore its consideration will properly broaden the subject. While SOC is related to a set of soil chemical, physical and biological attributes as well as temporal and spatial variations, changes in total SOC content may be difficult to detect because of the natural soil variability. In general, biological properties and water soluble carbon are much more sensitive to soil management than is SOC as a whole. The four soil forms used in this study behaved differently in numerous ways and some of the underlying reasons for such behaviour may relate directly to the type of clay minerals occurring in each soil. Therefore a better understanding of the detailed nature of clay minerals in each soil and the way in which they relate to overall soil chemical and physical properties would provide a sound basis for being able to predict, at least in general terms, soil behaviour in the context of land use change. The determination of bulk density would also broaden this subject as many studies worldwide (Boone, 1994; Amezketa, 1999; Mills and Fey 2004a; Abu, 2013) have reported a significant increase in bulk density when undisturbed land is converted to arable agriculture.

Lastly, there is a need to extend this study to other South African regions where comparable land uses can be found. This would allow other landscape factors such as climate, topography, parent material and vegetation to be investigated.

REFERENCES

Abu, S.T. (2013). Evaluating long-term impact of land use on selected soil physical quality indicators. Nigeria. *Soil Research*, 51, 47-476.

Adesodun, J.K., Adeyemi, E.F. and Oyegoke, C.O. (2007). Distribution of nutrient elements within water stable aggregates of two tropical agro-ecological soils under different land uses. *Soil and Tillage Research*, 92, 190-197.

AFNOR, **(**2005) PR NFX31-515.Qualité du sol. Mesure de la stabilité des agrégats de sol. Mars, 13p. Association Francaise de Normalisation, France.

Aghasi, M., Shainberg, I. and Morin, J. (1981). Effect of electrolyte concentration and soil sodicity on infiltration rate and crust formation. *Soil Science Society of America Journal,* 45, 848-851.

Aghasi, B., Jalalian, A. and Honarjoo, N. (2010). Decline in soil quality as a result of land use change in Ghareh Aghaj watershed of Semirom, Isfahan, Iran. *African Journal of Agricultural Research*, 6, 992-997.

Alvarez, R. and Alvarez, C.R. (2000). Soil organic matter pools and their associations with carbon mineralization kinetics, *Soil Science Society of America Journal*, 64, 184-189.

Alves, M.E. and Lavorenti, A. (2004). Remaining phosphorus and sodium fluoride pH in soils with different clay contents and clay mineralogies, São Paulo State, Brazil. *Pesquisa Agropecuaria Brasileira Journal*, 39, 241-246.

Amezketa, E. (1999). Soil Aggregate Stability: A Review. *Journal of Sustainable Agriculture*, 14, 83-151.

Anderson, D.W. (1988). The effect of parent material and soil development on nutrient cycling in temperate ecosystems. *Biogeochemistry,* 42, 122-133.

Anderson, S. and Ingvar Nilsson, S. (2001). Influence of pH and temperature on microbial activity, substrate availability of soil-solution bacteria and leaching of dissolved organic C in a mor humus. *Soil Biology and Biochemistry*, 33, 1181-1191.

Angers, D.A. (1992). Changes in soil aggregation and organic carbon under corn and alfalfa. *Soil Science Society of America. Journal*, 56, 1244-1249.

Ashman, M. R., Hallett, P. D. and Brookes, P. C. (2003). Are the links between soil aggregate size class, soil organic matter and respiration rate artefacts of the fractionation procedure? *Soil Biology and Biochemistry* 35, 435-444.

Aucamp, A. J. (2008). Linking cultivated pastures with rangelands. *Newsletter of the Grassland Society of Southern Afric*a, 8, 110-115.

Beare, M.H., Hendrix, P.F. and Coleman, D.C. (1994).Water-stable aggregates and organic fractions in conventional and no-tillage soils. *Soil Science Society of America Journal*, 58, 777-786.

Bekwet, W. and Stroosnijder, L. (2003). Effects of agroecological land use succession on soil properties in Chemoga watershed, Blue Nile basin, Ethiopia. *Geoderma,* 111, 85-98.

Boone, R .D. (1994). Light fraction soil organic matter: origin and contribution to net nitrogen mineralization. *Soil Biology and Biochemistry*, 26, 1459-1468.

Boajilla, A. and Gallali, T. (2010). Land use effect on soil and particulate organic carbon, and aggregate stability in some soils in Tunisia. *African Journal of Agricultural Research*, 5,764-774.

Bongiovanni, M.D. and Lobartini, J.C. (2006). Particulate organic matter, carbohydrate, humic acid contents in soil macro- and microaggregates as affected by cultivation. *Geoderma*, 136, 660-665.

Bouyoucos, G.J. (1962) Hydrometer method improved for making particle size analyses of soils, *Agronomy Journal,* 54, 464-465.

Buol, S.W., Sanchez P.A., Cate, R.B. and Granger, M.A. (1975). Soil fertility capability and classification. In: Bornemisza E. and Alvarado A. (eds) A technical soil classification system of soil fertility management, Madison, *Wisconsin*, pp. 126-145.

Bronick, C. J. and Lal, R. (2005). Soil structure and management: A review. *Geoderma*, 124, 3-22.

Campbell, C. A., Bowren K. E., Schnitzer, M, Zentner, R. P and Townley-Smith, L. (1991). Effect of crop rotations and fertilization on soil biochemical properties in a thick Black Chernozem. *Canadian Journal of Soil Science*, 71, 377-387.

Cambardella, C. A. and Elliott, E. T. (1992). Particulate soil organic matter. Changes across a grassland cultivation sequence. *Soil Science Society of American Journal,* 56, 777-783.

Cambardella, C. A. and Elliott, E. T. (1994). Carbon and nitrogen dynamics of soil organic matter fractions from cultivated grassland soils. *Soil Science Society of American Journal*, 58, 123-130.

Cambardella, C.A., Gajda, A.M., Doran JW, Wienhold, B.J. and Kettler, T.A. (2001). Estimation of particulate and total organic matter by weight losson- ignition. In: R. Lal *et al*. (eds.) Assessment methods for soil carbon. *CRC Press, Boca Raton,* pp. 210-219.

Camp, C. (1994). Owen Sitole College of Agricultural Report Planning Document. Department of Agriculture and Environmental Affairs, KwaZulu Natal. Cedara Report No: N/A94/6

Carter, M. R. (2002). Soil quality for sustainable land management: organic matter and aggregation interactions that maintain soil functions. *Agronomy Journal*, 94, 38-47.

Chevallier, T.E., Blanchart, A.A. and Feller, C. (2004). The physical protection of SOC in aggregates: a mechanism of carbon storage in a Vertisol under pasture and market gardening (Martinique, West Indies). *Agriculture, Ecosystem and Environment,* 103, 375-387.

Covaleda, S., Pajares,S.,Gallardo,J.F., and Etchevers, J.D. (2006). Short-term changes in C and N distribution in soil particle size fractions induced by agricultural practices in a cultivated volcanic soil from Mexico. *Organic Geochemistry*, 37, 1943-1948.

Covaleda, S., Pajares,S.,Gallardo,J.F., and Etchevers, J.D. (2011). Land-use effects on the distribution of soil organic carbon within particle-size fractions of volcanic soils in the Transmexican Volcanic Belt (Mexico) *Soil Use and Management*, 11, 1341-1350.

Day,T. (1965). Particle fractionation and particle-size analysis. In: C.A. Black *et al.* (eds) Methods of Soil Analysis, Part 2.*Agronomy*, pp. 1367-1378.

Dominy, C.S., Haynes, R.J. and van Antwerpen, R. (2001). Long-term effects of sugarcane production on soil quality in the South Coast and Midlands areas of KwaZulu-Natal. South African Sugar Technology Association, pp. 222-227.

Dominy, C. and Haynes, R. (2002). Influence of agricultural land management on organic matter content, microbial activity and aggregate stability in the profiles of two Oxisols. *Biological Fertility of Soils*, 36, 298-305.

Doran, J.W. and Parkin, T.B. (1994). Defining and assessing soil quality. In: J. W. Doran, D. C. Coleman, D. F. Bezdicek, and B. A. Stewart. (eds) Defining soil quality for a sustainable environment. *Soil Science Society of America, WI,* pp. 3-21.

Doran, J.W.and Jones, A.J. (1996). Methods for assessing soil quality. In: C. E. Pankhurst, B. M. Doube, and V. V. S. R. Gupta. (eds) Biological Indicators of Soil Health. *CAB International: New York,* 1-28.

Dorner, J., Dec, D., Peng, X. and Horn, R. (2009). Change of shrinkage behaviour of an Andisol in southern Chile: Effects of land use and wetting/drying cycles. *Soil and Tillage Research,*106, 45-56.

du Preez C.C. and Snyman H.A. (1993). Organic matter content of a soil in a semi-arid climate with three long-standing veld conditions. *African Journal of Range and Forage Science,*10, 108-110.

du Preez, H.G and Claassens, A.S. (1999).Changes in inorganic matter and organic phosphorus in soil under maize (*Zea maize*) cultivation. *South African Journal of Plant and Soil*.10, 70-76.

du Preez, C.C., Van Huyssteen, C.W., Mnkeni, P.N.S. (2011). Land use and soil organic matter in South Africa 2: A review on the influence of arable crop production. *South African Journal of Science*, 107, 358-366.

Du Toit, M.E., du Preez, C.C., Hensley M. and Bennie, A.T.P. (1994). Effect of cultivation on the organic matter content of selected dryland soils in South Africa. *South African Journal of Plant and Soil*, 11, 71-79.

Drenman Maud and Partners. (1986). Departmental Report. Nothern Natal Agricultural Development Centre, Report No: 5778.

Elliott, E T. (1986). Aggregate structure and carbon, nitrogen, and phosphorus in native and cultivated soils. *Soil Science Society of American Journal*, 50,627-633.

Emadi, M., Baghernejad M. and Memarian, H. (2000).Effect of land-use change on soil fertility characteristics within water-stable aggregates of two cultivated soils in northern Iran. *Department of Soil Science, Agriculture Faculty, Shiraz University, Shiraz, Iran.*

Esteban, G.J. and Robert, B.J. (2001). The distribution of soil nutrients with depth: Global patterns and the imprint of plants. *Biogeochemistry*, 53, 51-77.

FAO (Food Agriculture Organization) (1995) Planning for sustainable use of land resources. *FAO Land and Water Bulletin 2. Rome, FAO of the United Nations*.

Falkengren-Grerup, U. and Diekmann, M. (2003). Use of a gradient of N-deposition to calculate effect-related soil and vegetation measures in deciduous forests. *Forest Ecology Management*, 180, 113-124.

Farina, M.P.W. (1981). The Hunter System of Soil Analysis. *Fertilizer Society of South Africa Journal*, 18, 22-24.

Feller, C. Fritsch, E., Ross, R. and Valentin, C. (1991). Effects of texture on the storage and dynamics of organic matter in some low activity clay soils. *Pedology*, 26, 25-36.

Feller, C and Beare, M. H. (1997). Physical control of soil organic matter dynamics in the tropics. *Geoderma*, 79, 69-116.

Fey, M.V., Mills, A.J. and Yaalon, D.H. (2006). The alternative meaning of pedoderm and its use for soil surface characterization. *Geoderma*, 133, 474-477.

Franzluebbers, A.J., Hons, F.M. and Zuberer, D.A. (1994). Long-term changes in soil carbon and nitrogen pools in wheat management systems. *Soil Science Society of American Journal*, 58, 1639-1645.

Gee, G.W. and Bauder, J.W. (1986). Particle size analysis. In: A. Klute (eds). Methods of soil analysis: Part 1, Agronomy (2nd ed.). American Society of Agronomy, Madison, *Wisconsin*, pp. 383-411.

Geissen, V.,R. Sanchez-Hernandez, C., Kampichler, R., Ramos-Reyes, A., Sepulveda-Lozada,S., Ochoa-Goana, B.H.J., de Jong, E., Huerta-Lwanga, S. and Hernandez-Daumas. (2009). Effects of land-use change on some properties of tropical soils — an example from Southeast Mexico. *Geoderma*, 151, 87-97.

Griffiths, B.S, Ball B.C, Daniel, T.J, Hallet, P.D, Wheatley, R.E, Osler, G.and Bohanec, M. (2010) Integrating soil quality changes to arable agricultural systems following organic matter addition, or adoption of a ley-arable rotation. *Applied Soil Ecology*, 46, 43-53.

Graham, R.C., J.O. Ervin and Wood, H.B. (1995). Aggregate stability under oak and pine after four decades of soil development. *Soil Science Society of American Journal*, 59, 1740-1744.

Hajabbasi, M.A., Lalalian, A. and Karimzadeh, R. (1997). Deforestation on effects on soil physical and chemical properties, Lordegan, Iran, plant soil, 190, 301-308.

Hartemink A.E. (1997). Soil fertility decline in some major soil groupings under permanent cropping in Tanga region, Tanzania. *Geoderma*, 75, 215-229.

Hartemink, A.E. (1998). Soil chemical and physical properties as indicators of sustainable land management under sugar-cane in Papua New Guinea. *Geoderma*, 85, 283-306.

Haynes, R.J. and Beare, M.H. (1994). Aggregation and organic carbon storage in meso-thermal, humid soils. In: M.R. Carter (eds), Structure and Organic Carbon Storage in Agricultural Soils. *Advances in Soil Science*. *Lewis Publications, New York.*

Haynes, R.J. and Francis, G.S. (1990). Effects of mixed cropping farming systems on changes in soil properties on the Canterbury Plains. *New-Zealand Journal of Ecology*, 14, 73-82.

Haynes, R. J. and Swift, R.S. (1990) Stability of soil aggregates in relation to organic constituents and soil water content. *Journal of Soil Science*, 41, 73-83.

Haynes, R.J., Swift, R.S. and Stephen, R.C. (1991). Influence of mixed cropping rotations (pasture-arable) on organic matter content, water stable aggregation and clod porosity in a group of soils. *Soil Tillage Research*, 19, 77-87.

Haynes, R.J. and Williams, P.H. (1993). Nutrient cycling under grazed pasture. *Agronomy*, 49, 119-199.

Hillel, D. (1998). Environmental Soil Physics. *Academic Press London*.

Hunter, A. (1975). New techniques and equipment for routine soil/plant analytical procedures in Soil Management in Tropical America. *N.C State University. Raleigh.*

Islam K. R. and Weil, R. R. (2000). Land use effects on soil quality in a tropical forest ecosystem of Bangladesh, *Agriculture, Ecosystems and Environment*, 79, 9-16.

Ishaq, M., Ibrahim M. and Lal, R. (2002). Tillage effects on soil properties at different levels of fertilizer application in Punjab, Pakistan. *Soil Tillage. Research*, 68, 93-99.

IUSS Working Group WRB. (2014). World Reference Base for Soil Resources 2014. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome.

Jobbagy, E.G and Jackson, R.B. (2004).The uplift of soil nutrients by plants: biogeochemical consequences across scales. *Ecology,* 85, 2380-2389.

Johnson, D.W. (1992). Base cations. In: Johnson DW and Lindberg SE. (eds) Atmospheric Deposition and Forest Nutrient Cycling. Springer-Verlag, *New York, US*, pp. 13-17.

Kabrick, J.M., Goyne, K.W., Fan, Z. and Meinert, D. (2011). Landscape determinations of exchangeable calcium and magnesium in Ozark highland forest soils. *Soil Science Society of American Journal*, 75, 164-180.

Kauffmann, S., Sombrooek., W. and Mantel, S. (1998). Soils of rainforests: characterization and major constraints of dominant forest soils in the humid tropics. In: A Schulte *et al* (eds) Soils of Tropical forest Ecosystems. *Springer-Verlag, Berlin*, pp. 9-20.

King, J.A. and Campbell, B.M. (1994). Soil organic matter relations in five land cover types in the Miombo region (Zimbabwe). *Forest Ecology Management*, 67, 225–239.

Koutika, L.-S., Bartoli, F., Andreux, F., Cerri, C.C., Burtin, G., Chone, T. and Philipy, R. (1997). Organic matter dynamics and aggregation in soil under rain and pastures of increasing age in the eastern Amazon Basin. *Geoderma,* 76, 87-112.

Kong, A. Y. Y., Six, J., Bryant, D. C., Denison, R. F. and van Kessel, C. (2005). The relationship between carbon input, aggregation, and soil organic carbon stabilization in sustainable cropping systems. *Soil Science Society of America Journal*, 69, 1078-1085.

Kong, X.B., Zhang, F.R. and Qi, W. (2006). Influence of land use change on soil nutrients in an intensive agricultural region of North China. *Soil Tillage Research*, 88, 85–94.

Lal, R. (1994). Sustainable land use systems and soil resilience. In: Greenland D.J., Szabolcs I. (eds) Soil Resilience and Sustainable land use, *Cambridge University Press*, pp. 41-68.

Le Bissonnais, Y. (1996). Aggregate stability and assessment of soil crustability and erodibility: I. Theory and methodology. *European Journal of Soil Science,* 47, 425-437.

Le Bissonnais, Y.and Arrouays, D. (1997). Aggregate stability and assessment of soil crustability and erodibility: II. Application to humic loamy soils with various organic carbon contents. *European. Journal of Soil Science*, 48, 39-48.

Legout, C., Leguédois, S. and Le Bissonnais, Y. (2005). Aggregate breakdown dynamics under rainfall compared with aggregate stability measurements. *European Journal of Soil Science,* 56, 225-237.

Leinweber, P., Reuter, G. and Brozio, K. (1993). Cation exchange capacities of organo-mineral particle-size fractions in soils from long-term experiments. *Journal of Soil Science*, 44, 111-119.

Lilienfein, J.W., Wilcke, W., Ayarza, M.A., Vilelal., Lima S.do C. and Zech, W. (2000). Chemical fractionation of phosphorus, sulphur and molybdenum in Brazilian savannah Oxisols under different land use. *Geoderma,* 96, 31-456.

Lobe, I., Amelung, W. and du Preez, C.C. (2001). Losses of soil carbon and nitrogen with prolonged arable cropping from sandy soils of the South African Highveld. *European Journal of Soil Science*, 52, 93-101.

Lutzow, M.V., Leifeld, J., Kainz, M., Kögel-Knabner, I. and Munch, J.C. (2002). Indications for SOM quality in soils under different management. *Geoderma*, 105, 243-258.

Madikizela, S. (2014). The effects of burning or mulching of harvest residues on selected soil properties in a *Eucalyptus* plantation in northern KwaZulu-Natal. MSc thesis. University of KwaZulu-Natal.

Majaliwa, J.G.M., Twongyirwe, R.,Nyenje, M., Oluka, B., Ongom, J., Sirike, D., Mfitumukiza, E., Azanga, R., Natumanya, R. and Barasa B. **(**2010). The effect of land cover change on soil properties around Kibale National Park in southwestern Uganda. *Applied Environmental Soil Science*, 10, 1-11.

Manson, A. D. and Roberts, VG. (2000). Analytical Methods Used by the Soil Fertility and Analytical Services Section. *KZN Agri-Report.No. N/A/2001/04. KwaZulu-Natal Department of Agriculture and Environmental Affairs, Pietermaritzburg, South Africa.*

Mao, R. and Zeng, D.H. (2010). Changes in soil particulate organic matter, microbial biomass,and activity following afforestation of marginal agricultural lands in a semi-arid area of northeast China. *Environmental Management,* 46, 110-116.

Miles, N. and Hardy, M.B. (1999). Soil fertility management in pasture small-plot trials: potential pitfalls. *African. Journal of Range Forage and Sciences*, 16, 101-107.

Mills, A.J. and Fey, M.V. (2003). Declining soil quality in South Africa: effects of land use on soil organic matter and surface crusting. *South African Journal of Science*, 99, 429-436.

Mills, A.J. and Fey, M.V. (2004a). Frequent fires intensify soil crusting: physicochemical feedback in the pedoderm of long-term burn experiments in South Africa. *Geoderma,* 121, 45-64.

Mills, A.J. and Fey, M.V. (2004b). Effects of vegetation cover on the tendency of soil to crust in South Africa. *Soil Use and Management,* 20, 308-317.

Milne, R.M. and Haynes, R.J. (2002). Comparative effects of annual permanent dairy pastures on soil physical properties in the Tsitsikamma region of South Africa. MSc Agric dissertation, Pietermaritzburg, University of KwaZulu-Natal.

Mueller, L., Kay, B.D., Hu, C., Li, Y., Schindler, U., Behrendt, A., Shepherd, T.G. and Ball, B.C. (2009). Visual assessment of soil structure: evaluation of methodologies on sites in Canada, China and Germany: part I: comparing visual methods and linking them with soil physical data and grain yield of cereals. *Soil Tillage Research*, 103, 178-187.

Mueller, L., Schindler, U., Mirschel, W., Shepherd, T.G., Ball, B.C., Helming, K., Rogasik, J., Eulenstein, F. and Wiggering, H. (2010). Assessing the productivity function of soils. A review. *Agronomy Sustainable Development*, 30, 601-614.

Murphy, J. and Riley, J.P. (1962). A modified single solution method for determination of phosphate in natural waters. *Analytica Chimica Acta*, 27, 31-36.

Naidu, R., McClure, S., McKenzie, N.J. and Fitzpatrick, R.W. (1996). Soil solution composition and aggregate stability changes caused by long-term farming at four contrasting sites in South Australia. *Australian Journal of Soil Research,* 34, 511-527.

Nelson, D. and Sommers, W. (1982). Total carbon, organic carbon, and organic matter. In: A.L. Page. (eds) Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties, second ed. *Agronomy Monographs* 9, *ASA-SSA, Madison, WI,* pp. 539-579.

Nel, P.C., Barnard, R.O., Steynberg, R.E., De Beer, J.M. and Groeneveld, H.T. (1996). Trends in maize grain yields in a long-term fertilizer trial. *Field Crops Research,* 47, 53-64.

Nsbiamana, D., R.J Haynes and F.M Wallis (2004). Size, activity and catabolic diversity of the soil microbial as affected by land use. *Applied Soil Ecology,* 26, 81-92.

Paustian, K, Collins H. P. and Paul, E. A. (1997). Management controls on soil carbon. In: E A Paul, K Paustian, E T Elliott and C V Cole (eds) Soil Organic Matter in Temperate Agroecosystems . *CRC Press, Boca Raton, FL,* pp. 15-49.

Payne, R.W., Murray, D.A., Harding, S.A., Baird, D.B and Soutar, D.M. (2011). GenStat for Windows (14th Edition). VSN International, Hemel Hempstead.

Powers, J.S. and Schlesinger, W.H. (2002). Relationships among soil carbon distributions and biophysical factors at nested spatial scales in rain forests of north-eastern Costa Rica. *Geoderma,* 109, 165-190.

Puget, P., Chenu, C. and Balesdent, J. (1995). Total and young organic matter distributions in aggregates of silty cultivated soils. *European Journal of Soil Science,* 46, 449-459.

Puget, P., Chenu, C. and Balesdent, J. (2000). Dynamics of soil organic matter associated with particle-size fractions of water-stable aggregates. *European Journal of Soil Science,* 51, 595-605.

Puget, P. and Lal, R. (2005). Soil organic carbon and nitrogen in a Mollisol in central Ohio as affected by tillage and land use. *Soil Tillage Research,* 80, 201-213.

Pulleman, M.M. and Marinissen, J.C.Y. (2004). Physical protection of mineralizable C in aggregates from long-term pasture and arable soil. *Geoderma*, 120, 273-282.

Prinsloo, M.A., Wiltshire, G.H. and du Preez, C.C. (1990). Loss of nitrogen fertility and its restoration in some Orange Free State soils. *South African Journal of Plant and Soil,* 7, 55-61.

Qongqo, L.L. and van Antwerpen, R. (2000). Effect of long-term sugarcane production on physical and chemical properties of soils in KwaZulu-Natal. *South African Sugar Technology Association*, 74, 114-121.

Raji, B.A and Ogunwole, J.O. (2006) Potential of soil carbon sequestration under various land use in the sub-humid and semi-arid Savanna of Nigeria. *International Journal of Soil Sciences,* 1, 33-43.

Reeves, D.W. (1997). The role of organic matter in maintaining soil quality in continuous cropping systems. *Soil and Tillage Research*, 43, 131-167.

Roberts, W.P. and Chan, K.Y. (1990). Tillage-induced increases in carbon dioxide loss from soil. *Soil Tillage Research,* 17, 143-151.

Saikh, H., Varadachari,C., and Ghosh, K. (1998). Effects of deforestation and cultivation on soil CEC and contents of exchangeable bases: a case study in Simlipal National park, India. *Plant and Soil,* 204, 175-181.

San Jose, J.J. and Montes, R.A. (2001). Management effects on carbon stocks and fluxes across the Orinoco savannas. *Forest Ecology Management*, 150, 293-311.

Sanchez, P.A., Palma, C.A. and Buol, S.W. (2003). Fertility capability soil classification: a tool to help assess soil quality in the tropics. *Geoderma,* 114, 57-185.

Schlesinger, W.H. and Pilmanis, A.M. (1998). Plant-soil interactions in deserts. *Biogeochemistry*, 42, 169-187.

Shainberg, I. and Singer, M.J. (1985). Effect of electrolytic concentration on the hydraulic properties of depositional crust. *Soil Science Society of America Journal*, 49, 1260-1263.

Shepherd, G., Bureh, R.J. and Gregory, P.J. (2000). Land use affects the distribution of soil inorganic nitrogen in smallholder production systems in Kenya. *Biology and Fertility of Soils*, 31, 348-355.

Shepherd, T.G., Saggar, S., Newman, R.H., Ross, C.W. and Dando, J.L. (2001). Tillage-induced changes to soil structure and organic carbon fractions in New Zealand soils. *Australian. Journal of Soil Research*, 39, 465-489.

Shepherd, T.G. (2003). Assessing soil quality using visual soil assessment. In: Currie, L.D., Hanly, J.A. (eds.), Tools for Nutrients and Pollutant Management: Applications to Agriculture and Environmental Quality. Occasional Report No. 17. *Fertilizer and Lime Research Centre, Massey University, Palmerston North*, pp. 153-166.

Šimanskỳ, V. (2012).Soil structure stability and distribution of carbon in water-stable aggregates in different tilled and fertilized haplic luvisol .*Soil Tillage Research*, 100, 125–132.

Six, J., Elliott, E. T., Paustian, K. and Doran, J. W. (1998): Aggregation and soil organic matter accumulation in cultivated and native grassland soils. *Soil Science Society of America Journal*. 62, 1367-1376.

Six, J., Elliott, E. T., Paustian, K. (1999). Aggregate and soil organic matter dynamics under conventional and no-tillage systems. *Soil Science Society of America Journal*, 63, 1350-1358.

Six, J., Paustian, K., Elliott, E. T., Combrink, C. (2000a). Soil structure and organic matter: I. Distribution of aggregate-size classes and aggregate associated carbon. *Soil Science Society of America Journal*, 64, 68-689.

Six, J., Elliott, E. T. and Paustian, K. (2000b). Soil structure and soil organic matter: II. A normalized stability index and the effect of mineralogy. *Soil Science Society of America Journal*, 64, 1042-1049.

Six, J., Conant, R. T., Paul, E. A. and Paustian, K. (2002). Stabilization mechanisms of soil organic matter: Implications for C-saturation of soils. *Soil Science Society of America*, 241, 155-176.

Snyman, H.A and du Preez, C.C. (2004).Rangeland degradation in semi-arid South Africa. 2. Influence on soil quality. *Journal of Soil Science*, 60, 483-490.

Soil Classification Working Group. (1991). Soil Classification: A Taxonomic System for South Africa. Pretoria: Soil and Irrigation Research Institute, Department of Agricultural Development.

Spohn, M. and Giani, L. (2010). Water-stable aggregates, glomalin-related soil protein, and carbohydrates in a chronosequence of sandy hydromorphic soils. *Soil Biology and Biochemistry*, 42, 1505-1511.

Studdert, G. A., Echeverría, H. E. and Casanovas, E. M. (1997). Crop-pasture rotation for sustaining the quality and productivity of a typic argiudoll. *Soil Science Society of America Journal*, 61, 1466-1472.

Sumann M.W., Amelung L. and Haumaier, W. (1998). Climatic effects on soil organic P in the North American Great Plains identified by ^{31}P nuclear magnetic resonance. Soil *Science Society of America*, l62, 1580-1586.

Tayel, M.Y., Abdel-hady, M., and Eldardiry, E.I. (2010).Soil structure affected by some soil characteristics. *America Eurasian Journal Agriculture and Environmental Science*, 7, 705-712.

Tisdall, J.M. and Oades J.M. (1982). Organic matter and water-stable aggregates in soils. *Journal of Soil Science*, 33, 141-163.

Tisdale, S.L., W.L. Nelson, J.D. Beaton, and J.L Havlin. (1993). Soil Fertility and fertilisers (5th edition). Macmillan Publishing Company, New York.

Tornquist, C.G., Hons, F.M., Feagley, S.E. and Haggar, J. (1999). Agrosystem effects on soil characteristics of the Sarapiqui region of Costa Rica. *Agricultural Ecosystem Environment*, 73, 19-28.

Van der Linden, J. (2004). Vegetation analysis at Owen Sitole College of Agriculture., PhD thesis, School of Environmental Sciences, *University of Zululand*.

Van Antwerpen, R. (2005). A review of soil health indicators for laboratory use in the South African sugar industry. South African Sugar Technology Association, pp. 179-191.

Van Antwerpen, R. and Meyer, J.H. (1996). Soil degradation under sugarcane cultivation in Northern KwaZulu-Natal. South African Sugar Technology Association, pp.29-33.

Van Zyl A.J and du Preez CC. (1997). Phosphorus in selected virgin and cultivated South African soils. 1. Total, inorganic and organic phosphorus. *South African Journal of Plant and Soil*, 14, 9-17.

Voundi Nkana, J.C. and Tonye J. (2002). Assessment of certain soil properties related to different land-use systems in the Kaya watershed of the humid forest zone of Cameroon. *Land Degradation and Development*. Published online in Wiley Inter Science (www. Interscience.wiley.com) DOI: 10.1002/Idc.519, date accessed: 19-09-2014.

Walkey, A. (1947). A critical examination of a rapid method for determining organic carbon in soils-Effects of variations in digestion conditions and of inorganic constituents. *Soil Science*, 63, 251-264.

Wiltshire, G.H. and du Preez C.C. (1993). Long-term effects of conservation practices on the nitrogen fertility of a soil cropped annually to wheat. *South African Journal of Plant and Soil*, 10, 70-76.

Whitbread, Blair, G., Konboon, Y., Lefroy, R. and Naklang, K. (2003). Managing crop residues, fertilizers and leaf litters to improve soil C, nutrient balances, and the grain yield of rice and wheat cropping systems in Thailand and Australia. *Agriculture, Ecosystems and Environment* ,100, 251-263.

Wright, A.L. and Hons, F.M. (2004). Soil aggregation and carbon and nitrogen storage under soybean cropping sequences. *Soil Science Society of America Journal*, 68, 507-513.

White, R.E. (1981). Pathways of phosphorus in soil. In: T.W.G. Hucker, and G Catroux. (eds) Proceedings of a Symposium on Phosphorus in sewage sludge and animal wastes. *Holland*, pp. 21-46.

Zhang, M.K., He, Z.L., Chen, G.C., Huang, C.Y. and Wilson, M.J. (1996). Formation and water stability of aggregates in red soils as affected by organic matter. *Pedosphere*, 6, 39-45.

Zhang, T.Q. and Mackenzie A.F. (1997). Changes of soil phosphorus fractions under long-term corn monoculture. *Soil Science Society of American Journal*, 61, 485-493.

Zhang, Z. (1998). Cause of grassland degradation and related control measures of grazing pasture in Songshatan, Tianzhu. *Pedosphere*, 6, 39-45.

APPENDIX:

Appendix 4.1: Soil profile description of Shortlands, Westleigh, Inhoek and Oakleaf

Soil form and family	Shortlands 1210: EMPANGENI
Latitude and Longitude	28.63817^{0} S/ 31.94145^{0} E
Altitude (m)	135
Texture (%)	15-35
Permeability (s)	2.1 (Rapid)
ERD* (cm)	52
ED** (cm)	>100
Colour (dry)	2.5YR 3/3 (Dark reddish brown)
Soil form and family	Westleigh 2000: MAREETSANE
Latitude and Longitude	28.63232^{0} S/ 31.96441^{0} E
Altitude (m)	172
Texture (%)	5-15
Permeability	2.3 (Rapid)
ERD* (cm)	13
ED** (cm)	765
Colour (dry)	10YR 4/3 (Dark greyish brown)
Soil form and family	Inhoek 1100: OATLANDS
Latitude and Longitude	28.64235^{0} S/ 31.93705^{0} E
Altitude (m)	144
Texture (%)	15-35
Permeability (s)	3.6 (Good)
ERD* (cm)	35
ED** (cm)	>100
Colour (dry)	10Y 2.5/2.5 (Black)
Soil form and family	Oakleaf 2110:COOPER
Latitude and Longitude	28.64321^{0} S/ 31.92567^{0} E
Altitude (m)	48
Texture (%)	0-5
Permeability (s)	0.6 (Extremely rapid)
ERD* (cm)	30
ED** (cm)	> 100
Colour (dry)	2.5YR 4/1 (Dark reddish grey)

ERD* = effective rooting depth, ED** = effective depth

Appendix 4.2: The mean pH (H_2O and KCl) and exchangeable acidity in Shortlands soil form under undisturbed, irrigated pasture and arable land use systems (n = 4).

Land Use	Depth (cm)	pH (H_2O)	pH (KCl)	Exch acidity (mmol L^{-1})
Undisturbed	0-1	6.12±0.14	5.19±0.04	nd
	1-5	5.89±0.12	4.91±0.02	nd
	5-10	5.98±0.14	4.88±0.47	0.06
	10-20	6.13±0.23	4.89±0.10	0.05
	20-30	6.64±0.21	5.29±0.13	0.05
Pasture	0-1	6.58±0.18	5.93±0.03	nd
	1-5	6.24±0.20	5.52±0.25	nd
	5-10	6.25±0.11	5.25±0.16	0.07
	10-20	6.41±0.10	5.03±0.01	0.06
	20-30	6.41±0.09	5.03±0.10	0.06
Arable	0-1	6.05±0.01	4.99±0.15	nd
	1-5	5.96±0.12	4.88±0.26	nd
	5-10	6.18±0.14	4.84±0.40	0.06
	10-20	5.90±0.09	4.85±0.24	0.05
	20-30	6.17±0.19	5.00±0.11	0.06

nd = not determined

Appendix 4.3: The mean pH (H_2O and KCl) and exchangeable acidity in Westleigh soil form under undisturbed, irrigated pasture and arable land use systems (n = 4).

Land Use	Depth (cm)	pH (H_2O)	pH (KCl)	Exch acidity (mmol L^{-1})
Undisturbed	0-1	6.71±0.14	5.75±0.01	nd
	1-5	6.53±0.06	5.56±0.10	nd
	5-10	6.55±0.01	5.30±0.10	0.05
	10-20	6.58±0.22	5.36±0.03	0.05
	20-30	6.76±0.12	5.79±0.10	0.05
Pasture	0-1	6.58±0.13	5.69±0.13	nd
	1-5	6.45±0.11	5.42±0.05	nd
	5-10	6.66±0.13	5.33±0.08	0.07
	10-20	6.52±0.03	5.35±0.25	0.06
	20-30	6.84±0.25	5.38±0.20	0.06
Arable	0-1	6.29±0.15	5.21±0.11	nd
	1-5	6.20±0.29	5.15±0.02	nd
	5-10	6.21±0.13	5.13±0.27	0.06
	10-20	6.33±0.20	5.08±0.13	0.06
	20-30	6.87±0.27	5.16±0.06	0.06

nd = not determined

Appendix 4.4: The mean pH (H_2O and KCl) and exchangeable acidity in Inhoek soil form under undisturbed, irrigated pasture and arable land use systems (n = 4).

Land Use	Depth (cm)	pH (H_2O)	pH (KCl)	Exch acidity (mmol L^{-1})
Undisturbed	0-1	6.21±0.22	5.17±0.41	nd
	1-5	6.11±0.14	4.89±0.32	nd
	5-10	6.34±0.11	4.83±0.21	0.05
	10-20	6.44±0.33	6.39±0.12	0.06
	20-30	7.77±0.13	6.39±0.13	0.05
Pasture	0-1	6.60±0.19	5.77±0.31	nd
	1-5	6.45±0.43	5.41±0.20	nd
	5-10	6.39±0.20	5.10±0.09	0.05
	10-20	6.39±0.15	5.07±0.33	0.05
	20-30	6.57±0.13	5.24±0.16	0.05
Arable	0-1	6.41±0.11	5.30±0.12	nd
	1-5	6.46±0.01	5.36±0.08	nd
	5-10	6.41±0.36	5.41±0.00	0.07
	10-20	6.46±0.13	5.28±0.10	0.06
	20-30	6.78±0.28	5.34±0.03	0.06

nd = not determined

Appendix 4.5: The mean pH (H_2O and KCl) and exchangeable acidity in Oakleaf soil form under irrigated pasture and arable land use systems (n = 4).

Land use	Depth (cm)	pH (water)	pH (KCl)	Exch acidity (mmol L^{-1})
Pasture	0-1	6.21±0.22	5.21±0.13	nd
	1-5	6.36±0.04	5.75±0.17	nd
	5-10	6.33±0.43	5.22±0.04	0.06
	10-20	6.24±0.18	5.78±0.38	0.05
	20-30	6.42±0.20	5.28±0.26	0.06
Arable	0-1	5.97±0.16	5.05±0.15	nd
	1-5	5.98±0.13	5.15±0.11	nd
	5-10	5.71±0.09	4.65±0.01	0.06
	10-20	5.96±0.12	4.81±0.13	0.06
	20-30	6.48±0.12	5.24±0.20	0.07

nd = not determined

Appendix 4.6: The summary of statistics (t-test) for the mean pH (water) in three soil forms (Sd: Shortlands; We: Westleigh and Ik: Inhoek) under undisturbed, irrigated pasture and arable land use systems (n = 4).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Soil form
Land_Use	2	1.115	0.557	3.870	**<0.029**	Sd
Soil_Depth	4	0.968	0.242	1.680	0.174	
Land_Use.Soil_Depth	8	0.939	0.117	0.810	0.595	
Land_Use	2	0.776	0.388	2.680	0.079	We
Soil_Depth	4	1.217	0.304	2.100	0.096	
Land_Use.Soil_Depth	8	0.559	0.070	0.480	0.862	
Land_Use	2	0.095	0.048	0.700	0.502	Ik
Soil_Depth	4	4.131	1.033	15.180	**<0.001**	
Land_Use.Soil_Depth	8	3.863	0.483	7.100	**<0.001**	

Appendix 4.7: The summary of statistics (t-test) for the mean pH (KCl) in three soil forms (Sd: Shortlands; We: Westleigh and Ik: Inhoek) under undisturbed, irrigated pasture and arable land use systems (n = 4).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Soil form
Land_Use	2	2.096	1.048	16.570	**<0.001**	Sd
Soil_Depth	4	1.380	0.345	5.450	0.001	
Land_Use.Soil_Depth	8	1.609	0.201	3.180	0.007	
Land_Use	2	1.730	0.865	3.880	**<0.028**	We
Soil_Depth	4	0.745	0.186	0.840	0.510	
Land_Use.Soil_Depth	8	0.417	0.052	0.230	0.982	
Land_Use	2	0.564	0.282	4.690	0.014	Ik
Soil_Depth	4	2.556	0.639	10.630	**<0.001**	
Land_Use.Soil_Depth	8	8.847	1.106	18.400	**<0.001**	

Appendix 4.8: The summary of statistics (t-test) for the mean pH (water) in Oakleaf soil form under irrigated pasture and arable land use systems (n = 4).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Land_Use	1	0.850	0.850	4.210	0.049
Soil_Depth	4	0.897	0.224	1.110	0.370
Land_Use.Soil_Depth	4	0.057	0.014	0.070	0.990

Appendix 4.9: The summary of statistics (t-test) for the mean pH (KCl) in Oakleaf soil form under irrigated pasture and arable land use systems (n = 4).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Land_Use	1	3.493	3.493	17.690	**<0.001**
Soil_Depth	4	3.537	0.884	4.480	0.006
Land_Use.Soil_Depth	4	0.192	0.048	0.240	0.912

Appendix 4.10: The summary of statistics (t-test) for the mean exchangeable acidity in three soil forms (Sd: Shortlands; We: Westleigh and Ik: Inhoek) under undisturbed, irrigated pasture and arable land use systems (n = 4).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Soil form
Land_Use	2	0	0	1.791	0.186	Sd
Soil_Depth	2	0	0	1.790	0.186	
Land_Use.Soil_Depth	4	0	0	3.522	**<0.020**	
Land_Use	2	0	0	0.831	0.447	We
Soil_Depth	2	0	0	2.361	0.113	
Land_Use.Soil_Depth	4	0	0	1.404	0.259	
Land_Use	2	0	0	1.753	0.193	Ik
Soil_Depth	2	0	0	3.252	0.054	
Land_Use.Soil_Depth	4	0	0	0.253	0.907	

Appendix 4.11: The summary of statistics (t-test) for the mean exchangeable acidity measured in Oakleaf soil form under irrigated pasture and arable land use systems (n = 4).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Land_Use	1	0	0	0.350	0.563
Soil_Depth	1	0	0	0.350	0.563
Land_Use.Soil_Depth	1	0	0	1.410	0.258

Appendix 4.12: The summary of statistics (t-test) for the mean soil organic carbon in three soil forms (Sd: Shortlands; We: Westleigh and Ik: Inhoek) under undisturbed, irrigated pasture and arable land use systems (n = 4).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Soil form
Land_Use	2	21.592	10.796	62.18	**<0.001**	Sd
Soil_Depth	2	2.710	1.355	7.810	0.002	
Land_Use.Soil_Depth	4	2.689	0.672	3.871	0.014	
Land_Use	2	19.744	9.872	28.511	**<0.001**	We
Soil_Depth	2	1.665	0.832	2.405	0.109	
Land_Use.Soil_Depth	4	2.262	0.565	1.632	0.195	
Land_Use	2	25.091	12.545	24.530	**<0.001**	Ik
Soil_Depth	2	7.875	3.937	7.691	0.002	
Land_Use.Soil_Depth	4	2.599	0.650	1.270	0.307	

Appendix 4.13: The summary of statistics (t-test) for the mean soil organic carbon in Oakleaf soil form under irrigated pasture and arable land use systems (n = 4).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Land_Use	1	29.943	29.943	256.870	**<0.001**
Soil_Depth	2	5.777	2.889	24.780	**<0.001**
Land_Use.Soil_Depth	2	4.747	2.374	20.360	**<0.001**

Appendix 4.14: The summary of statistics (t-test) for the mean particulate organic matter in three soil forms (Sd: Shortlands; We: Westleigh; Ik: Inhoek) under undisturbed, irrigated pasture and arable land use systems (n = 4).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Soil form
Land_Use	2	0.001	0.001	0.200	0.823	Sd
Soil_Depth	4	0.048	0.012	4.430	**<0.004**	
Land_Use.Soil_Depth	8	0.014	0.002	0.630	0.748	
Land_Use	2	0.098	0.049	10.250	**<0.001**	We
Soil_Depth	4	0.048	0.012	2.500	**<.001**	
Land_Use.Soil_Depth	8	0.066	0.008	1.730	0.118	
Land_Use	2	0.428	0.214	5.920	**<0.001**	Ik
Soil_Depth	4	0.673	0.168	4.660	**<0.001**	
Land_Use.Soil_Depth	8	1.080	0.135	3.730	0.002	

Appendix 4.15: The summary of statistics (t-test) for the mean particulate organic matter measured in Oakleaf soil form under undisturbed, irrigated pasture and arable land use systems (n = 4).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Land_Use	1	13.439	13.439	19.620	**<0.001**
Soil_Depth	4	21.616	5.404	7.890	**<0.001**
Land_Use.Soil_Depth	4	16.908	4.227	6.170	**<0.001**

Appendix 4.16: The summary of statistics (t-test) for the mean available phosphorus in three soil forms (Sd: Shortlands; We: Westleigh; Ik: Inhoek) under undisturbed, irrigated pasture and arable land use systems (n = 4).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Soil form
Land_Use	2	84.500	42.250	3.630	0.040	Sd
Soil_Depth	2	81.170	40.580	3.490	0.045	
Land_Use.Soil_Depth	4	101.330	25.330	2.180	0.098	
Land_Use	2	48.720	24.360	1.990	0.156	We
Soil_Depth	2	122.390	61.190	5.000	0.014	
Land_Use.Soil_Depth	4	24.280	6.070	0.500	0.739	
Land_Use	2	41.167	20.583	8.480	**<0.001**	Ik
Soil_Depth	2	56.167	28.083	11.580	0.031	
Land_Use.Soil_Depth	4	33.167	8.292	3.420	0.022	

Appendix 4.17: The summary of statistics (t-test) for the mean available phosphorus in Oakleaf soil form under irrigated pasture and arable land use systems (n = 4).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Land_Use	1	196.000	196.000	2.550	0.136
Soil_Depth	1	64.000	64.000	0.830	0.379
Land_Use.Soil_Depth	1	182.250	182.250	2.370	0.149

Appendix 4.18: The summary of statistics (t-test) for effective cation exchange capacity measured in three soil forms (Sd: Shortlands; We: Westleigh and Ik: Inhoek) under undisturbed, irrigated pasture and arable land use systems (n = 4).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Soil form
Land_Use	2	54.340	27.170	1.410	0.263	Sd
Soil_Depth	2	14.210	7.100	0.370	**< 0.001**	
Land_Use.Soil_Depth	4	58.710	14.680	0.760	0.561	
Land_Use	2	57.770	28.890	0.980	0.387	We
Soil_Depth	2	22.360	11.180	0.380	**<0.001**	
Land_Use.Soil_Depth	4	49.500	12.370	0.420	0.792	
Land_Use	2	310.760	155.380	3.960	0.031	Ik
Soil_Depth	2	90.320	45.160	1.150	0.001	
Land_Use.Soil_Depth	4	509.540	127.390	3.240	0.027	

Appendix 4.19: The summary of statistics (t-test) for the effective cation exchange capacity in Oakleaf soil form under irrigated pasture and arable land use systems (n = 4).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Land_Use	1	230.736	230.736	24.800	**<0.001**
Soil_Depth	1	14.669	14.669	1.580	0.233
Land_Use.Soil_Depth	1	15.406	15.406	1.660	0.222

Appendix 4.20: The summary of statistics (t-test) for the mean exchangeable calcium in three soil forms (Sd: Shortlands; We: Westleigh and Ik: Inhoek) under undisturbed, irrigated pasture and arable land use systems (n = 4).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Soil form
Land_Use	2	1581891	790945	3.300	0.052	Sd
Soil_Depth	2	470781	235391	0.980	0.387	
Land_Use.Soil_Depth	4	538431	134608	0.560	0.692	
Land_Use	2	683197	341598	0.630	0.539	We
Soil_Depth	2	647969	323984	0.600	0.557	
Land_Use.Soil_Depth	4	728156	182039	0.340	0.851	
Land_Use	2	5127928	2563964	4.920	0.015	Ik
Soil_Depth	2	1049603	524801	1.010	0.379	
Land_Use.Soil_Depth	4	6876646	1719161	3.300	0.025	

Appendix 4.21: The summary of statistics (t-test) for the mean exchangeable calcium in Oakleaf soil form under irrigated pasture and arable land use systems (n = 4).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Land_Use	1	3643327	3643327	34.250	**<0.001**
Soil_Depth	1	557636	557636	5.240	**<0.041**
Land_Use.Soil_Depth	1	416993	416993	3.920	**<0.071**

Appendix 4.22: The summary of statistics (t-test) for the mean exchangeable magnesium in three soil forms (Sd: Shortlands; We: Westleigh and Ik: Inhoek) under undisturbed, irrigated pasture and arable land use systems (n = 4).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Soil form
Land_Use	2	206832	103416	1.530	0.236	Sd
Soil_Depth	2	22947	11473	0.170	0.845	
Land_Use.Soil_Depth	4	167642	41911	0.620	0.653	
Land_Use	2	149008	74504	0.920	0.409	We
Soil_Depth	2	474363	237181	2.940	0.070	
Land_Use.Soil_Depth	4	195217	48804	0.600	0.663	
Land_Use	2	664513	332257	2.810	0.078	Ik
Soil_Depth	2	1079158	539579	4.560	0.020	
Land_Use.Soil_Depth	4	1720342	430086	3.640	0.017	

Appendix 4.23: The summary of statistics (t-test) for the mean exchangeable magnesium in Oakleaf soil form under irrigated pasture and arable land use systems (n = 4).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Land_Use	1	390000	390000	10.190	**<0.008**
Soil_Depth	1	1560	1560	0.040	0.843
Land_Use.Soil_Depth	1	225	225	0.010	0.94

Appendix 4.24: The summary of statistics (t-test) for the mean exchangeable potassium in three soil forms (Sd: Shortlands; We: Westleigh and Ik: Inhoek) under undisturbed, irrigated pasture and arable land use systems (n = 4).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Soil form
Land_Use	2	340450	170225	17.710	**<0.001**	Sd
Soil_Depth	2	430722	215361	22.410	**<0.001**	
Land_Use.Soil_Depth	4	75430	18857	1.960	0.129	
Land_Use	2	222187	111094	0.94	0.403	We
Soil_Depth	2	33371	16685	0.14	0.869	
Land_Use.Soil_Depth	4	362202	90551	0.77	0.556	
Land_Use	2	12378	6189	1.470	0.248	Ik
Soil_Depth	2	56482	28241	6.690	0.004	
Land_Use.Soil_Depth	4	9271	2318	0.550	0.701	

Appendix 4.25: The summary of statistics (t-test) for the mean exchangeable potassium in Oakleaf soil form under irrigated pasture and arable land use systems (n = 4).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Land_Use	1	56565	56565	48.450	**<0.001**
Soil_Depth	1	19367	19367	16.590	**<0.001**
Land_Use.Soil_Depth	1	88903	88903	76.150	**<0.001**

Appendix 4.26: The summary of statistics (t-test) for the mean weight diameter in three soil forms (Sd: Shortlands; We: Westleigh and Ik: Inhoek) under undisturbed, irrigated pasture and arable land use systems (n = 4).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Soil form
Land_Use	2	16.554	16.554	28.350	**<0.001**	Sd
Soil_Depth	2	0.335	0.167	0.290	0.752	
Land_Use.Soil_Depth	4	0.393	0.197	0.340	0.716	
Land_Use	2	60.219	30.110	115.110	<0.001	We
Soil_Depth	2	0.075	0.038	0.140	0.866	
Land_Use.Soil_Depth	4	3.397	0.849	3.250	0.013	
Land_Use	2	13.697	6.848	26.180	**<0.001**	Ik
Soil_Depth	2	4.556	2.278	3.900	0.026	
Land_Use.Soil_Depth	4	3.964	0.991	1.700	0.164	

Appendix 4.27: The summary of statistics (t-test) for the mean weight diameter measured in Oakleaf soil form under irrigated pasture and arable land use systems (n = 4).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Land_Use	1	16.554	16.554	28.350	**<0.001**
Soil_Depth	2	0.335	0.167	0.290	0.752
Land_Use .Soil_Depth	2	0.393	0.197	0.340	0.716

Appendix 4.28: Correlation matrix for the Shortlands soil form under the undisturbed land use system.

	pH (H_2O)	**pH (KCl)**	**SOC**	**POM**	**MWD**	**P**	**K**	**Ca**	**Mg**	**Acidity**	**ECEC**	**Zn**	**Mn**	**Cu**	**Clay**
pH (H_2O)	1.00														
pH (KCl)	**0.61***	1.00													
SOC	**-0.58***	0.14	1.00												
POM	0.11	**0.72***	0.45	1.00											
MWD	0.17	0.03	0.09	-0.54	1.00										
P	-0.46	0.05	**0.92***	0.46	0.57	1.00									
K	-0.51	-0.08	0.52	0.83	0.14	**0.78***	1.00								
Ca	**0.81***	0.69	-0.03	-0.06	0.17	-0.18	-0.52	1.00							
Mg	**0.86***	0.67	-0.23	-0.42	0.24	-0.34	-0.59	**0.92***	1.00						
Acidity	-0.10	0.26	0.21	**0.98***	0.01	0.34	0.52	-0.52	-0.35	1.00					
ECEC	**0.84***	**0.74***	-0.07	0.08	0.24	-0.18	-0.48	**0.98***	**0.97***	-0.29	1.00				
Zn	-0.43	-0.30	-0.07	0.47	-0.42	0.15	0.45	-0.46	-0.46	0.66	-0.44	1.00			
Mn	-0.12	-0.14	0.21	-0.47	0.44	0.19	0.10	-0.08	-0.01	-0.63	-0.04	-0.72	1.00		
Cu	-0.45	-0.63	-0.42	-0.65	-0.56	-0.34	-0.05	-0.50	-0.41	0.27	-0.50	0.78	-0.60	1.00	
Clay	-0.69	**-0.77***	-0.03	-0.74	**0.55***	-0.05	0.15	-0.68	-0.83	0.04	**-0.80***	0.29	-0.07	0.49	1.00

SOC: Soil organic carbon (%); POM: Particulate organic matter (%); MWD: Mean weight diameter (mm); P: phosphorus (mg kg^{-1}); K: Potassium (cmol$_c$ kg^{-1}); Ca: Calcium (cmol$_c$ kg^{-1});Mg: Magnesium (cmol$_c$ kg^{-1}); Acidity (mmol kg^{-1}); ECEC: Effective cation exchange capacity (cmol$_c$ kg^{-1}); Zn: Zinc (mg L^{-1}); Mn : Manganese (mg L^{-1}); Cu: Copper (mg L^{-1}); Clay (%).

*Correlation is significant at $p < 0.05$

Appendix 4.29: Correlation matrix for the Shortlands soil form under the pasture land use system.

	pH (H_2O)	**pH (KCl)**	**SOC**	**POM**	**MWD**	**P**	**K**	**Ca**	**Mg**	**Acidity**	**ECEC**	**Zn**	**Mn**	**Cu**	**Clay**
pH (H_2O)	1.00														
pH (KCl)	-0.04	1.00													
SOC	-0.05	0.41	1.00												
POM	-0.26	0.36	0.49	1.00											
MWD	-0.16	0.20	**0.40***	0.11	1.00										
P	0.67	0.54	**0.72***	-0.50	-0.65	1.00									
K	0.12	0.55	**0.82***	0.70	-0.82	**0.80***	1.00								
Ca	0.30	-0.15	0.35	0.18	-0.27	0.48	0.63	1.00							
Mg	-0.04	-0.30	0.34	0.22	-0.30	0.32	0.60	0.95	1.00						
Acidity	0.04	0.30	0.64	0.02	-0.55	**0.73***	**0.85***	**-0.79***	**0.79***	1.00					
ECEC	0.18	-0.11	0.44	0.25	-0.38	0.50	**0.72***	**0.99***	**0.97***	**0.85***	1.00				
Zn	0.67	0.28	**0.80***	-0.30	**-0.82***	**0.91***	**0.85***	**0.55***	0.44	0.68	0.59	1.00			
Mn	**-0.93***	-0.32	-0.08	0.27	0.01	0.56	-0.09	-0.04	0.27	0.05	0.06	-0.42	1.00		
Cu	0.60	-0.18	0.23	**-0.98***	-0.28	0.40	-0.05	-0.21	-0.28	-0.06	-0.22	0.43	-0.42	1.00	
Clay	0.52	0.72	0.45	-0.44	**0.65***	0.65	0.31	-0.34	-0.50	0.05	-0.32	0.50	-0.64	0.56	1.00

SOC: Soil organic carbon (%); POM: Particulate organic matter (%); MWD: Mean weight diameter (mm); P: phosphorus (mg kg^{-1}); K: Potassium (cmol$_c$ kg^{-1}); Ca: Calcium (cmol$_c$ kg^{-1});Mg: Magnesium (cmol$_c$ kg^{-1}); Acidity (mmol kg^{-1}); ECEC: Effective cation exchange capacity (cmol$_c$ kg^{-1}); Zn: Zinc (mg L^{-1}); Mn : Manganese (mg L^{-1}); Cu: Copper (mg L^{-1}); Clay (%).

*Correlation is significant at $p < 0.05$

Appendix 4.30: Correlation matrix for the Shortlands soil form under the arable land use system.

	pH (H_2O)	**pH (KCl)**	**SOC**	**POM**	**MWD**	**P**	**K**	**Ca**	**Mg**	**Acidity**	**ECEC**	**Zn**	**Mn**	**Cu**	**Clay**
pH (H_2O)	1.00														
pH (KCl)	-0.02	1.00													
SOC	0.03	0.21	1.00												
POM	-0.14	0.36	0.50	1.00											
MWD	-0.11	0.00	**0.41***	-0.21	1.00										
P	0.17	0.24	**0.71***	0.51	-0.05	1.00									
K	0.08	0.25	**0.53***	0.42	-0.32	**0.50***	1.00								
Ca	0.36	-0.18	0.15	-0.13	-0.07	0.28	0.63	1.00							
Mg	-0.30	0.45	0.14	0.32	-0.10	0.13	0.60	0.71	1.00						
Acidity	0.01	0.25	0.44	0.01	-0.35	**0.53***	**0.65***	**-0.63***	**0.79***	1.00					
ECEC	0.40	0.41	0.43	0.35	-0.38	0.20	**0.42***	**0.89***	**0.90***	**0.43***	1.00				
Zn	-0.02	-0.08	**0.40***	-0.10	-0.32	**0.41***	**0.55***	**0.65***	0.34	0.38	0.49	1.00			
Mn	-0.93	-0.31	-0.18	0.67	0.21	0.36	-0.09	-0.14	0.17	0.15	0.36	-0.31	1.00		
Cu	0.10	-0.02	0.23	-0.18	-0.28	0.20	-0.05	-0.41	-0.18	-0.21	-0.12	0.33	-0.22	1.00	
Clay	0.50	0.48	0.43	-0.24	**0.51***	0.35	0.31	-0.30	-0.30	0.09	-0.30	0.30	-0.34	0.46	1.00

SOC: Soil organic carbon (%); POM: Particulate organic matter (%); MWD: Mean weight diameter (mm); P: phosphorus (mg kg^{-1}); K: Potassium (cmol$_c$ kg^{-1}); Ca: Calcium (cmol$_c$ kg^{-1});Mg: Magnesium (cmol$_c$ kg^{-1}); Acidity (mmol kg^{-1}); ECEC: Effective cation exchange capacity (cmol$_c$ kg^{-1}); Zn: Zinc (mg L^{-1}); Mn : Manganese (mg L^{-1}); Cu: Copper (mg L^{-1}); Clay (%).

*Correlation is significant at $p < 0.05$

Appendix 4.31: Correlation matrix for the Westleigh soil form under the undisturbed land use system.

	pH (H_2O)	**pH (KCl)**	**SOC**	**POM**	**MWD**	**P**	**K**	**Ca**	**Mg**	**Acidity**	**ECEC**	**Zn**	**Mn**	**Cu**	**Clay**
pH (H_2O)	1.00														
pH (KCl)	**0.91***	1.00													
SOC	0.06	0.12	1.00												
POM	0.29	0.35	**0.62***	1.00											
MWD	0.05	-0.08	0.47	**-0.62***	1.00										
P	0.69	**0.86***	0.02	-0.25	0.30	1.00									
K	0.66	**0.97***	0.05	-0.10	0.04	**0.89***	1.00								
Ca	0.66	**0.89***	-0.20	-0.01	0.05	**0.96***	**0.91***	1.00							
Mg	-0.38	-0.45	-0.10	0.30	**-0.73***	-0.68	-0.55	-0.54	1.00						
Acidity	0.40	0.14	0.10	-0.33	0.04	-0.09	-0.09	-0.11	0.13	1.00					
ECEC	0.66	**0.91***	-0.21	0.03	-0.08	**0.92***	**0.90***	**0.99***	-0.41	-0.09	1.00				
Zn	0.64	**0.79***	-0.03	-0.12	0.33	**0.96***	**0.86***	**0.93***	-0.69	-0.26	**0.88***	1.00			
Mn	**-0.89***	-0.70	-0.03	0.56	-0.38	**-0.74***	-0.58	-0.67	0.51	-0.39	-0.63	-0.60	1.00		
Cu	**-0.79***	**-0.91***	0.25	0.05	-0.11	**-0.93***	**-0.89***	**-0.97***	0.59	-0.05	**-0.94***	**-0.89***	**0.77***	1.00	
Clay	-0.03	0.46	-0.35	0.49	**-0.77***	0.33	0.47	0.52	0.28	-0.24	0.62	0.28	0.05	0.38	1.00

SOC: Soil organic carbon (%); POM: Particulate organic matter (%); MWD: Mean weight diameter (mm); P: phosphorus (mg kg^{-1}); K: Potassium ($cmol_c$ kg^{-1}); Ca: Calcium ($cmol_c$ kg^{-1});Mg: Magnesium ($cmol_c$ kg^{-1}); Acidity (mmol kg^{-1}); ECEC: Effective cation exchange capacity ($cmol_c$ kg^{-1}); Zn: Zinc (mg L^{-1}); Mn : Manganese (mg L^{-1}); Cu: Copper (mg L^{-1}); Clay (%).

*Correlation is significant at $p < 0.05$

Appendix 4.32: Correlation matrix for the Westleigh soil form under the pasture land use system.

	pH (H_2O)	**pH (KCl)**	**SOC**	**POM**	**MWD**	**P**	**K**	**Ca**	**Mg**	**Acidity**	**ECEC**	**Zn**	**Mn**	**Cu**	**Clay**
pH (H_2O)	1.00														
pH (KCl)	0.45	1.00													
SOC	0.28	0.15	1.00												
POM	-0.27	-0.58	-0.25	1.00											
MWD	0.17	-0.46	-0.26	0.33	1.00										
P	-0.64	-0.56	-0.29	0.55	0.36	1.00									
K	-0.46	-0.51	-0.21	0.09	0.53	0.67	1.00								
Ca	0.61	0.52	0.05	-0.41	-0.20	-0.41	**-0.86***	1.00							
Mg	0.58	0.61	-0.08	-0.37	-0.21	-0.42	**-0.84***	**0.94***	1.00						
Acidity	0.02	-0.02	0.39	0.19	0.16	0.50	-0.08	0.14	-0.07	1.00					
ECEC	0.57	0.52	-0.01	-0.37	-0.20	-0.36	-0.82	**0.99***	**0.97***	0.11	1.00				
Zn	-0.49	-0.46	-0.64	**0.89***	0.48	**0.71***	0.22	-0.02	-0.11	0.33	0.00	1.00			
Mn	**-0.95***	**-0.87***	-0.17	0.56	-0.21	0.65	0.51	-0.64	-0.62	0.07	0.61	0.35	1.00		
Cu	-0.49	-0.56	0.03	-0.03	0.39	0.51	0.70	-0.66	-0.70	0.24	0.67	0.07	0.50	1.00	
Clay	**-0.81***	-0.70	-0.43	0.38	-0.27	0.13	0.13	-0.40	-0.31	-0.45	0.38	0.08	**0.73***	0.33	1.00

SOC: Soil organic carbon (%); POM: Particulate organic matter (%); MWD: Mean weight diameter (mm); P: phosphorus (mg kg^{-1}); K: Potassium (cmol$_c$ kg^{-1}); Ca: Calcium (cmol$_c$ kg^{-1});Mg: Magnesium (cmol$_c$ kg^{-1}); Acidity (mmol kg^{-1}); ECEC: Effective cation exchange capacity (cmol$_c$ kg^{-1}); Zn: Zinc (mg L^{-1}); Mn : Manganese (mg L^{-1}); Cu: Copper (mg L^{-1}); Clay (%).

*Correlation is significant at $p < 0.05$

Appendix 4.33: Correlation matrix for the Westleigh soil form under the arable land use system.

	pH (H_2O)	**pH (KCl)**	**SOC**	**POM**	**MWD**	**P**	**K**	**Ca**	**Mg**	**Acidity**	**ECEC**	**Zn**	**Mn**	**Cu**	**Clay**
pH (H_2O)	1.00														
pH (KCl)	0.45	1.00													
SOC	0.55	0.39	1.00												
POM	-0.12	0.29	0.03	1.00											
MWD	0.29	-0.04	-0.42	-0.11	1.00										
P	-0.47	-0.12	-0.45	**0.97***	-0.47	1.00									
K	-0.38	0.24	0.04	0.04	-0.17	-0.25	1.00								
Ca	-0.25	0.14	-0.01	-0.33	-0.14	-0.49	**0.91***	1.00							
Mg	-0.02	0.03	0.50	-0.55	-0.09	-0.58	0.17	0.43	1.00						
Acidity	0.27	-0.09	0.24	-0.31	0.37	-0.24	-0.62	-0.35	0.45	1.00					
ECEC	-0.25	0.15	0.08	-0.34	-0.15	-0.53	**0.87***	**0.99***	0.56	-0.26	1.00				
Zn	0.04	**0.75***	0.31	0.08	-0.53	-0.08	0.70	0.62	0.16	-0.50	0.61	1.00			
Mn	-0.38	-0.21	0.05	0.51	**-0.84***	0.50	-0.09	-0.09	0.25	-0.10	-0.03	0.09	1.00		
Cu	0.15	-0.34	-0.51	-0.11	-0.12	0.52	**-0.87***	**-0.82***	-0.37	0.30	**-0.83***	-0.56	0.26	1.00	
Clay	0.07	-0.41	0.07	0.09	-0.48	0.14	-0.52	-0.36	0.43	0.31	-0.27	-0.33	0.81	0.54	1.00

SOC: Soil organic carbon (%); POM: Particulate organic matter (%); MWD: Mean weight diameter (mm); P: phosphorus (mg kg^{-1}); K: Potassium ($cmol_c$ kg^{-1}); Ca: Calcium ($cmol_c$ kg^{-1});Mg: Magnesium ($cmol_c$ kg^{-1}); Acidity (mmol kg^{-1}); ECEC: Effective cation exchange capacity ($cmol_c$ kg^{-1}); Zn: Zinc (mg L^{-1}); Mn : Manganese (mg L^{-1}); Cu: Copper (mg L^{-1}); Clay (%).

*Correlation is significant at $p < 0.05$

Appendix 4.34: Correlation matrix for the Inhoek soil form under the undisturbed land use system

	pH (H_2O)	**pH (KCl)**	**SOC**	**POM**	**MWD**	**P**	**K**	**Ca**	**Mg**	**Acidity**	**ECEC**	**Zn**	**Mn**	**Cu**	**Clay**
pH (H_2O)	1.00														
pH (KCl)	0.47	1.00													
SOC	-0.22	-0.35	1.00												
POM	-0.15	-0.17	0.34	1.00											
MWD	-0.40	-0.38	**0.66***	0.33	1.00										
P	-0.59	-0.70	**0.42***	0.26	0.69	1.00									
K	-0.32	-0.37	0.13	-0.62	0.44	0.44	1.00								
Ca	**0.85***	0.31	-0.28	0.72	-0.43	-0.43	-0.47	1.00							
Mg	**0.75***	0.52	-0.30	0.72	-0.36	-0.44	-0.54	**0.95***	1.00						
Acidity	-0.36	0.00	0.12	-0.66	-0.05	-0.23	-0.07	-0.64	-0.66	1.00					
ECEC	**0.82***	0.41	-0.29	0.73	-0.39	-0.43	-0.48	**0.99***	**0.98***	-0.68	1.00				
Zn	-0.02	-0.65	-0.35	-0.20	0.03	0.37	0.51	-0.18	-0.33	-0.23	-0.24	1.00			
Mn	-0.24	**-0.79***	-0.16	-0.31	0.12	0.48	0.52	-0.42	-0.59	0.03	-0.49	**0.95***	1.00		
Cu	-0.15	0.28	-0.02	0.38	-0.40	-0.24	-0.69	0.12	0.27	-0.05	0.17	-0.18	-0.23	1.00	
Clay	0.49	-0.05	-0.02	0.02	-0.42	-0.38	-0.22	0.36	0.17	0.28	0.27	-0.30	-0.24	0.43	1.00

SOC: Soil organic carbon (%); POM: Particulate organic matter (%); MWD: Mean weight diameter (mm); P: phosphorus (mg kg^{-1}); K: Potassium (cmol$_c$ kg^{-1}); Ca: Calcium (cmol$_c$ kg^{-1});Mg: Magnesium (cmol$_c$ kg^{-1}); Acidity (mmol kg^{-1}); ECEC: Effective cation exchange capacity (cmol$_c$ kg^{-1}); Zn: Zinc (mg L^{-1}); Mn : Manganese (mg L^{-1}); Cu: Copper (mg L^{-1}); Clay (%).

*Correlation is significant at $p < 0.05$

Appendix 4.35: Correlation matrix for the Inhoek soil form under the pasture land use system.

	pH (H$_2$O)	**pH (KCl)**	**SOC**	**POM**	**MWD**	**P**	**K**	**Ca**	**Mg**	**Acidity**	**ECEC**	**Zn**	**Mn**	**Cu**	**Clay**
pH (H$_2$O)	1.00														
pH (KCl)	**0.71***	1.00													
SOC	-0.26	0.32	1.00												
POM	-0.17	-0.06	**0.53***	1.00											
MWD	0.46	0.37	-0.25	-0.09	1.00										
P	-0.25	-0.17	0.50	**0.84***	0.15	1.00									
K	-0.50	-0.40	0.35	0.10	-0.24	0.18	1.00								
Ca	-0.13	0.00	0.09	**-0.82***	-0.11	-0.49	0.52	1.00							
Mg	0.04	-0.07	-0.40	**-0.89***	-0.01	**-0.82***	0.24	**0.76***	1.00						
Acidity	0.21	0.3	0.15	0.10	0.04	0.18	0.01	**-0.21***	-0.11	1.00					
ECEC	-0.06	-0.05	-0.16	**-0.86***	-0.07	-0.69	0.43	**0.94***	**0.93***	-0.18	1.00				
Zn	-0.39	-0.29	0.27	**0.81***	0.15	**0.81***	-0.21	-0.63	**-0.85**	-0.42	**-0.79***	1.00			
Mn	-0.44	-0.34	0.68	-0.03	-0.42	0.30	**0.80***	0.46	0.14	0.12	0.34	-0.11	1.00		
Cu	-0.17	-0.12	-0.04	-0.51	-0.31	-0.58	0.69	**0.81***	**0.78***	0.36	**0.86***	**-0.79***	0.43	1.00	
Clay	-0.57	-0.58	-0.16	-0.60	-0.18	-0.50	0.25	0.60	**0.73***	0.06	**0.71***	-0.31	0.29	0.50	1.00

SOC: Soil organic carbon (%); POM: Particulate organic matter (%); MWD: Mean weight diameter (mm); P: phosphorus (mg kg^{-1}); K: Potassium (cmol$_c$ kg^{-1}); Ca: Calcium (cmol$_c$ kg^{-1});Mg: Magnesium (cmol$_c$ kg^{-1}); Acidity (mmol kg^{-1}); ECEC: Effective cation exchange capacity (cmol$_c$ kg^{-1}); Zn: Zinc (mg L^{-1}); Mn : Manganese (mg L^{-1}); Cu: Copper (mg L^{-1}); Clay (%).

*Correlation is significant at $p < 0.05$

Appendix 4.36: Correlation matrix for the Inhoek soil form under the arable land use system.

	pH (H$_2$O)	**pH (KCl)**	**SOC**	**POM**	**MWD**	**P**	**K**	**Ca**	**Mg**	**Acidity**	**ECEC**	**Zn**	**Mn**	**Cu**	**Clay**
pH (H$_2$O)	1.00														
pH (KCl)	0.42	1.00													
SOC	0.14	-0.46	1.00												
POM	-0.02	0.02	0.03	1.00											
MWD	0.15	-0.14	-0.24	-0.39	1.00										
P	0.40	**0.72***	-0.57	-0.87	0.28	1.00									
K	-0.13	0.37	-0.02	-0.18	-0.18	-0.23	1.00								
Ca	-0.29	**-0.80***	0.70	0.58	0.00	**-0.89***	0.17	1.00							
Mg	-0.20	-0.71	0.91	0.94	-0.26	**-0.88**	0.02	**0.90***	1.00						
Acid	0.44	**0.89***	-0.37	-0.42	-0.05	**0.86**	-0.07	**-0.92***	**-0.74***	1.00					
ECEC	-0.26	**-0.78***	0.79	0.75	-0.11	**-0.91**	0.13	**0.99***	**0.96***	**-0.87**	1.00				
Zn	-0.02	0.64	-0.55	-0.83	0.01	0.52	0.56	-0.38	-0.60	0.36	-0.47	1.00			
Mn	0.16	**0.90***	-0.13	-0.22	-0.50	0.37	0.56	-0.52	-0.34	0.69	-0.45	0.53	1.00		
Cu	0.04	0.49	-0.47	**-0.97**	0.32	0.48	0.54	-0.26	-0.57	0.24	-0.38	**0.94***	0.32	1.00	
Clay	-0.38	-0.32	0.66	0.29	-0.55	-0.64	0.36	0.69	**0.71***	-0.56	**0.72***	0.05	0.06	0.05	1.00

SOC: Soil organic carbon (%); POM: Particulate organic matter (%); MWD: Mean weight diameter (mm); P: phosphorus (mg kg^{-1}); K: Potassium (cmol$_c$ kg^{-1}); Ca: Calcium (cmol$_c$ kg^{-1});Mg: Magnesium (cmol$_c$ kg^{-1}); Acidity (mmol kg^{-1}); ECEC: Effective cation exchange capacity (cmol$_c$ kg^{-1}); Zn: Zinc (mg L^{-1}); Mn : Manganese (mg L^{-1}); Cu: Copper (mg L^{-1}); Clay (%).

*Correlation is significant at $p < 0.05$

Appendix 4.37: Correlation matrix for the Oakleaf soil form under the pasture land use system.

	pH (H_2O)	**pH (KCL)**	**SOC**	**POM**	**MWD**	**P**	**K**	**Ca**	**Mg**	**Acidity**	**ECEC**	**Zn**	**Mn**	**Cu**	**Clay**
pH (H_2O)	1.00														
pH (KCl)	-0.28	1.00													
SOC	0.17	0.29	1.00												
POM	0.08	0.48	0.28	1.00											
MWD	-0.08	-0.41	0.03	-0.46	1.00										
P	0.16	-0.13	-0.26	0.15	0.42	1.00									
K	0.34	-0.36	-0.31	0.31	0.13	**0.81***	1.00								
Ca	0.35	-0.20	-0.10	0.35	-0.09	0.11	0.89	1.00							
Mg	0.12	-0.08	0.12	0.11	-0.39	-0.71	0.33	0.62	1.00						
Acidity	-0.33	0.37	0.27	-0.29	0.02	-0.26	**-0.99***	**-0.94***	-0.49	1.00					
ECEC	0.30	-0.17	-0.01	0.29	-0.22	-0.21	**0.78***	**0.95***	**0.84***	**-0.85***	1.00				
Zn	0.18	-0.18	-0.29	0.17	0.41	**0.99***	**0.85***	0.20	-0.64	-0.35	-0.12	1.00			
Mn	-0.31	0.39	0.26	-0.26	0.07	-0.14	**-0.99***	**-0.93***	-0.58	**0.99***	**-0.88***	-0.23	1.00		
Cu	-0.07	-0.22	-0.01	-0.12	-0.39	**-0.81***	**-0.89***	0.17	**0.81***	-0.19	0.44	**-0.76***	0.33	1.00	
Clay	-0.04	0.21	0.32	-0.02	-0.43	**-0.94***	-0.46	0.16	**0.83***	0.06	0.45	**-0.92***	0.04	**0.72***	1.00

SOC: Soil organic carbon (%); POM: Particulate organic matter (%); MWD: Mean weight diameter (mm); P: phosphorus (mg kg^{-1}); K: Potassium ($cmol_c$ kg^{-1}); Ca: Calcium ($cmol_c$ kg^{-1});Mg: Magnesium ($cmol_c$ kg^{-1}); Acidity (mmol kg^{-1}); ECEC: Effective cation exchange capacity ($cmol_c$ kg^{-1}); Zn: Zinc (mg L^{-1}); Mn : Manganese (mg L^{-1}); Cu: Copper (mg L^{-1}); Clay (%).

*Correlation is significant at $p < 0.05$

Appendix 4.38: Correlation matrix for the Oakleaf soil form under the arable land use system.

	pH (H_2O)	**pH (KCl)**	**SOC**	**POM**	**MWD**	**P**	**K**	**Ca**	**Mg**	**Acidity**	**ECEC**	**Zn**	**Mn**	**Cu**	**Clay**
pH (H_2O)	1.00														
pH (KCl)	**0.66***	1.00													
SOC	0.26	-0.01	1.00												
POM	-0.42	-0.47	-0.10	1.00											
MWD	**0.61***	0.14	-0.17	0.28	1.00										
P	0.22	-0.34	-0.16	-0.11	0.44	1.00									
K	0.44	-0.41	0.76	0.34	0.26	-0.09	1.00								
Ca	-0.05	0.58	-0.22	-0.27	0.12	0.44	-0.57	1.00							
Mg	0.05	0.40	-0.01	-0.09	0.40	0.56	-0.35	**0.92***	1.00						
Acidity	0.32	-0.46	0.48	-0.24	-0.06	-0.13	0.23	-0.66	**-0.74***	1.00					
ECEC	0.02	0.53	-0.10	-0.21	0.23	0.49	-0.46	**0.99***	0.96	-0.70	1.00				
Zn	-0.06	0.36	-0.26	0.05	-0.02	0.33	-0.30	**0.83***	0.74	-0.46	**0.83***	1.00			
Mn	-0.40	-0.29	**-0.96***	0.26	-0.32	0.40	0.34	-0.08	0.02	-0.16	-0.03	0.03	1.00		
Cu	-0.18	-0.04	-0.57	-0.18	0.32	0.66	-0.41	0.38	0.54	-0.30	0.41	0.02	0.27	1.00	
Clay	-0.07	0.19	-0.39	-0.31	0.35	0.69	-0.39	0.59	0.73	-0.44	0.63	0.22	0.26	**0.95***	1.00

SOC: Soil organic carbon (%); POM: Particulate organic matter (%); MWD: Mean weight diameter (mm); P: phosphorus (mg kg^{-1}); K: Potassium (cmol$_c$ kg^{-1}) ; Ca: Calcium (cmol$_c$ kg^{-1});Mg: Magnesium (cmol$_c$ kg^{-1}); Acidity (mmol kg^{-1}); ECEC: Effective cation exchange capacity (cmol$_c$ kg^{-1}); Zn: Zinc (mg L^{-1}); Mn : Manganese (mg L^{-1}); Cu: Copper (mg L^{-1}); Clay (%).

*Correlation is significant at $p < 0.05$