CHARACTERIZATION OF SPATIAL DISTRIBUTION OF SOIL ORGANIC CARBON STOCKS IN SELECTED LAND USE TYPES AND LANDSCAPES IN CHAMA DISTRICT

BY

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DECLARATION

I, Fred Chikuta, declare that this dissertation represents a genuine research I carried out and that no part of this dissertation has been submitted for any other degree or diploma at this or another university or institution.

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Signature Date

APPROVAL FORM

This dissertation of Mr. Fred Chikuta is approved as fulfilling part of the requirements for the award of the degree of Master of Science in Integrated Soil Fertility Management of the University of Zambia.

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DEDICATION

I dedicate this dissertation to my late parents Douglas.H.Chikuta and Bertha.E.Chikuta with endless love and good memories.

ABSTRACT

Soil Organic carbon (SOC) because of its influence on all aspects of soil fertility, is a useful indicator of soil health and the performance of mixed farms, and increasing SOC can improve productivity, stability and resilience of the soil. Thus the overall objective of the study was to characterize the spatial distribution of SOC in selected land use types and landscapes of Chama District of Zambia. The grid survey of 10m by 10m was used to sample the soils in the top 20cm of the soil for all the land uses and landscapes, composite samples were made for each land use type that was replicated 5 times. The other parameters determined were soil texture and bulky density.

The percentage SOC was determined for all the selected land use types and landscapes by using the Walkley-Black experiment. The Analysis of Variance (ANOVA) preceded by Duncan's Multiple Range Test (DMRT) was used. Results of this study have shown that there are statistically significant differences in the levels of SOC in the top 20 cm layers of soils under different land use types in the study area. The levels of SOC ranged from 0.02 % to 2.62 % with soils under maize cultivation having the highest levels and soils in game management areas having the lowest levels. The high levels in soils under maize production could be attributed to the use of chemical fertilizers and high dry matter production associated with the application of chemical inorganic fertilization which leads to higher inputs of carbon to the soil through increased root bio mass, root turn over, stubble and crop debris. The low carbon content was estimated in the Game Management Area soils (0.02%), which could be attributed to low dry matter production and sandy soils in most of this area.

The results also showed that topography had a major influence in the SOC content of the top 20cm layer of the soils in the study area; this was very evident in that the SOC content showed a general tendency to increase from the summit to the depression. The SOC content at the depression was 2.38% as compared to the summit with a SOC content of 1.57%. The high SOC values at the depression could have been attributed to the chemical stabilization, decreased decomposition because of low redox conditions, and higher litter inputs from vegetation and upslope contributions. The Least Significant Difference (LSD) and the t-test was used to ascertain the influence of topography on SOC content.

Results showed that soil texture influences SOC content through the role of clay in the protection of soil organic matter from decomposition and role of clay and silt in water availability and therefore plant productivity. This was clearly evident at the depression catena positions where the clay content was 40.8% and the SOC content was at its highest (2.38%).

Generally, grasses, such as maize, rice and pastures had high levels of SOC (1.35%) and the forest Land Use Type (LUT) had 0.55% SOC.

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CHAPTER ONE

1.0 INTRODUCTION

Soil carbon is the generic name for carbon held within the soil, primarily in association with its organic matter. Soil carbon is the largest terrestrial pool of carbon. Humans have, and will most likely continue to have significant impact on the size of this pool. Soil carbon plays a key role in the carbon cycle and thus it is important in global climate models (Lal *et al*;2008).

According to West *et.al*., (2010) and Saha *et.al*, (2012), a decline in Soil Organic Carbon (SOC) creates an array of negative effects on land productivity. Katyal *et.al.*, (2001) further clarifies that maintaining and improving the level of SOC is a pre-requisite to ensure soil quality, crop productivity and sustainability of agricultural ecosystems. Batjes (1998) highlighted that soil contains a significant part of the global carbon stock estimated to be about 3.5%. Bhattacharyya *et al*., (2009) stated that current research trends show that there is growing interest in assessing the role of soil as a sink for carbon under different land-use management practices, including forest ecosystems. Increase in SOC content by 0.01% can substantially reduce the adverse consequences of annual increase in atmospheric carbon dioxide concentration. (Lal *et al*., 1998)

According to (West *et.al*., (2010), Saha *et.al*., (2012),the magnitude of variation in SOC content and stock (increase/decrease) depends on the type of land-use, degree of land-use change and post-conversion land management.

Soil Organic Carbon plays a major role in the global carbon budget, and can act as a source or sink of atmospheric carbon, thereby possibly influencing the course of climate. Changes in the soil organic carbon (SOC) stocks are now taken into account in international negotiations regarding climate change.(Batjes, 1998).

A better understanding of the spatial variability of SOC is important for the refining agricultural management practices and for improving sustainable land use (McGrath and Zhang, 2004). It provides a valuable base against which subsequent and future measurements can be evaluated. Information about the spatial distribution of soil organic carbon (SOC) pools at a proper scale is critical for developing feasible carbon sequestration programmes in Zambia.

To develop public policy for conservation programmes, information is needed on spatial distribution and baselines of the soil organic carbon pools in association with different land uses. (Bationo and Buerkert, 2001***).***

SOC plays an important role in supplying plant nutrients, enhancing cation exchange capacity, improving soil aggregation and water retention and supporting soil biological activity (Dudal and Deckers, 1993). Although it has been difficult to quantify the effects of SOC on crop and ecosystem productivity (Dudal and Deckers,1993), results from experiments in some African countries already indicate favourable responses due to SOC. Cultivated systems have reduced carbon contents due to reduced tree cover and increased mineralization due to surface disturbance. (Windmeijer and Andriesse, 1993).

Soil organic matter is not only a major regulator of various processes underlying the supply of nutrients and the creation of a favourable environment for plant growth but also regulates various processes governing the creation of soil- based environmental services .

Carbon content and status in the soil is closely associated with clay and silt and clay type, which influences the stabilization of organic carbon. Aggregates physically protect SOC through formation of barriers between microbes and enzymes and their substrates thereby controlling microbial turnover (Six *et al*., 2002a, b).

Soil organic carbon plays an important role in ensuring good health of the soil environment and is critical in providing needed ecosystem services. A higher content of SOC will result in a higher Fertilizer Use Efficiency (FUE).

1.1 Statement of the Problem

In Zambia, no documented work has been done in studying the spatial distribution of Soil Organic Carbon (SOC) pools that can aid the formulation or development of feasible Carbon Sequestration Programmes.There is no base line data on the spatial distribution of Soil Organic Carbon pools in Zambia.

1.2 Objectives

The overall objective of the study was to characterize the spatial distribution of the soil organic carbon (SOC) in Chama district of Zambia.

1.3 Specific Objectives

- To assess the spatial distribution characteristics of SOC in selected land use types in Mphalausenga Agricultural Block of Chama District.
- To determine factors influencing SOC stocks using GIS.

1.4 Research Hypothesis

There are major differences in the spatial distribution of SOC Stocks in the Soils of Mphalausenga Agricultural Block of Chama District and the amounts of SOC Stocks show great variation among different Land Use Types (LUTs), Soil types and landscapes.

1.5 Justification of the study

Data on the spatial distribution of soil organic carbon pools in Zambia is very vital for the development of public policy for conservation programmes. Thus, knowledge of SOC stocks and changes is needed to devise plans for, sustainable management of eco-systems, mitigation of GHG emissions, likely impacts of climate change on soils/ecosystems in future and formulation of policies on carbon credits.etc.

CHAPTER TWO

2.0 LITERATURE REVIEW

According to McGrath and Zhang (2004), Soil Organic Carbon (SOC) is a dynamic component of terrestrial systems, with both internal and external changes with the atmosphere and the biosphere. SOC plays an important role in enhancing crop production (Stevenson and Cole, 1999) and mitigating greenhouse gas emissions (Lal *et al*., 1995).

Improved estimations of SOC stocks and fluxes could greatly help scientists to monitor and predict ecosystems response to climate change, as well as aiding policy makers when they take land use and management decisions and assisting land managers gain better access to carbon markets (Lal et al.,1995).

The Intergovernmental Panel on Climate Change (IPCC) developed the Revised Guidelines for National Greenhouse Gas Inventories to provide methods for estimating emissions by sources and removal by sinks of greenhouse gases (Houghton *et al*., 1997), in which the Land Use and Land Use Change section provides a method to estimate average annual C sources or sinks from soils with changes in land use and management over a 20-year inventory period.

Wang *et al*., (2001) referred SOC to be similar to other soil properties in that SOC levels exhibit variability as a result of dynamic interactions between parent material, climate and geological history, on regional and continental scales. However, landscape attributes including slope, aspect, elevation and land use may be the dominant factors of SOC in an area with the same parent material and single climate regime (Rezaei and Gilkes, 2005).

According to Buol *et al*., (1989), landscape attributes affect organic matter activity, run-off and run-on processes, condition of natural drainage, and exposure of soil to wind and precipitation. The SOC content of cropland is also strongly dependent upon crop and soil management practices, such as crop species and rotation, tillage methods, fertilizer rate, manure application, pesticide use, irrigation, and drainage, and soil and water conservation.

Important factors controlling SOC levels include climate, hydrology, parent material, soil fertility, biological activity, vegetation patterns and land use. SOC is sensitive to impact of human activities, viz. deforestation, biomass burning, land use changes and environmental pollution. To sustain the quality and productivity of soils, knowledge of SOC in terms of its amount and quality is essential (Jenny, 1941)

According to Amundson, 2001, Janzen, 2004, and Post *et al*.2001, they pointed out that the spatial distribution of the soil organic carbon (SOC) at landscape scales is controlled by interactions of edaphic, topographic and biological factors through time and understanding these interactions is essential to quantify the role of SOC in global carbon cycle.

According to Bouwman, (1990), human modifications of the plant cover and soil through land use changes also produce considerable alterations, usually loss of carbon and soil stocks of soil organic matter. Davidson and Ackerman,(1993) alluded that between 20% to 40% of SOC is lost after the cultivation of previously untilled soils and most of this loss occurs within the first few years , thus both land use and the type of vegetation must be taken into account when relating SOC with environmental conditions.

According to Schulp *et al*., (2009), in forest landscapes, SOC stocks significantly tend to differ between different tree species and between unmanaged and managed locations. Whilst in agricultural land, land use history usually explain much of the SOC variability, while the current land use has a small effect which is attributed to slow response of SOC to land use changes and it takes many decades before land use significantly alters the SOC stock, while effects of past land use on SOC stocks are preserved for a long time.

According to Moore *et al*., 1993; Hao *et al*., 2002; Moorman *et al*., 2004; Ziadat, 2005; Yoo *et al*., 2006a and Papiernik *et al*., 2007, they attributed that topography is one of the key factors of soil formation and its effects on soil Carbon have been well documented;

General topographical influences on soil C are likely to differ in magnitude under agricultural systems with different tillage. Tillage controls soil organic matter dynamics by three major actions, such as periodic disruption of soil structure, incorporating plant residues within soil horizon, and altering soil microclimate (Balesdent *et al*., 2000).

Berhe *et al*.,2007 found that in many dry, temperate and humid landscapes, the largest SOC pools tend to occur in topographically low areas (i.e. valleys).This pattern of accumulation has been attributed to various factors, including the chemical stabilization and burial, decreased decomposition because of low redox conditions, and higher litter inputs from vegetation and upslope contributions, Also according to Gregorich *et al*.,1998and Jenny,1941they alluded that topographical factors such as slope aspect and slope gradient, affect ET and water infiltration, thereby modifying the soil moisture regime and consequently, net primary production, plant litter production and decomposition.

According to Jenny (1941), low altitudes, where conditions are more favourable for biological activity (longer growing season), the SOC values are high which is mainly attributed to high plant productivity and also the harsh conditions and low plant productivity that occur at high altitudes cause a reduction of SOC storage.

Topography affects soil Carbon through erosion and redistribution of fine soil particles and organic matter across landscape, and through water redistribution leading to varying leaching, infiltration, and runoff potentials (Ovalles and Collins, 1986; Pennock and de Jong, 1990; Kravchenko and Bullock, 2000; Creed *et al*., 2002). These three major mechanisms in turn influence various soil processes, such as soil aggregation, erosion, mineralization rates, as well as soil moisture, temperature, and aeration regimes (Franzluebbers *et al*., 1994; Hernanz *et al*., 2002). Periodic disruption of soil structure due to tillage tends to reduce soil C and N contents. No-till (NT) management is believed to lessen C losses associated with soil disturbance.

According to Jenny (1980) the spatial variation of SOC is a function of a number of factors such as relief, parent material, climate, plant cover, anthropogenic activities, time and the C sequestration potential of eco-regions can be assessed by integrating and aggregating spatial data characterizing these factors (e.g., soil properties, land use or land cover, and climatic regime) and their temporal variations.

The importance of soil textural (clay and silt) properties for the SOC content of soils was stressed repeatedly as clays are important component in the direct stabilization of organic molecules and micro-organisms (Amato and Ladd, 1992; Feller *et al*., 1992).Feller *et al*. (1992) reported that independent of climatic variations such as precipitation, temperature, and duration of the dry season, SOC increased with clay and silt contents but there was a poor relationship with the amount of rainfall.

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Study Site

Chama District is situated in the eastern part of Muchinga Province of Zambia at longitude 11°15'0" S and latitude 32°49'60" E. It is located at an elevation of 934 meters above sea level. The study area is characterised by a tropical climate with the mean annual temperature of about 25.5^{o}C and the average annual precipitation of about 653 mm. The rainfall distribution is usually poor.

Agriculture is the leading industry, and maize is the most common crop. Chama is also a major rice growing area. Cotton is a lucrative crop for some. Sorghum and soya beans are grown. Other common food crops include groundnuts, sweet potatoes, pumpkin, cabbage , sunflowers, As of the 2011 Zambian Census, the district had a population of 94,890 people.

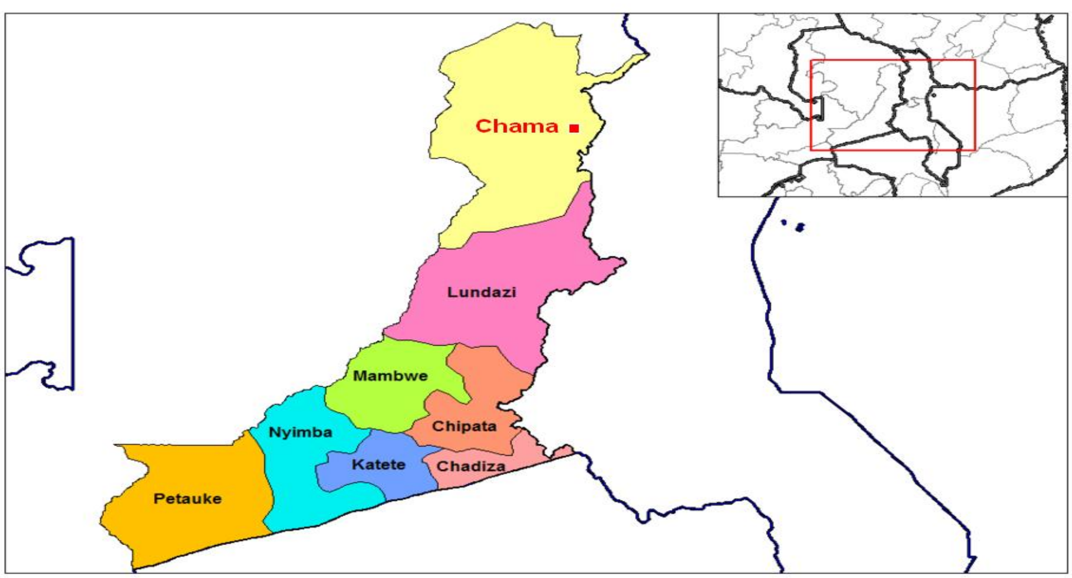

Figure 1: Location of Chama District (Source: MAL-2012)

3.2 Identification of Land Use Types

The study was conducted in the following land use types; Sparse forest, Dense Forest,Maize,Cotton,Sorghum,Soyabeans,Game Management Area, Pasture Lands and Paddy Rice. According to the Central Statistical Office and Department of Forestry data, the land use types were partitioned as indicated in Figure 2 below, in the study area.

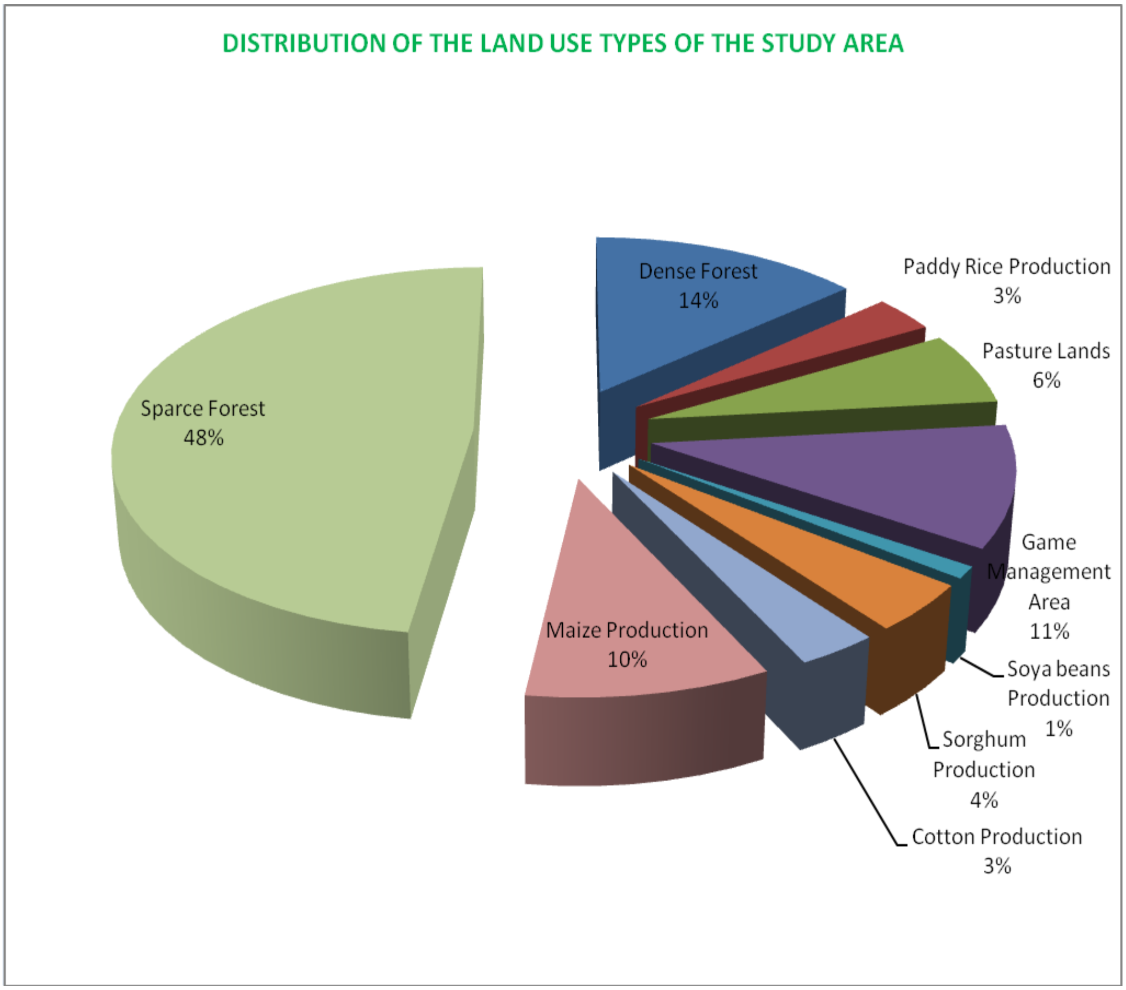

Figure 2: Distribution of the Land Use Types of the Study Area (.Source: Central Statistical Office/Forestry Department)

3.3 Methods of Soil Analysis

The soil organic carbon was determined by the Walkley-Black method in the laboratory. The Soil clods from all the different LUTs were carefully collected for the measurement of bulky density so that the SOC stocks could be estimated in the first 20 cm per kg/ha basis. The Bulky density was determined by the Wax Method and soil texture was determined by the hydrometer method.

3.4 Soil Sampling Structure

The method of sampling was that of a grid. A 10m x 10m grid was used for each LUT and the soils collected were homogenized by hand mixing and sieved for the determination of SOC after being air dried. At each sampling point the GPS coordinates and elevation were collected.

The other soil samples were collected from the five (5) natural catena's that served as replicates and the slopes were varied per each soil catena whilst the vegetation type and the climate was uniform in all the catena's. Soil samples were collected from the summit, shoulder and the depression for the analysis of the Soil Organic Carbon.

3.5 Description of the Study Blocks in Chama District.

The study area is composed of four agricultural blocks, namely Bazimu, Lunzi, Luangwa and Mphalausenga.The study was conducted in Mphalausenga Block, the block was selected because of it diverse in the landscapes and there is a high concentration of farmers.

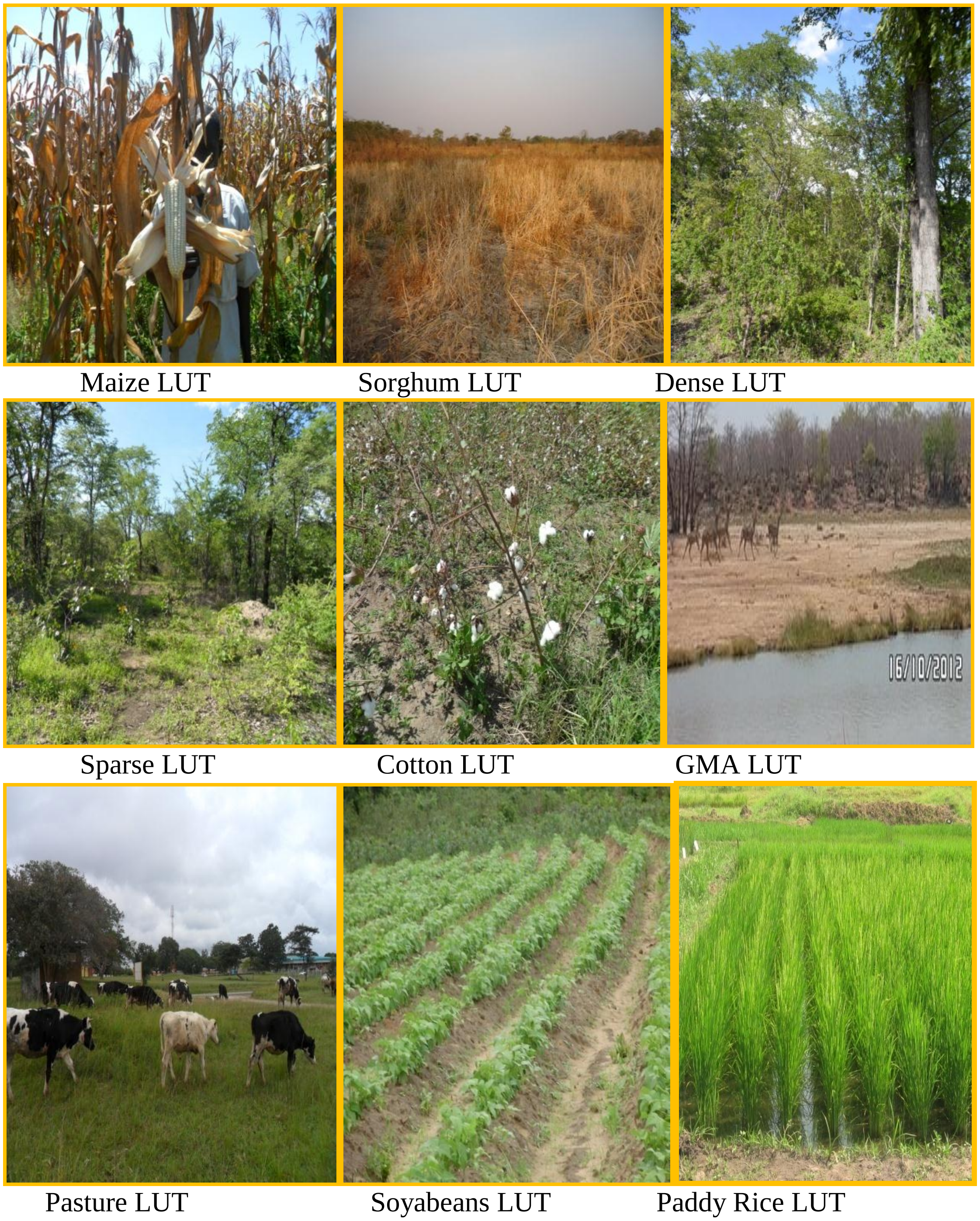

Figure 3: Selected Land Use Types from which the soil samples were collected for the determination of SOC in the study area.

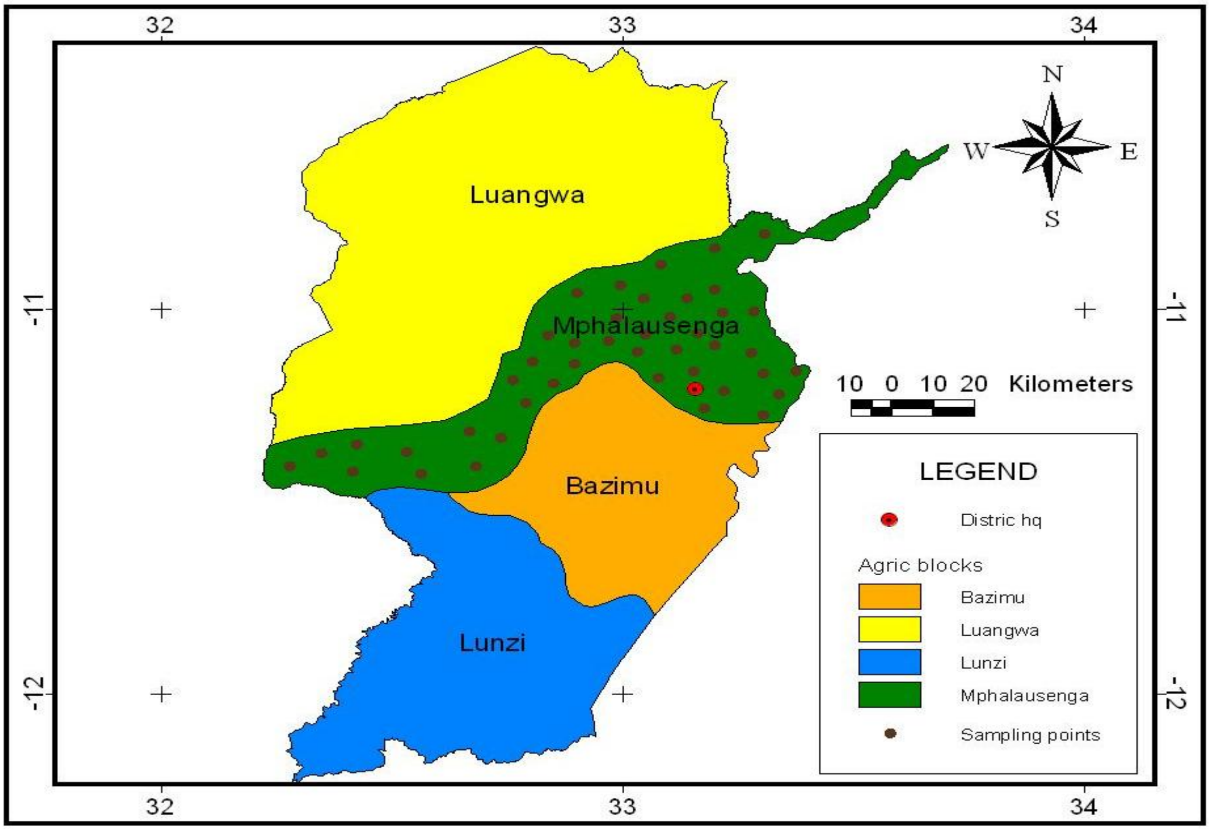

Figure 4: Soil sampling locations of the study area (n=60)

3.6 Description of Soils in the Study Area

Based on the Exploratory Soils Map of Zambia (ZARI, 1992), the study area is dominated by soils of older alluvial plains and higher river terraces in the rift valley trough (slopes 0-3%), also referred to as the V_t series. The dominant soils were V_t4 and V_t6. By description the V_t4 is a complex of imperfectly drained, olive brown to brown, firm, sodic, clayey soils (ortho-haplic SOLONETZ) and well drained, very deep, yellowish red to strong brown, friable to slightly firm, slight weathered and moderately leached, clayey soils having a clear clay increase with depth, in places cracking (chromic-haplic LUVISOLS with eutric VERTISOLS)

The V_t6 are a complex of imperfectly drained to poorly drained, very deep, very dark greyish brown, firm, calcareous, cracking clay soils (orthi-calcic VERTISOLS) and moderately well drained, deep dark reddish brown, slightly firm, slightly weathered and moderately leached calcareous, fine clayey soils having a clear clay increase with depth; in places slightly cracking (Calcari-haplic LUVISOLS and vertic LUVISOLS)

Source: (Exploratory Soils Map of Zambia.)

The soils from different land uses were analysed in the laboratory for the following parameters,

1. **Soil Organic Carbon (SOC) by the use of the Walkley-Black Method** (Walkley and Black, 1934)

The Walkley Black (WB) method used for determining Soil Organic Matter (OM) and it utilizes a specified volume of acidic dichromate solution reacting with a determined amount of soil in order to oxidize the OM. The oxidation step is then followed by titration of the excess dichromate solution with ferrous sulfate which gives a volume of ferrous sulfate in m. The OM is calculated using the difference between the total volume of dichromate added and the volume titrated after reaction.

2. **Bulk Density by the use of the wax method**. (Grossman and Reinsch, 2002)

Bulk density is a measure of a soils mass per unit volume of soil. It is used as a measure of soil wetness, volumetric water content, and porosity. Factors that influence the measurement include; organic matter content, the porosity of the soil, and the soil structure these factors will intern control hydraulic conductivity.

3. **Textural Classes by the use of the Hydrometer Method**. (Bouyoucos, G.J. 1962)

This test method covers the quantitative determination of the distribution of particle sizes of the fine-grained portion of soils. The sedimentation or hydrometer method is used to determine the particle-size distribution of the material that is finer than the No.

200 (75-um) sieve and larger than about 0.2-um. The test is performed on material that passes the No. 10 (2.0-mm) or finer sieve and results are presented as a percent of the mass of the maximum particle size used for the sedimentation test specimen. 1.2 This method can be used to evaluate the fine-grained fraction of the soil with a wide range of particle sizes by combining the sedimentation results with a sieve analysis resulting in the complete gradation curve.

Soil Organic Carbon was calculated by the formula below,

$$\textbf{SOC}\ (kg/m^2) = \mathbf{100 \times (Soil\ Sampling\ Depth \times \%\ C \times BD)}$$

Where,

Soil Sampling Depth is the thickness of the soil layer (cm) -0-20cm

%C= is the concentration of total carbon measured by the Walkley- black method.

BD=Bulk Density of the soil sample (g/cm^3)

3.7 Statistical Analysis

The Analysis of Variance (ANOVA) preceded by Duncan's Multiple Range Test (DMRT) was used in determining the significant differences in the levels of SOC in the top 20cm layers of the soils under different land use types in the study area.

The Least Significant Difference (LSD) and the t-test was used to ascertain the influence of topography on SOC content.

CHAPTER 4

4.0 RESULTS AND DISCUSSION

4.1 Characterization of Land Use Types

The mean values of SOC and bulk densities of the top 20 cm layer of soils in different land use types that were considered in this study are presented in Table 1. Figure 5 gives a graphical representation of the mean values of SOC under the different land use types within the study area.

Table 1: Mean values of Soil Organic Carbon and bulk densities in the top 20 cm of soil under different Land Use Types in the study area.

Land Use Type	Thickness(cm)	SOC (%)	Bulk Density(g/cm^3)	SOC (kg/m^2)	SOC (kg/ha)
Cotton	20	0.9^d	1.65	29.7	2.97×10^5
Maize	20	2.6^a	1.32	68.6	6.86×10^5
Sorghum	20	0.4^f	1.66	12.9	1.29×10^5
Paddy Rice	20	1.3^b	1.35	35.4	3.54×10^5
Soya beans	20	0.4^f	1.79	13.6	1.36×10^5
Sparse Forest	20	0.4^f	1.67	17.0	1.7×10^5
Dense Forest	20	0.6^e	1.57	18.8	1.88×10^5
Pasture Lands	20	1.1^c	1.66	36.5	3.65×10^5
Game Management Area	20	0.02^g	1.52	0.6	6.0×10^3

[*Letter captions with the same letter are not significantly different while the letter captions with different letters are significantly different*]

The ANOVA generated a $P<0.01$ and the analysis was proceeded by the Duncan's Multiple Range Test (DMRT) and the results showed no significant differences in the following LUTs, Soyabeans, Sorghum and sparse forest land use types in the SOC values. However, there were significant differences in the SOC values in the dense forest, cotton, Pasture lands, paddy rice, maize and GMA land use types.

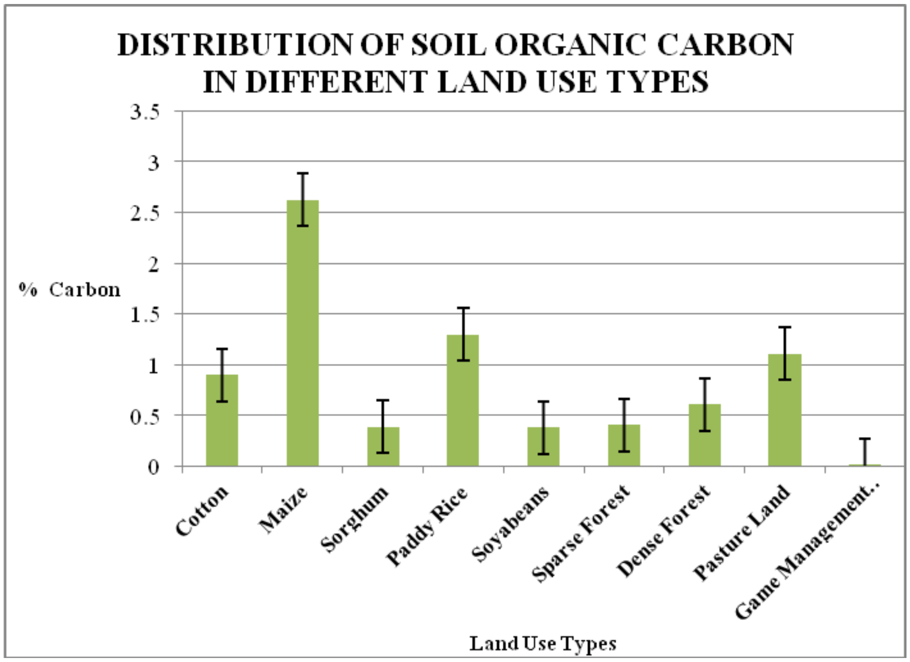

Figure 5: Mean values of the SOC in different Land Use Types in Chama.

4.2 Characterization of SOC in Land Use Types.

4.2.1 Maize

The SOC amounts of the soil under maize production was 2.62% and this was relatively high, which is consistent with the findings of Glendining *et al*., (1996) that chemical fertilizers can increase shoot and root production of crop which in turn increase residue input into the soil. The soils under maize were loamy and the land had been under fertilization for the past 5 seasons. The loamy soils affected the SOC amounts to be high, this was attributed to the stabilizing properties that clay has on organic matter. Organic matter can be trapped in the very small spaces between clay particles making them inaccessible to micro-organisms and therefore slowing decomposition.

4.2.2 Pasture Lands:

The SOC amounts for the soils under pasture land was 1.11%, this was mainly attributed to the dung from the grazing animals containing manure which is a precursor to soil organic matter and thus provides available nutrients. This is consistent with the findings of Dormaar *et al*., (1988).The dominant pastures grown in this area is the natural pastures.

4.2.3 Paddy Rice

The SOC content of the soil under paddy rice was 1.3% and this was attributed to rice producing a greater dry matter production and results of this work indicated that SOC density of paddy soils was higher than that of corresponding soils in dry cropland. This was because the decomposition of much of the organic material occurs under anaerobic conditions in paddy soils, which not only slowed down decomposition but also led to the formation of hydrocarbons rather than just carbon dioxide (Greenland, 1995). Also the paddy soils silt and clay content is generally high which led to larger SOC accumulation.

4.2.4 Dense Forest

The SOC amounts in soils under dense forest was 0.61% and this was mainly attributed to increased biomass residues into the soil as compared to the sparse forest were there is reduced biomass.

4.2.5 Sparse Forest

The SOC content in soils under sparse forest was 0.41% and was attributed to reduced residue input into the soil coupled with the sandy soils that have poor stocks of SOC.

4.2.6 Game Management Area

The SOC content in the game management area (GMA) was 0.02% and was attributed to reduced residue input into the soil coupled with the sandy soils that have poor stocks of SOC. Most of the area in the GMA is bear and is prone to high temperatures of above $40^{o}C$.

4.2.7 Cotton

The SOC content in the Cotton Land use type was 0.9% and the reduced SOC as compared to the Maize Land use type is mainly attributed to the sandy soils and lack of use of chemical fertilizers.

4.2.8 Soya beans

The lower SOC content in the Soya beans Land use type (0.38%) as compared to Maize Land use type is mainly attributed to the sandy soils and lack of use of chemical fertilizers.

4.2.9 Sorghum

The lower SOC content in the Sorghum Land use type (0.39%) as compared to Maize Land use type is mainly attributed to the sandy soils, lack of use of chemical fertilizers and reduced biomass.

4.3 Characterization of SOC in Catena Positions

Table 2: Mean values of Soil Organic Carbon in different topographic positions along Soil Catenas at different Sites.

Soil Catena Position	Elevation(Above Sea Level)	% Carbon
Soil Catena Site 1		
Summit	1114m	1.83
Shoulder	1107m	2.68
Depression	1098m	2.83
Soil Catena Site 2		
Summit	1032m	2.26
Shoulder	1026m	2.48
Depression	1020m	2.71
Soil Catena Site 3		
Summit	780m	1.45
Shoulder	773m	1.61
Depression	763m	2.07
Soil Catena Site 4		
Summit	885m	1.14
Shoulder	875m	1.49
Depression	856m	2.08
Soil Catena Site 5		
Summit	872m	1.14
Shoulder	863m	1.66
Depression	856m	2.22

From Table 2 above, the amount of Soil Organic Carbon showed greater variation between the summit and the depression. According to Buol *et al*., (1989), landscape attributes affect organic activity, run-off and run-on processes and this was evident at the summit. The summit exhibited less amounts of SOC due to a lot of run-off of the top fertile soils down the slope.

The ANOVA for the catena positions generated a P>F (0.0539) and the t-test (LSD) for SOC values showed that the means of SOC values were significantly different between the depression and summit catena position. The SOC values at shoulder catena positions did not significantly differ from those of the summit and depression.

Figure 6 shows the distribution of the soil organic carbon (SOC) in different soil catena's with respect to different topographic positions in selected landscapes.

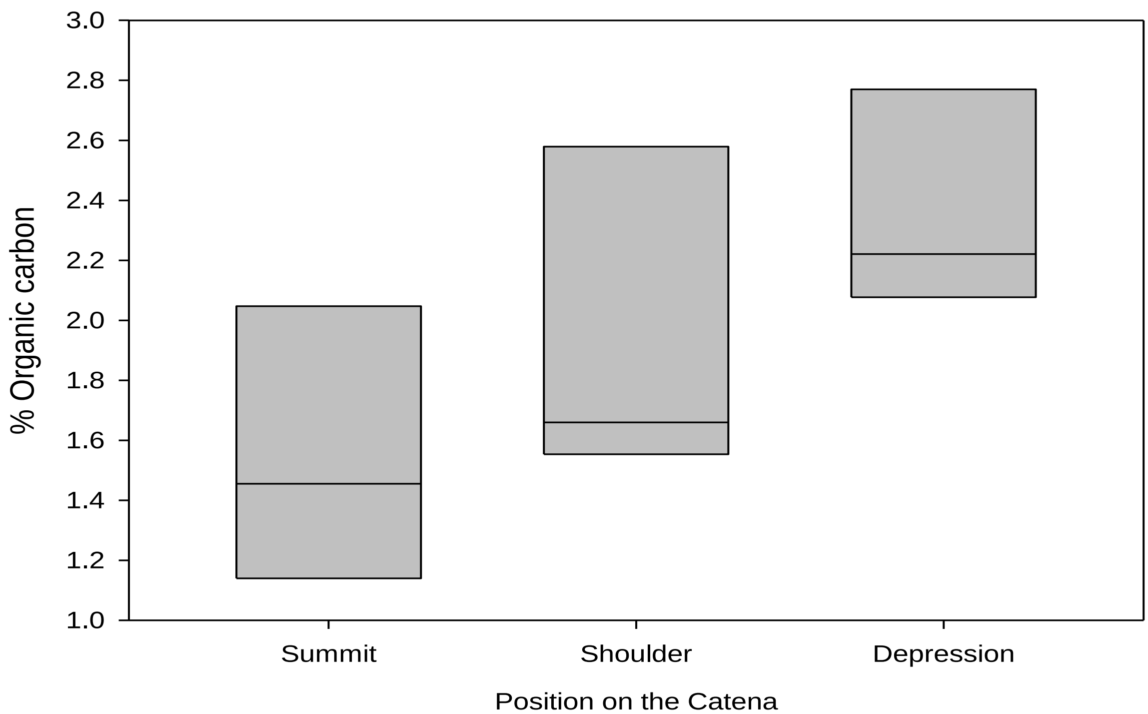

Figure 7. Distribution of organic carbon as the function of the position on the catena

The box plots above showed great variation in carbon content between the summit and depression positions of the catena in the study area. According to Berthe *et al* .,(2007);Gregorich *et al*.,(1998);Jenny,(1941),the largest SOC pools tend to occur in topographically low areas (i.e. valleys and depressions).This pattern of accumulation was attributed to various factors, including the chemical stabilization and burial, decreased decomposition because of low redox conditions, and higher litter inputs from vegetation and upslope contributions. The above attributes were in agreement with the determined results from the walkley black experiment in that the carbon content in the depression was about 50% more than that of the summit and this investigation was consistent in all the 5 catena sites.

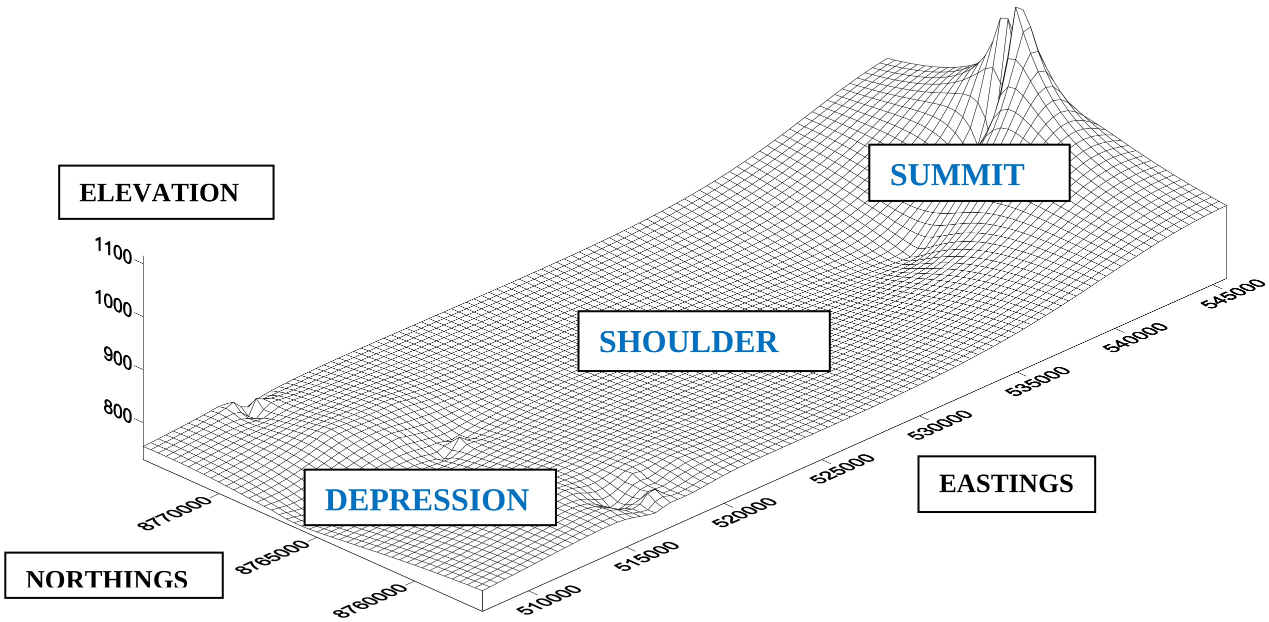

Figure 7: Wireframe Map of Mphalausenga Agricultural Block.

The summit had higher relative elevation, lower SOC and lower flow accumulation values than the depression. The summit tended to have coarser texture with higher sand and lower silt contents, while finer texture characterized the depression and SOC values were higher at the depression.

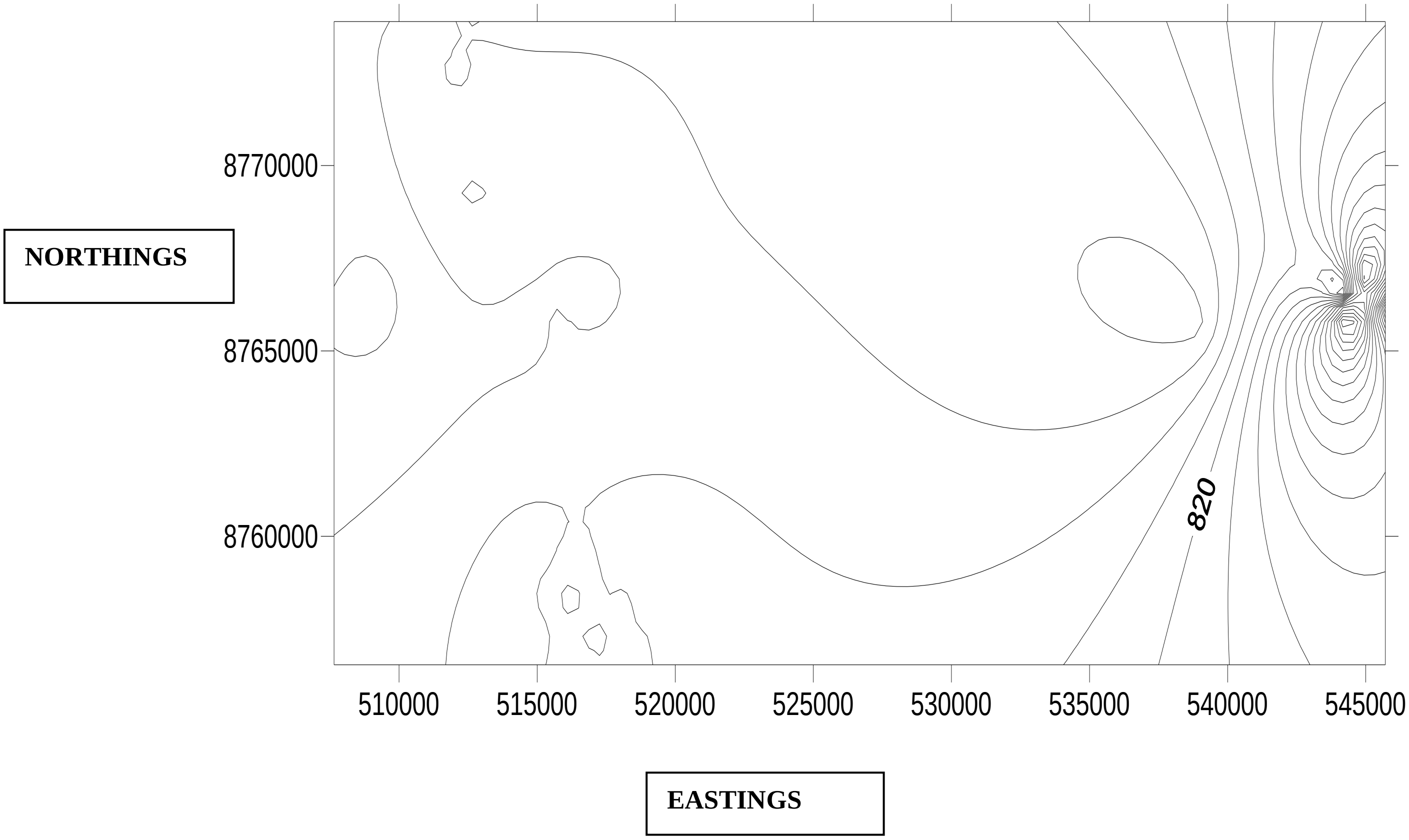

Figure 8: Contour Map of Mphalausenga Agricultural Block.

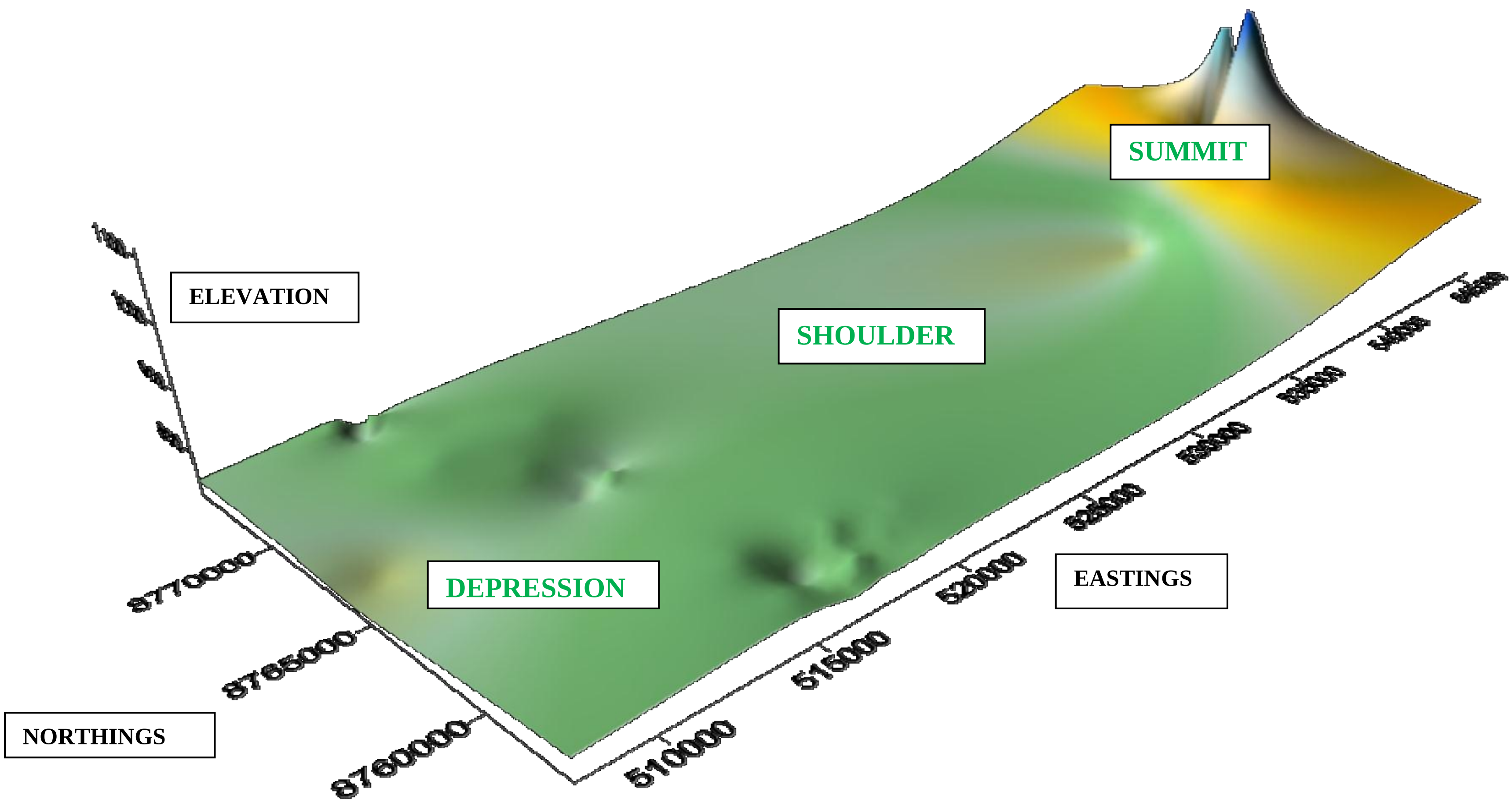

Figure 9: Digital Elevation Model of Mphalausenga Agricultural Block.

4.4 Characterization of SOC according to Textural Classes.

Table 3: Results showing the relationship between the Soil Texture and SOC values for different selected landscapes.

Land Use Type	% Clay	% Sand	% Silt	Textural Class	SOC (%)
Scarce Forest	6.8	79.6	13.6	Loamy Sand	0.41
Catena(Shoulder)	4.8	79.6	15.6	Loamy Sand	1.99
Cotton	10.8	67.6	21.6	Sandy Loam	0.9
Maize	10.8	47.6	41.6	Loam	2.62
Soya beans	8.8	79.6	11.6	Loamy Sand	0.38
Paddy Rice	8.8	70.6	20.6	Sandy Loam	1.3
Dense Forest	14.8	73.6	11.6	Sandy Loam	0.61
Sorghum	8.8	75.6	15.6	Sandy Loam	0.39
Catena(Summit)	8.8	71.6	19.6	Sandy Loam	1.57
Catena(Depression)	40.8	29.6	29.6	Clay	2.38
GMA	6.8	79.6	13.6	Loamy Sand	0.02
Pasture Lands	8.8	75.6	15.6	Sandy Loam	1.11

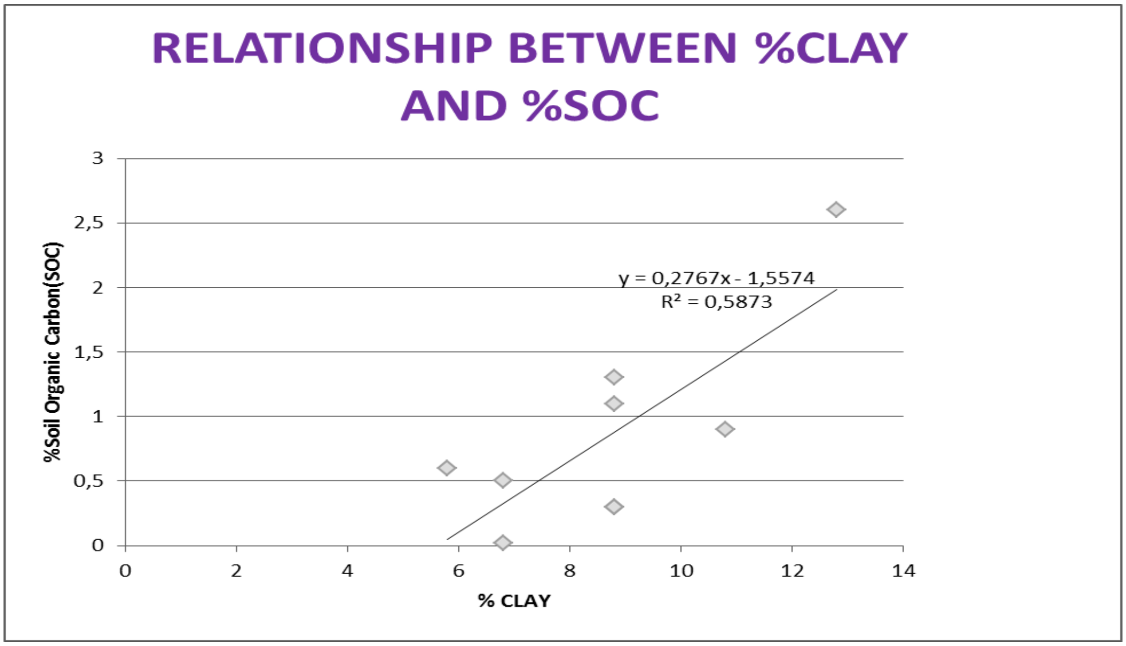

Figure 10: Relationship between the percentage clay and the percentage of the SOC.

Soil texture influenced SOC content through the role of clay in the protection of soil organic matter from decomposition (Anderson *et al*.,1981) and the role of clay and silt in water availability (Schimel,1986) and therefore plant productivity. This was very evident at the depression catena positions where the clay content was 40.8% and the SOC was at its highest (2.38%).

Figure 11, showed a very positive relationship between the percentage clay content and percentage SOC content of the soils in the study area. The summit tended to have coarser texture with higher sand and lower silt contents, while finer texture characterized the depression and SOC values were higher at the depression.

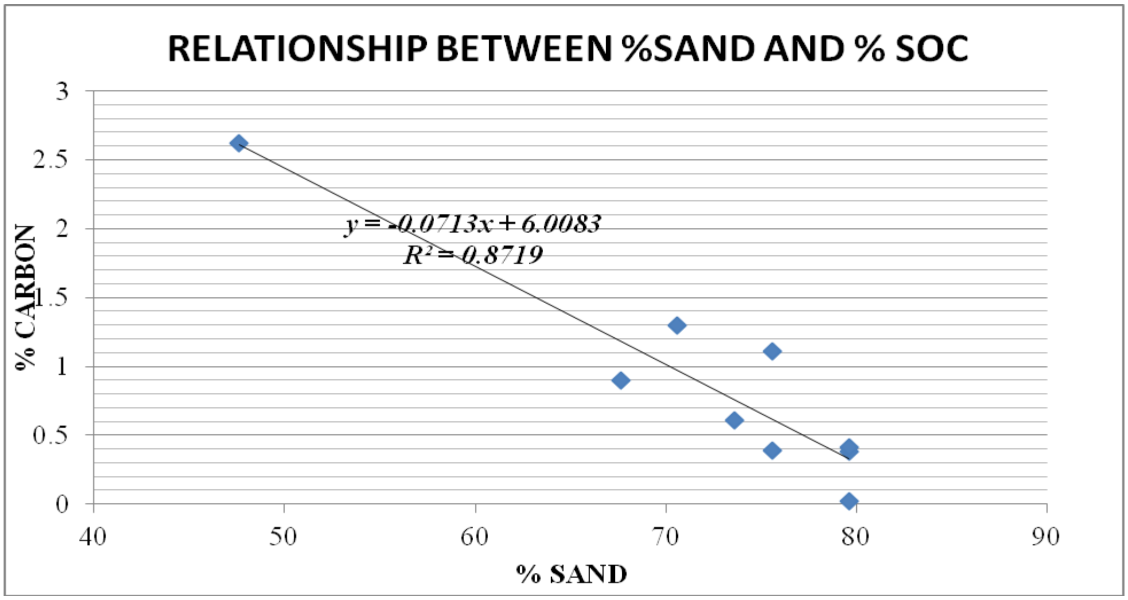

Figure 11: Relationship between the percentage sand and the percentage of the SOC.

Figure 11, showed a very negative relationship between the percentage sand content and percentage SOC content of the soils in the study area. The summit tended to have coarser texture with higher sand and lower silt contents.

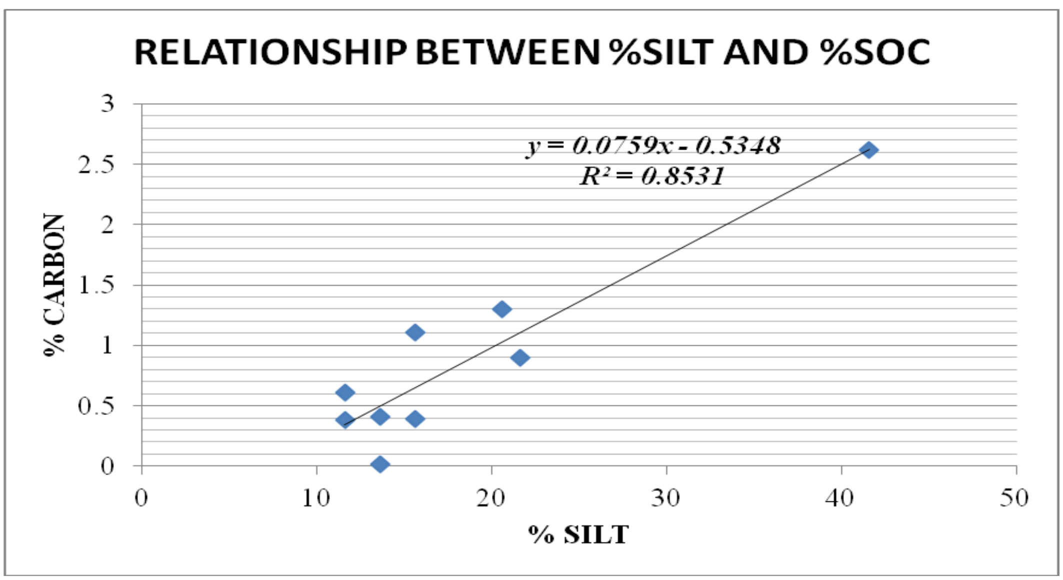

Figure 12: Relationship between the percentage Silt and the percentage of the SOC.

Figure 12, showed a very positive relationship between the percentage silt content and percentage SOC content of the soils in the study area.

CHAPTER 5

5.0 CONCLUSION AND RECOMMENDATIONS

Results of this study have shown that there are statistically significant differences in the levels of SOC in the top 20 cm layers of soils under different land use types in the study area. The levels of SOC ranged from 0.02 % to 2.62 % with soils under maize cultivation having the highest levels and soils in game management areas having the lowest levels. The high SOC levels in soils under maize production were attributed to the high production of biomass due to the use of chemical fertilizers in the maize fields compared to other land use types where lesser amount of biomass was produced due to lower usage of chemical fertilizers or no chemical fertilizers. The high dry matter production under maize were associated with the application of chemical inorganic fertilization which leads to higher inputs of carbon to the soil through increased root mass, root turn over, stubble and crop debris. The low carbon content was estimated in the Game Management Area soils (0.02%), which was attributed to low dry matter production and sandy soils in most of the area.

The results also showed that topography had a major influence in the SOC content of the top 20 cm layer of the soils in the study area, this was very evident in that the SOC content showed a general tendency to increase from the summit to the depression. The SOC content at the depression was 2.38% as compared to the summit with a SOC content of 1.57%. The high SOC values in the study area were attributed to the chemical stabilization, decreased decomposition because of low redox conditions, and higher litter inputs from vegetation and upslope contributions.

Results showed that soil texture influences SOC content through the role of clay in the protection of soil organic matter from decomposition and role of clay and silt in water availability (Anderson et al., 1981)   This was clearly evident at the depression catena positions where the clay content was 40.8% and the SOC content was at its highest (2.38%).Figure 11, showed a very positive relationship between the percentage clay content and percentage SOC content of the soils in the study area. The summit tended to have coarser texture with higher sand and lower silt contents, while finer texture characterized the depression and SOC values were higher at the depression.

Generally, grasses, such as maize, rice and pastures had high levels of SOC (1.35%) and the forest LUT had 0.55% SOC. Results showed that topography, soil texture and land use type influenced the levels of SOC in the study area.

5.1 RECOMMENDATIONS

From the results of the study i would recommend the following to the farming community; the farmers should utilize the biomass such as dry dung, dry leaves and agricultural crop residues to improve the soil quality as most of the soils in the study area have poor stocks of SOC.

Also i strongly recommend the farmers in both plateau and hilly areas of the study area to practice mixed cropping, leguminous crops may be grown alternately with cereals and cash crops. The farmers cultivating in hilly landscapes are recommended to practice contour farming and use of cover crops.

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Appendix 1:GPS Co-ordinates and Elevations above sea level for the study area.

LAND USE TYPE	GPS Co-ordinates	Elevation	Replications	%Carbon
	S11° 014’29.1”,E033°009’16.9”	789m	Rep I	
	S11° 014’28.1”,E033°009’19.9”	776m	RepII	
	S11° 014’27.1”,E033°008’17.9”	788m	Rep III	
	S11° 014’29.1”,E033°009’23.9”	796m	Rep IV	
Cotton	S11° 014’30.1”,E033°010’17.9”	778m	Rep V	0,9
	S11° 13’ 57.1”,E033° 09 ‘38.7”	785m	Rep I	
	S11° 13’ 57.1”,E033° 09 ‘42.7”	776m	RepII	
	S11° 13’ 43.1”,E033° 09 ‘37.1”	789m	Rep III	
	S11° 13’ 59.3”,E033° 10 ‘38.7”	791m	Rep IV	
Maize	S11° 14’ 01.3”,E033° 10 ‘34.9”	785m	Rep V	2,621
	S11° 07 ‘03”,E033° 07’ 44.9”	770m	Rep I	
	S11° 09 ‘04”,E033° 07’ 45.9”	773m	RepII	
	S11° 08 ‘03”,E033° 06’ 49.9”	782m	Rep III	
	S11° 08 ‘03”,E033° 08’ 45.9”	777m	Rep IV	
Sorghum	S11° 07 ‘03”,E033° 07’ 44.9”	768m	Rep V	0,3915
	S11° 09’ 28.9”,E033° 24’ 14.1”	731m	Rep I	
	S11° 09’ 57.9”,E033° 21’ 23.1”	732m	RepII	
	S11° 09’ 09.6”,E033° 04’ 12.1”	743m	Rep III	
	S11° 09’ 43.9”,E033° 24.3’ 49.1”	745m	Rep IV	
Paddy Rice	S11° 09’ 28.9”,E033° 04’ 54.1”	729m	Rep V	1,3021
	11° 014’12.1”,E033° 010’18.7”	785m	Rep I	
	11° 013’23.1”,E033° 009’56.7”	787m	RepII	
	11° 013’23.1”,E033° 008’18.7”	788m	Rep III	
	11° 014’01.1”,E033° 009’56.9”	775m	Rep IV	
Soyabeans	11° 014’57.3”,E033° 008’48.7”	773m	Rep V	0,383
	S11° 09’ 52.3”,E033° 08’ 35.6”	780m	Rep I	
	S11° 09’ 42.8”,E033° 08’ 45.9”	745m	RepII	
	S11° 09’ 54.3”,E033° 08’ 25.6”	753m	Rep III	
	S11° 09’ 58.3”,E033° 08’ 12.6”	743m	Rep IV	
Sparse Forest	S11° 10’ 02.3”,E033° 08’ 09.6”	751m	Rep V	0,4106
	S11°05’59.5”,E033°06’55.2”	780m	Rep I	
	S11°05’45.2”,E033°06’34.2”	777m	RepII	
	S11°06’00.5”,E033°06’51.2”	734m	Rep III	
	S11°05’32.5”,E033°06’48.4”	725m	Rep IV	
Dense Forest	S11°05’33.5”,E033°06’45.2”	756m	Rep V	0,6064
	S11°14’23.4”,E033°09’21.1”	773m	Rep I	
	S11°14’33.7”,E033°09’43.1”	774m	RepII	
	S11°13’43.6”,E033°09’32.6”	778m	Rep III	
	S11°14’47.8”,E033°09’06.4”	767m	Rep IV	
Pasture Lands	S11°13’59.9”,E033°08’53.1”	749m	Rep V	1,1064
	S11°09’47.9”,E033°24’13.7”	1114m	Rep I	
	S11°09’57.6”,E033° 24’10.9”	1056m	RepII	
	S11°09’12.9”,E033°24’43.8”	1112m	Rep III	
	S11°09’53.9”,E033°24’36.7”	1096m	Rep IV	
Game Management Area	S11°09’57.1”,E033°24’14.7”	1110m	Rep V	0,02181

Appendix 2: Textural classes for different Land Use Types and Catena Positions in the study area.

Land Use Type	% Clay	% Sand	% Silt	Textural Class
Scarce Forest	6.8	79.6	13.6	Loamy Sand
Catena(Shoulder)	4.8	79.6	15.6	Loamy Sand
Cotton	10.8	67.6	21.6	Sandy Loam
Maize	10.8	47.6	41.6	Loam
Soyabeans	8.8	79.6	11.6	Loamy Sand
Paddy Rice	8.8	70.6	20.6	Sandy Loam
Dense Forest	14.8	73.6	11.6	Sandy Loam
Sorghum	8.8	75.6	15.6	Sandy Loam
Catena(Summit)	8.8	71.6	19.6	Sandy Loam
Catena(Depression)	40.8	29.6	29.6	Clay
GMA	6.8	79.6	13.6	Loamy Sand
Pasture Lands	8.8	75.6	15.6	Sandy Loam

Appendix 3: Dry and moist soil color for different land use types in the study area as determined from the mussel color chart.

LAND USE TYPE	Soil Colour	
	Dry	Moist
Cotton	Dusky red (7.5Y 4/4	Dark Reddish Brown (7.5 Y 2/1)
Maize	Dark Brown (10YR 3/4)	Brownish Black (10YR 2/3)
Sorghum	Brown (5YR 3/2)	Dark Brown (10YR 2/2)
Paddy Rice	Brownish Black (5YR 3/2)	Brownish Black (10YR 2/2)
Soyabeans	Yellowish Brown (10YR 5/6)	Dark Reddish Brown (2.5 Y 3/6)
Sparse Forest	Yellowish Brown (10YR 5/8)	Brown (10YR 4/6)
Dense Forest	Dark Brown (10YR 3/4)	Brownish Black (10YR 2/3)
Pasture Lands	Dark Brown (10YR 3/4)	Brownish Black (5YR 3/1)
Game Management Area	Dark Brown (10YR 3/4)	Brown (10YR 4/6)

Appendix 4: Anova Table for the Land Use Type

Source of Variation	df	ss	ms	v.r	F pr
Replicates stratum	4	0.07759	0.01940	1.71	
Replicates*Units*stratum	8	21.62984	2.70373	238.95	<.001
Crop Residue	32	0.36207	0.01131		
Total	44	22.06950			

Appendix 5: Tables of means for the selected landscapes

Grand mean 0.896

Crop	Cotton	Dense Forest	GMA	Maize	Paddy Rice
	0.902	0.587	0.02	2.621	1.302
Crop	Pasture Lands	Sorghum	Soyabeans	Sparse Forest	
	1.106	0.392	0.383	0.417	

Appendix 6: Duncan's Multiple Range Test for different Land Use Types

Land Use Type	Mean
GMA	0.02^{g}
Soybeans	0.3832^{f}
Sorghum	0.3916^{f}
Sparse Forest	0.4174^{f}
Dense Forest	0.5874^{e}
Cotton	0.9016^{d}
Pasture Lands	1.1064^{c}
Paddy Rice	1.3024^{b}
Maize	2.6210^{a}

Appendix 7: Anova for Soil Catena Positions

Source	df	ss	ms	F value	Pr>F
Model	2	1.66991413	0.83495707	3.76	0.0539
Error	12	2.66406880	0.22200573		
Corrected Total	14	4.33398293			

R-Square	CV%	Root MSE	Carbon Mean
0.385307	23.82157	0.471175	1.977933

Appendix 8: Results of t-Test (LSD) for carbon amongst the Soil Catena Positions

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	0.0222006
Critical Value of t	2.17881
Least Significant Difference	0.6493

Means with the same letter are not significantly different

T Grouping	**Mean**	**N**	**Position**
A	2.3830	5	Depression
B A	1.9850	5	Shoulder
B	1.5658	5	Summit