CARBON STORAGE POTENTIAL OF GRASSLAND ECOSYSTEMS IN THE EASTERN ARC MOUNTAINS: A CASE STUDY OF UDZUNGWA MOUNTAINS, TANZANIA

BY

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ABSTRACT

Grasslands are believed to store carbon in below and above ground. However, little is known on the actual proportion amount of carbon stored in the different carbon pools in the grassland ecosystems. This study aimed at quantifying below and above ground carbon stocks of floodplain and upland grasslands. Quadrants measuring 1 m^2 were established systematically along transects in the floodplain and upland grasslands. Above ground vegetation and litter were sampled in 1 m x 1 m plots and below ground roots and soils were sampled in pits of 0.5 m x 0.5 m x 0.6 m. Soil samples were taken from 0 – 15 cm, 15 – 30 cm, 30 – 45 cm and 45 – 60 cm depth. Carbon in shoots, litter and roots was determined by Loss on Ignition method. Carbon in soils was determined by Walkley Black method. Data were analyzed using descriptive statistics and ANOVA. The above ground carbon in upland grassland was 12.60 ± 0.50 t ha^{-1} and 3.09 ± 0.11 t ha^{-1} for vegetation and litter respectively. Below ground carbon was 7.82 ± 0.57 t ha^{-1} for roots and 40.26 ± 1.17 t ha^{-1} for soils. In the floodplain grasslands above ground carbon was 33.04 ± 1.18 t ha^{-1} for vegetation and 1.89 ± 0.08 t ha^{-1} for litter. On the other hand below ground carbon was 6.22 ± 0.25 t ha^{-1} and 24.63 ± 0.88 t ha^{-1} for roots and soil respectively. In total upland grasslands has potential to store 63.77 ± 2.35 t ha^{-1} of carbon while the floodplain grasslands storage was 65.78 ± 2.39 t C ha^{-1}. With exception of roots all other pools showed a significant difference in carbon storage between floodplain and upland grasslands ($P = 0.000$). Both upland and floodplain grasslands have high potential for carbon storage and emission mitigation.

DECLARATION

I, Laswai Francis Faustine, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work and that it has neither been submitted nor being concurrently submitted for a higher degree award in any other institution.

Laswai Francis Faustine Date

(MSc. Forestry)

The above declaration is confirmed

Prof. P.K.T Munishi Date

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Dr Zahabu E Date

(Co-Supervisor)

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DEDICATION

This work is dedicated to my wife Mrs. Elly Laswai, my daughters Happyness and Glory and my son Godwin for their moral support and courage during the whole period of the study.

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
EAMs	Eastern Arc Mountains
C	Carbon
cc	Cubic Centimetre
cm	Centimetre
CLS	Carbon in Litters
CRS	Carbon in Roots
CSH	Carbon in Shoots
CSO	Carbon in Soil
CV	Coefficient of Variation
FBD	Forest and Beekeeping Division of Tanzania
FAO	Food and Agriculture Organisation of the United Nations
g	grams
GHG	Green House Gases
IPCC	Intergovernmental Panel on Climate Change
LOI	Loss on ignition
m	Meter
m.e	Mill equivalent
Mc	Moisture correction
$MgCha^{-1}$	Mega gram Carbon per hectare
$mm\ yr^{-1}$	Millimetre per year
ml	Millilitre

N	Normality
NSS	National Soil Service
O.C	Organic carbon
^oC	Degrees Centigrade
ODWS	Oven Dry Weight of Soil
ODWT	Oven Dry Weight Total
Pg	Peta gram
s.e	Allowable error
s.d.	Standard deviation
Sq km	Square Kilometre
SOC	Organic Carbon
SFW	Sample Fresh Weight
SODW	Sample Oven-Dry Weight
SUA	Tons of Carbon per hectare
$t\ ha^{-1}\ yr^{-1}$	Tons per hectare per year
TC	Total Carbon
TFW	Total Fresh Weight
$t\ ha^{-1}$	Tonnes per hectare
TPRI	Tropical Pesticides Research Institute
Vol	Volume
WODS	Weight of Oven Dried samples
VtA	Valuing the Arc
WSI	Weight of Sample after Ignition

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Grassland is defined as a “land covered with herbaceous plants and less than 10% tree and shrub cover” and wooded grassland as 10 – 40% tree and shrub cover (White, 1983). These grasslands occur on different soils: heavy clay, loam, sand, gravel and peat. They also occur in freshwater or brackish water systems where they support specific biodiversity like rare and threatened plant and animal species and communities (Ramsar Convention Bureau, 2003).

Grasslands in the world are estimated to cover 52.5 million square kilometres (sq km) or 40.5% of the terrestrial area; where 8.3% of the global land area excluding Greenland and Antarctica is occupied by the non woody grasslands (Reynolds, 2005).

Grasslands have a potential to store/sequester carbon due to their vast acreage as perennial vegetations (Frank *et al*., 2004). In Africa most of grasslands are found in semi arid to arid areas, savannah, bush lands and woodlands, and also cover the natural grazing areas of the extensive highland areas (Reynolds, 2005). In Eastern Africa 75 percent of the land is dominated by either pure grasslands or grasslands with varying amounts of woody vegetation within or above the grass layer (Reid *et al.*, 2005). The grasslands of eastern Africa are very diverse, with a range of dominant species dependent on rainfall, soil type and management or grazing system. Eastern Africa is renowned as a centre of genetic diversity of tropical grasses and the centre of greatest diversity of cultivated grass species Boonman (1993) cited by Reid *et al.* (2005).

Tanzania is one of the tropical countries found in eastern Africa with sizeable grassland areas that could be potential for carbon storage. Carbon storage potential refers to uptake and storage of carbon, especially by trees and plants that absorb carbon dioxide and release oxygen (Ducks, 2007). The grassland cover in Tanzania is estimated to be 193 604 sq km which is about 21% of 888 600 sq km total land area and are found in lowland and highland areas including those in the Eastern Arc Mountains (EAMs) (FBD, 1999). Grasslands which are found in Kilombero flood plain and Kilolo highland are dominated by perennial grasses and other few annual herbaceous plants.

Research on carbon storage potential in grasslands ecosystems has been conducted in various parts of the world (Jaramillo *et al*., 2002; Lal, 2003; Lasco *et al*., 2005). Most carbon storage in grasslands, savannas, and deserts is in below ground (Sampson *et al.,* 1993). In Africa however, little research has been done on carbon storage potential in terrestrial grasslands. Study by Millis *et al.* (2009) in semi arid areas of South Africa found storage potential of soils from 0 – 50 cm as 164 t C ha^{-1}; storage by roots as 11.4 t C ha^{-1} and shoots storage was 2 t C ha^{-1}. In Tanzania little is known in carbon storage in grassland ecosystems. Most studies had concentrated mainly in forest ecosystems (Munishi, 2001; Munishi and Shear, 2004; Zahabu, 2006; Shirima, 2009). Furthermore the information about carbon storage in EAMs grasslands is also missing.

1.2 Problem Statement and Justification

Climate change is widely recognised as the most serious environmental threat facing our planet today, and the major challenges are to find ways to reduce greenhouse gas (GHG) emissions and to adapt to future climates (Matthews *et al*., 2007). Due to the current initiatives to reduce emission of greenhouse gases (GHG) and the need to sequester carbon by different ecosystems, understanding issues of carbon in different ecosystems is important.

The EAMs have important vegetation types like grasslands, forests, tree outside forests and agroforestry. The grasslands found in the EAMs areas support the life of different organisms like amphibians, reptiles, mammals, birds and micro-organisms (Mittermeier, 2000). The value of these mountains has been based mainly on timber, biodiversity conservation, hydrological services, scenic beauty and carbon sequestration.

Most of carbon storage studies in the EAMs have been done in natural forests (Munishi, 2001; Munishi *et al.,* 2002; Munishi *et al.,* 2004; Munishi and Shear, 2004; Zahabu, 2006; Shirima, 2009) and in agroforestry systems (Mugasha, 2009) and in some forest plantations (Wesaka, 2009). Therefore less is known on carbon storage potential of grassland ecosystems in EAMs, hence necessitate this study to explore an important gap in carbon estimates in these ecosystem part of Mountains. Generally the main objective of this study was to determine carbon storage potential of grasslands vegetation and soil both in lowlands and highlands in Udzungwa Mountains of Tanzania. Understanding the quantities of carbon stock in grassland ecosystems in EAMs will contribute to the important information required to estimate value of the EAMs in terms of carbon services.

1.3 Objectives of the Study

1.3.1 Main objective

The main objective of this study was to determine carbon storage potential in grassland ecosystems of Udzungwa Mountains of the Eastern Arc Mountains in Tanzania.

1.3.2 Specific objectives

The specific objectives of this study were to:

(i) Quantify above ground carbon stock in the grassland ecosystems of the EAMs

(ii) Quantify below ground carbon stocks in roots and/ rhizomes in the grasslands of the EAMs

(iii) Quantify the soil carbon stock in the grassland ecosystem of the EAMs, and

(iv) Assess the differences in carbon storage between upland and floodplain grassland ecosystems of the EAMs

1.3.3 Research questions

(i) What is the amount of carbon stored in the above ground vegetation of grasslands ecosystems in EAMs

(ii) What is the carbon stock in the belowground parts of the vegetation in the EAMs?

(iii) What is the soil carbon storage potential of the grassland ecosystems in the EAMs?

(iv) How do the upland and flood plain grasslands differ in carbon storage?

1.3.4 Limitations of the study

The study needed different chemicals in the analysis of carbon in the soil and they were too expensive. The wind was too strong sometimes make the reading in electronic balance for fresh weight in the field be difficult or take long time to stabilize.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Carbon Storage in Grasslands Ecosystem

Grasslands in the world are estimated to cover 52.5 million square kilometres (sq km) or 40.5% of the terrestrial area; where as in Eastern Africa 75% of the land is dominated by either pure grasslands or grasslands with varying amounts of woody vegetation within or above the grass layer (Reid *et al.*, 2005; Reynolds, 2005). In Tanzania grasslands coverage is estimated to be 193 604 sq km (20.48%) out of 888 600 sq km of total land area (FBD, 1999). The way land is used is a central question that must be addressed so that there is a balance between the ecosystem services that it provides, including food, fuel, fibre and income, adequate sanitary water, biodiversity and carbon storage (Matthews *et al.*, 2007). Different studies have been conducted to ascertain carbon storage potential of grassland and came up with various results for example Soussana *et al.* (2007) obtained 2.4 t C ha^{-1} yr^{-1} stored in the European Green Grass project. Lasco *et al.* (2005) in their study found that the grasslands ecosystem have stored less than 20 Mg C ha^{-1} or 20 t C ha^{-1} in above ground vegetation. White *et al.* (2000) reported that carbon in grasslands of above and below ground pools ranged between 91 - 131 t C ha^{-1}. Study conducted in Philippines by Delaney (1999) in open grassland areas found the storage potential of 116 t C ha^{-1} in both below and above ground. Estimates done using the soil/plant simulation model showed that carbon in grasslands and savannas is 417 Pg C ha^{-1} (Sampson *et al.*, 1993). In Tanzania most of the studies had concentrated mainly in forest ecosystems for example Munishi (2001) in Uluguru and Usambara Mountains found carbon stored in forest vegetation as 384 ± 10 and 517 ± 17 t C ha^{-1}. Zahabu (2006) investigated carbon stored by different plants in Usambara natural forests. The author found 77 t C ha^{-1} stored by the growing trees.

2.2 Carbon Stored in Herbaceous Shoots

Lales *et al.* (2001) study in wetland rice and ratoon sugarcane in Philippines found that they can store 3.1 and 13.1 t C ha^{-1} respectively. Thevathasan and Gordon (2004) in their study in monoculture pasture found shoot biomass to be 1089 ± 126.0 gram per square meter (g m^{-2}) and carbon content to be 544.7 ± 63.0 g m^{-2} in three months. Lales *et al.* (2001*)* in Philippines found that *Imperata cylindrica* (cogon) and *Saccharum spontaneum* (talahib) which were the dominant species in grassland ecosystem had an ability to store 5.1 and 11.4 t C ha^{-1} respectively in the shoot system. The method used by (Lales *et al.*, 2001*)* to convert biomass to carbon content was 50% as a factor. Delaney (1999) in Philippines found carbon stored by shoots in open grasslands as 50.8 t C ha^{-1}. Mills *et al.* (2009) found grassland shoots to store 2 t C ha^{-1} in semi arid areas of South Africa. Estimates done by Parton *et al*. (1987) using the soil/plant simulation model in grasslands and savannas found that, 560 Pg C is stored in biomass and litter, while 1100 - 1400 Pg C is stored in roots and soils of the terrestrial biosphere. Study by Delaney (1999) on carbon storage potential by herbaceous litter at open grassland in Philippines found litter to store 1 t C ha^{-1}. Lasco *et al*. (2005) reported that grasslands in Philippines have 17.15 t ha^{-1} of biomass in herbaceous shoots of which by using a conversion factor of 50%, carbon stored was 8.57 t ha^{-1}.

2.3 Carbon Storage in Herbaceous Roots

Grasslands possess underground biomass component that serves as a large carbon storage sink for atmospheric carbon dioxide (Frank *et al.*, 2004). Jaramillo *et al.* (2002) quantified the root biomass and root C pools in pastures of different ages, in the Los Tuxtlas Region, Veracruz, in Mexico and observed that the total root biomass to 1 m depth ranged from 3.1 to 5.4 Mg ha^{-1} in pastures of 12, 20 and 28 years-old with corresponding carbon pools of 1.0 to 1.9 Mg ha^{-1}. Thevathasan and Gordon (2004) study in monoculture pasture found root biomass to be 5.03 tones per hectare (t ha^{-1}) and carbon content to be 49.67 % in three months. Mills *et al*. (2009) found roots to store 11.4 t C ha^{-1} in grasslands within semi arid areas of South Africa. Study by Delaney (1999) on carbon storage potential by roots at open grassland in Philippines found root to stored 5.1 t C ha^{-1}. The quantity of carbon stored in roots was reported by Lales *et al*. (2001) in Philippines as 1.0 to 3.5 Mega gram per hectare (Mg ha^{-1}) where by roots of *Saccharum spontaneum* and *Imperata cylindrica* as dominant species in the grasslands stored 1.7 and 3.4 t C ha^{-1} respectively.

2.4 Carbon Storage in Grassland Soils

Globally, grassland soils store an estimated 194 billion tons C, or roughly 8% of the world’s soil carbon (IPCC, 2001). Study by Delaney (1999) on carbon storage potential by soil of open grassland in Philippines reported 64.1 t C ha^{-1}. In eastern Oregon, (Scholefield, 2005; Machado *et al.*, 2006) found that after 73 years, grassland pasture with no tillage and large amounts of grass residue had higher soil organic carbon (SOC) content, with 36.4 tons C acre^{-1}. Estimates for C stored in grassland soil are about 70 t ha^{-1} (FAO, 2004). Lales *et al*. (2001) and Lasco *et al.* (2005) found grassland soil to have carbon stock between 12 to 228 Mg ha^{-1}. Bronson *et al*. (2004) found that total C for grassland soil in the 0 - 2 inch layer as 2.4 ± 0.2 tons acre^{-1}. Fisher *et al.* (1994) in their study in Colombia to compare pasture and savannas in storing carbon in different layers found that in 0 – 20 cm deep savannas store 64.0 t C ha^{-1} and pasture grown with *Andropogon gayanus* store 71.1 t C ha^{-1}. Storage at 20 - 40 cm soil layer in savannas was 42.7 t C ha^{-1} and *A gayanus* pasture storage was 51.9 t C ha^{-1}. Storage at 40 – 100 cm in savannas was 79.8 t C ha^{-1} and pasture found to have 114.2 t C ha^{-1}. Below ground carbon dominates in grassland, and is mainly contained in roots and soil organic matter (FAO, 2010).

CHAPTER THREE

3.0 MATERIAL AND METHODS

3.1 Study Site, Location and Descriptions

The study was carried in two sites. The first site is located in Kilolo District representing the upland grasslands in Iringa Region and the second site located in Kilombero District representing floodplain grasslands in Morogoro Region (Fig. 1 and Fig. 2).

3.1.1 Location of Kilolo site

Upland grassland study site is located in the western part of Udzungwa escarpment between latitude 7°45’S to 7°46’S and longitude 36°24’E to 36°25’E in Kilolo District with an altitude range from 1400 to 1750 m a.s.l.

3.1.2 Vegetation

The vegetation types found around the western Udzungwa highlands are extremely variable characterized by transitional rainforests, sub-montane, montane and upper montane forest types and there are some parts of wet grassland and extensive afromontane grasslands with grasses of *Hyparrhenia rufa* (Nees) Stapf, *Cymbopogon spp* and *Hyparrhenia spp,* ferns (*Pretis pterioides*) and few trees (*Acacia spp, Uapaca kirkiana* and *Parinari curatelifolia*) Lovett (1993), cited by Struhsaker *et al*. (2004).

3.1.3 Climate

The climate is cool and humid almost through out the year with an average annual temperature of 15°C in highlands but 30°C in lowlands. The annual rainfall in this area range from 500 to 2700 mm yr^{-1}.

3.1.4 Soil and Topography

Topography is dominated by undulating hills most of them dominated with red clay soil and loam soil (Struhsaker *et al*., 2004; Burgess *et al*., 2007; Shirima, 2009).

3.1.5 Previous land use

The upland grassland is found within the Udzungwa National Park and no human activities carried out in this National Park. Only wild animals are grazing the grasses during the dry season. No incidence of fire in this grassland has been reported for many years.

3.1.6 Location of Kilombero site

The floodplain grassland is located in eastern part of Udzungwa foothills between latitude 8°10'S to 8°11'S and longitude 36°37'E to 36°41'E in Kilombero District with an altitude range from 240 to 250 m a.s.l.

3.1.7 Vegetation

In eastern Udzungwa the vegetation varies from wet grasslands, miombo and highlands forests. This zone is mainly covered with tall grasses such as *Pennisetum purpureum* (elephant grass), *Panicum maximum* (guinea grass), *Hyparrhenia rufa*, *Phragmites mauritianus* (reed), *Cleistachne sorghoides* (Benth) and *Vetiveria nigritana* but no trees occur due to the long-term flooding (Kato, 2007).

3.1.8 Climate

The climate is hot (26 – 32°C) and humid throughout the year. High humid monsoon winds from the Indian Ocean causes abundant rains on the windward side of the escarpment. The annual precipitation in the Kilombero basin is between 1000 and 2000 mm from November to April (Kato, 2007). A large floodplain has developed on both sides of the Kilombero River.

3.1.9 Topography and Soil

The topography is flat land with loam and sandy soil and some cotton black soil in flooded areas. Also some area topography is undulating hills with red clay soil.

3.1.10 Previous land use

Over the past twenty years people were cultivating rice or paddy in this site but due to high level of floods every year they abandon the area which turned to floodplain grasslands. Livestock and wild animals graze in this area during the dry season. The area is also prone to annual fire during the dry season.

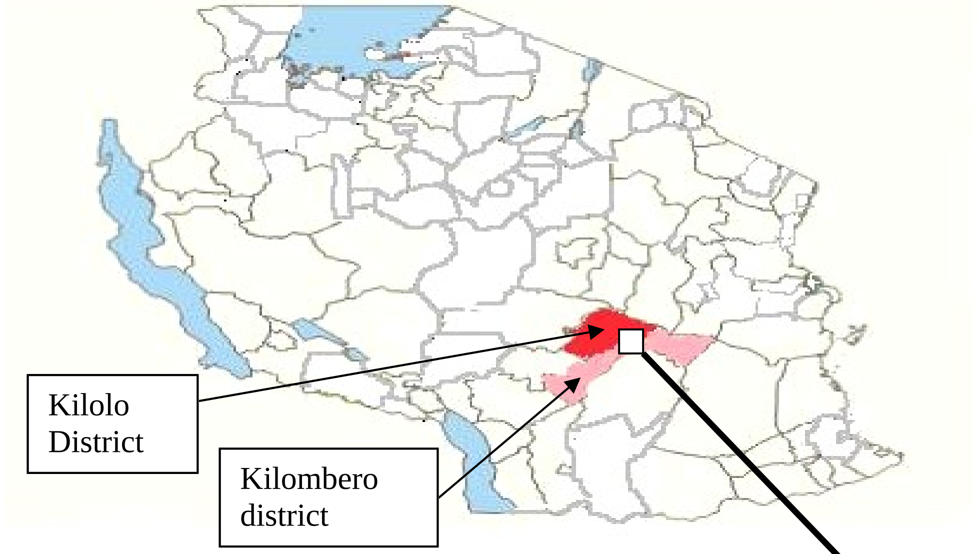

Figure 1: Sketch map of Tanzania locating districts where study was conducted

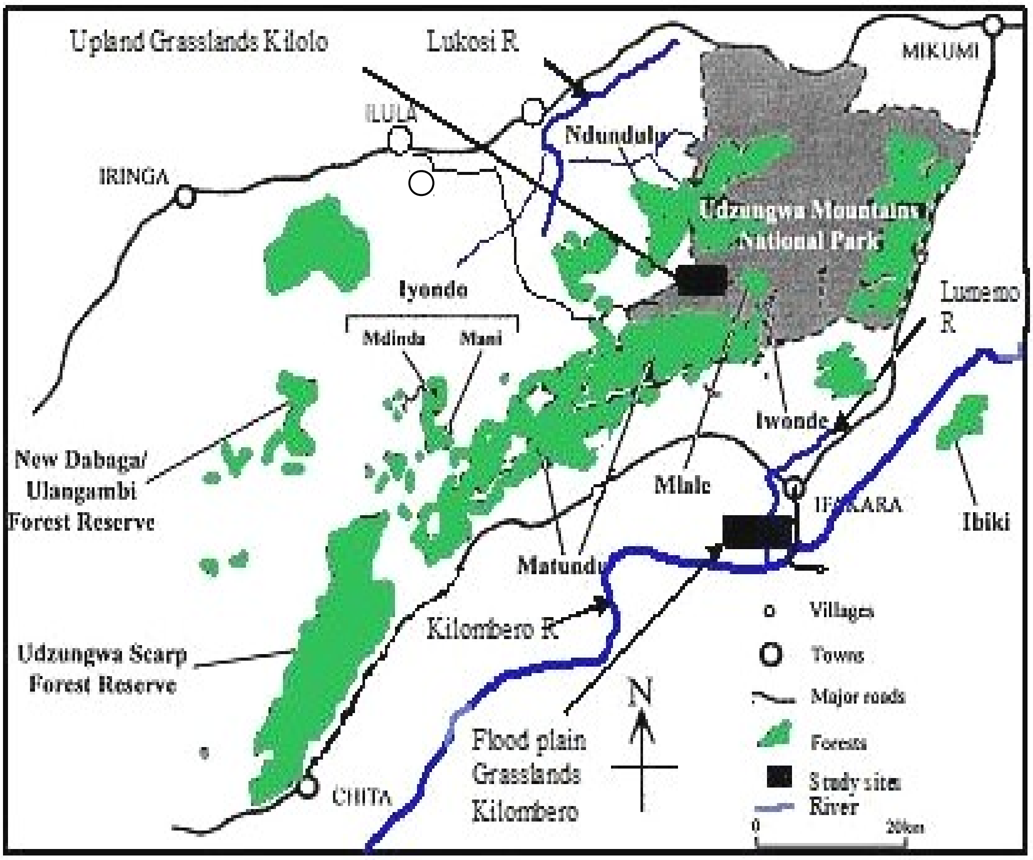

Figure 2: Detailed map of Udzungwa showing study sites

3.2 Data Collection Methods

3.2.1 Reconnaissance survey

The number of samples plots was estimated from reconnaissance survey made in the study area prior to the main study, where by, 15 plots were established randomly in order to obtain the coefficient of variation (CV). The average biomass obtained in pilot study for herbaceous shoots was 35 t ha^{-1} and its standard deviation (s.d) was 15.9 which gave up a CV of 0.45. Using allowable error (s.e) of 0.05 and sample statistic from the t-distribution for the 95 per cent confidence level as 2, then number of sample plots (n) was obtained. Therefore in this study number of sample plot used in data collection was 80 per study site.

3.2.2 Experimental design

Transects were established systematically within the study site and the first transect was chosen purposively. Along each transect plots of 1 m^2 were established at an interval of 100 m. The adjacent plot was established at alternate location on either side of the transect. All transects originated near the river bank and the first plot established at 50 m from the river bank for floodplains and for upland area transects were established 50 m away from a nearby valley (Fig. 3). Number of plots per transect was different depending on the extent of the grassland. The distance between transects was 200 m (Fig. 3). The same procedure has also been used by Lasco *et al*. (1998, 2001, 2005).

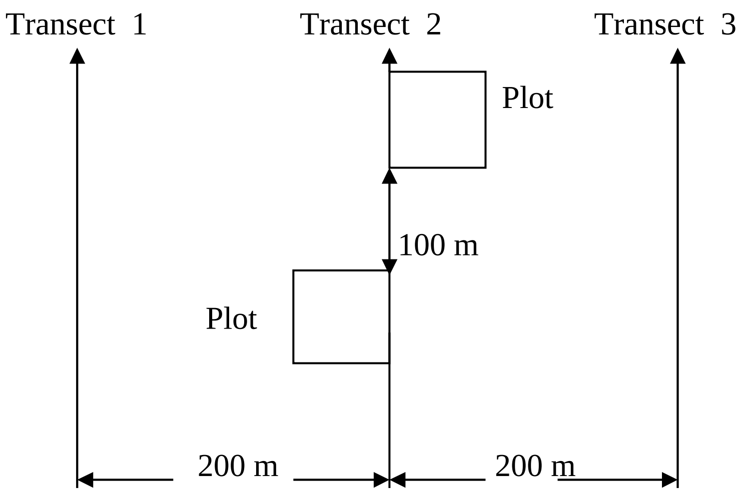

Figure 3: Sampling procedures in the field

3.2.2.1 Sampling of above ground biomass

From each plot of 1 m x 1 m all the herbaceous above ground vegetation were cut at root collar 2 cm above soil surface then weighed and the fresh weight was recorded. Then a sub sample of 100 g was sampled for laboratory analysis. According to Anderson and Ingram (1993), the above ground materials are cut at 2 cm above soil surface to avoid contamination with soil. Litter on the ground floor were collected from randomly laid out subplots of 0.3 m x 0.3 m within 1 m^2 plot and placed into separate bag, weighed to obtain fresh weight and labelled before brought to the laboratory for biomass determination.

3.2.2.2 Sampling underground plant parts

Underground parts of herbaceous vegetation were excavated in the same plot of 1 m x 1 m where the shoots were harvested. The pit was 0.6 m deep made using hand hoes. All roots in the pit were collected through sieving the soil. In areas with mud the sieving was done using water while in dry areas sieves of different sizes were used to separate roots from soil. Grass roots/rhizomes were weighed to obtain total fresh weight then labelled and recorded. Sub sample of about 50 g were taken for laboratory analysis of the biomass.

3.2.2.3 Soil sampling

Soil samples were collected at the middle of plot in 0.5 m x 0.5 m x 0.6 m pit and mixed to get composite for laboratory analysis of percentage organic carbon. The sampling depths were 0 - 15 cm; 15 - 30 cm; 30 - 45 cm and 45 - 60 cm and their weights recorded. Soils for bulk density were also collected in every layer using core sampler of 5 cm diameter, height of 5 cm and with volume of 98.2 cm^3

3.2.3 Laboratory analyses

3.2.3.1 Dry weight determination in shoots

The sub samples from shoots were oven dried at (70°C) to constant weight (Lasco *et al.*, 2005). Oven dry biomass of each plot was obtained by multiplying the biomass ratio to its total fresh weight (Lales *et al*., 2001; Lasco *et al*., 2001, 2005). Formula for calculating oven dry biomass was:

$$ODWT = TFW - (TFW \times (SFW - SODW)) / SFW \ldots\ldots\ldots\ldots\ldots (1)$$

Where:

ODWT = Total Oven Dry Weight (Biomass) (g)

TFW = Total Fresh Weight (g)

SFW = Sample Fresh Weight (g)

SODW = Sample Oven-Dry Weight (g)

The total oven dry weights obtained in grams per area of (1 × 1) m^2 were aggregated into t ha^{-1}.

3.2.3.2 Determination of carbon in plant materials

Procedures used to obtain carbon in shoots, roots and litter in the laboratory use the loss on ignition approach were as follows:

(1) The porcelain crucible with capacity of 30 cc was washed with distilled water and oven dried, then further dried in a furnace at 200°C and cooled in desiccators. The weight of crucible was recorded (W1).

(2) Exactly 1g of ground sample was placed into the clean pre weighed and labelled porcelain crucible. The sample was placed in the oven at 105°C to constant weight. The weight was recorded (W2).

(3) Then sample was placed in the furnace. The temperature was set at 450°C when the temperature reached 450°C; samples were heated in the furnace for five hours to obtain white ashes. The furnace was turned off and sample were let to cool and placed in desiccators. The weight of content was recorded (W3).

All the weights were made using analytical balance. The weight loss on ignition (LOI) was considered to be the carbon content of the sample. The following formula was used to compute carbon content:

Percentage LOI = (((W2-W1)-W3-W1)/W2-W1) x 100……………………….(2)

= (((WODS) - WSI) / WODS) ×100

Where: WODS = ((Weight crucible + dry sample) - Weight of empty crucible) (g)

WIS = ((Weight of crucible + ash) – Weight of empty crucible) (g)

(W2-W1) = Oven dry weight of sample

(W3-W1) = weight of sample after ignition

LOI in percentage gave the approximate organic matter of the biomass (Nelson and Sommers, 1996; Schumacher, 2002). The organic matter content obtained was used as a rough estimate for the total organic carbon content (Schumacher, 2002).

The percentage LOI obtained in every sample was multiplied by sample biomass to obtain carbon per sampled area. In this study the sample area was 1 m x 1 m which was further computed in carbon tones per hectare (C t ha^{-1}).

3.2.3.3 Determination of soil bulky density

Before analysis of carbon content, soils taken in the same layer for bulk density measurement were put in an oven at 103 ± 2°C until its weight became constant. The core sampler had diameter of 5cm, height 5 cm hence the volume of core sampler was 98.2 cm^3 using Pi as 3.142857. Soil bulk density for every layer in a plot was calculated as follows:

Bulk density (g cm^{-3}) = Weight of oven dry soil (g) / Volume (cm^3)……………….. (3)

3.2.3.4 Determination of organic carbon in the soil

Soil samples from the field for carbon analysis were air dried; sieved and 0.5 g of soil was used in titration instead of 1g since the soil seemed to have more organic matters. Soil organic carbon (SOC) was analyzed in the laboratory using Walkley and Black Method described in Nelson and Sommers (1996). The procedures used to determine carbon are provided in Appendix 9. Soil samples of 5 g were put in an Erlenmeyer flask of 300 cc, 10 mls of 1Normality potassium dichromate was added followed by 20 mls of concentrated sulphuric acid. The content was swirled to make sure all soil particles were in the solution. After 30 minutes, 50 mls of distilled water was added followed by 10 mls of concentrated Ortho-phosphoric acid. Exactly 1 ml or 10 drops of diphylimine indicator were added. The content were titrated versus standardized ferrous sulphate solution where by a prepared 0.5 N ammonium ferrous sulphate was titrated against 1N $K_2Cr_2O_7$ for standardization, the actual normality was found which was 0.45 and was used to compute the organic carbon in percent.

Percentage organic carbon = (millequivalent of potassium dichromate – millequivalent of ferrous sulphate) x millequivalent of carbon x factor / oven dry weight of soil x 100

Percentage O.C = (m.e $K_2Cr_2O_7$ – m.e $FeSO_4$) x m.e of carbon x factor) / ODWS x 100

Where:

m.e $K_2Cr_2O_7$ = ml $K_2Cr_2O_7$ x normality

m.e $FeSO_4$ or $(NH_4)_2$ $FeSO_4$ = ml $FeSO_4$ or $(NH_4)_2$ $FeSO_4$ x normality

Factor = 1.32; m.e of carbon = 0.003

ODWS = Oven dry weight of soil

m.e = Millequivalent

O.C = Organic Carbon

3.2.3.7 Determination of total carbon in grassland ecosystem

Average carbon stock per hectare from shoots, litter, roots and soil gave the total amount of carbon stored by the grassland area and was computed as follows:

Total carbon (TC) = $\sum C_{SH} + C_{LS} + C_{RS} + C_{SO}$

Where: C_{SH} is average carbon found in shoots;

C_{LS} is average carbon found in litters;

C_{RS} is average carbon found in roots and rhizomes;

C_{SO} is average soil carbon found in 0 - 60 cm deep

3.3 Data Analysis

Analysis was done by using descriptive statistics where by excel computer software tool was used to generate means per plot, and then extrapolated to per hectare for above ground vegetation (shoots), litter, roots and soil.

a) The analysis of biomass in herbaceous shoots, litter and roots were carried out in the laboratory where by oven dry biomass of each plot was obtained by multiplying the biomass ratio to its fresh weight (Lasco *et al*., 2005) as shown in section 3.2.3.1

Conversion of ODWT in grams per 1 m x 1 m to grams per hectare was done as follows:

Biomass (g ha^{-1}) = (ODWT g x 10 000 m^2) /1 m^2………………………………. (i)

Conversion of biomass in gram per hectare to tonnes per hectare was as follows:

Biomass (t ha^{-1}) = Biomass (g ha^{-1}) / 1000 ……………………………………………. (ii)

The biomass in t ha^{-1} for shoots, litter and roots obtained were converted to carbon using percentage LOI data:

Carbon (g / 1 m x 1 m) = biomass (g / 1 m x 1 m) x percentage LOI………………… (iii)

Carbon in grams per hectare was calculated as follow:

Carbon (g ha^{-1}) = (Carbon g / 1 m x 1 m x (10 000 m^2 / 1 m x 1 m))………………… (iv)

Carbon obtained was converted to tonnes per hectare using the following formula:

Carbon (t ha^{-1}) = Carbon (g ha^{-1}) / 1000.. (v)

b) Calculation for Bulk density:

Bulk density (g cm^{-3}) was obtained using the same formula as shown in section 3.2.3.3

Formula for calculating volume of the core sampler was:

Volume of the core sampler in cm^3 = $((Pi \times D^2 / 4) \times H)$………………………… (vi)

Where: H = Height of core in cm (5 cm)

D = Diameter of core in cm (5 cm)

Pi = Constant (3.142857)

The volume of core sampler was 98.2 cm^3

c) Soil organic carbon in every layer was analysed using the same formula as shown in 3.2.3.4

The depth of every layer was 0.15 m. Therefore carbon stored per hectare in every layer was calculated as follow:

Carbon (kg ha^{-1}) = Percentage O.C × 10 000 m^2 x Bulk density (kg m^{-3}) × 0.15 m…. (vii)

d) Carbon stored by different herbaceous species and its variation was analysed using SAS programme. For all data, plot means were subjected to analysis of variance (ANOVA) using the General Linear Model procedure in statistical analysis system (SAS) at 5% level of statistical significance (SAS Institute, 2000)

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Above Ground Carbon in Herbaceous Vegetation

The total carbon storage in the floodplain grassland was 33.04 ± 1.18 t ha^{-1} and for high altitude grasslands was land 12.60 ± 0.50 t ha^{-1} (Table 1). Flood plain grasslands have significantly higher carbon storage in vegetation, than highland grasslands ($P<0.05$)

Table 1: Average biomass and aboveground carbon storage in herbaceous vegetation in floodplain and upland grasslands ecosystems

Site	Biomass (t ha^{-1})	LOI percent	Carbon(t ha^{-1})^1	Carbon(t ha^{-1})^2
Flood plain grassland	35.97 ± 1.30	92	33.04 ± 1.18	17.98 ± 0.65
Upland grassland	15.01± 0.58	84	12.60 ± 0.50	7.51 ± 0.29

^{1}Carbon by loss on Ignition (LOI)

^{2}Carbon estimated by multiplying biomass (t ha^{-1}) by a factor of 0.5

The difference in carbon storage may be a result of differences in type of grasses in which the grasses in floodplain grasslands are taller (up to 2.0 m) compared to upland grasslands which are shorter with an average height of 0.9 m. Species variation, differences in altitude and climatic conditions could also contribute to the observed difference Boonman (1993), cited by Reid *et al.* (2005). Grassland systems can be productive ecosystems, but restricted length of the growing season, drought periods and grazing-induced shifts in species composition or production can reduce carbon uptake relative to that in other ecosystems (FAO, 2010).

Lasco *et al*. (2005) reported that grasslands in Philippines have 17.15 t ha^{-1} of biomass in herbaceous shoots of which by using a conversion factor of 50%, carbon stored found to be 8.57 t ha^{-1}. The values obtained in flood plain grasslands of 17.98 ± 0.65 t ha^{-1} was not consistent with the values obtained by Lasco *et al*. (2005) in which a factor of 50% was used (Table1). The values obtained for the upland grasslands (7.51 ± 0.29 t C ha^{-1}) was consistence to that obtained by Lasco *et al*. (2005) and Lales *et al*. (2001). They differ because the biomass obtained per sampled area at upland grasslands was lower which contribute to lower average of carbon found in the Udzungwa grasslands.

The values obtained by multiplying biomass with LOI of 84 – 92% factor for flood plains grasslands of 33.04 ± 1.18 t ha^{-1} carbon and upland grasslands 12.60 ± 0.50 t ha^{-1} carbon (Table 1) differed as compared to amount obtained by other researchers who studied carbon storage potential of different grassland ecosystems because they used a conversion factor of 49 – 50% to convert biomass to carbon. The above-ground carbon for the two sites (Table 1 and Fig. 3) are lower than those of Delaney (1999) in Philippines who found carbon stored by shoots in open grasslands to be 50.8 t ha^{-1}. The reasons for the difference in carbon storage may be mainly due to location, climatic condition, soil and extent of grazing (FAO, 2010).

4.2 Above Ground Carbon in Litter

The litter carbon in the flood plain grasslands was 1.89 ± 0.08 t ha^{-1} and in the highland grasslands was 3.09 ± 0.11 t ha^{-1} (Table 2). The quantity of litter carbon in the highland grasslands was significantly higher than in the flood plain grasslands. ($P<0.05$) (Appendix10). This is due to more litter accumulating over long time in highland grasslands where decomposition rate is low as a result of low temperatures accompanied by high moisture in the highlands.

Table 2: Average biomass and carbon storage by litter in floodplain and upland grassland ecosystems

Site	Biomass(t ha^{-1})	LOI percent	Carbon (t ha^{-1})[1]	Carbon(t ha^{-1})[2]
Floodplain grassland	2.16 ± 0.09	87	1.89 ± 0.08	1.08 ± 0.04
Upland grassland	4.23 ± 0.15	73	3.09 ± 0.11	2.11 ± 0.07

[1] Carbon by loss on Ignition (LOI)

[2] Carbon estimated by multiplying biomass (t ha^{-1}) by a factor of 0.50

The amount of carbon stored in litter for the flood plain grasslands was lower due to low production of biomass, annual fire, high rate of decomposition during dry season, removal of grass residues by floods during rain season and grazing of large herds of livestock and wild animals. In the upland grasslands there is limited occurrence of fire compared to low land; hence there was large layer of litter accumulation for several years with low rate of decomposition hence contribute to more biomass per unit area. Disturbances such as fire, drought and excessive forage consumption can lead to substantial losses of carbon from both soil and vegetation (Page *et al*., 2002; Ciais *et al*., 2005; Adam *et al*., 2009 cited by FAO (2010)). Carbon stored in litter in flood plain grasslands was lower compared to that of aboveground vegetation due to differences in biomass density (Fig. 3).

The values of carbon obtained in litter of 1.89 t ha^{-1} and 3.09 t ha^{-1} using percentage LOI as conversion factor (Table 2) are higher compared to the values obtained by Delaney (1999) in Philippine grasslands of 1 t ha^{-1} using 50% as conversion factor. Such differences may be caused by location, altitude and type of vegetation that constitute the litter.

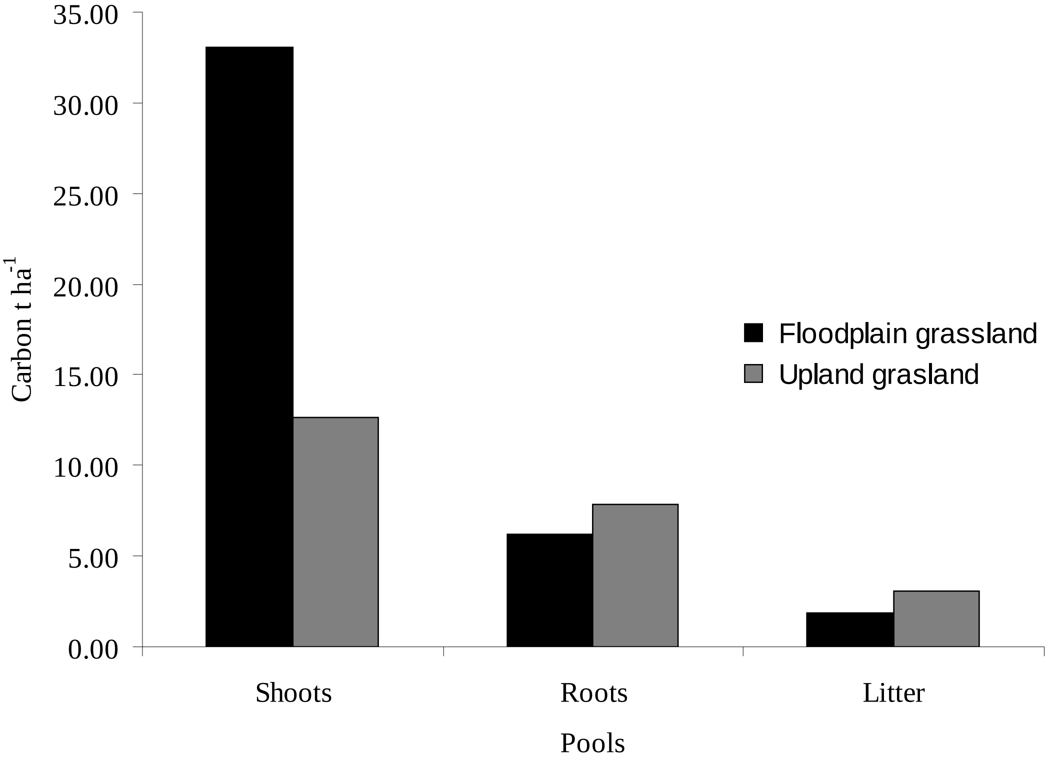

Figure 4: Carbon stored by aboveground vegetation, litter and roots in floodplain and upland grasslands.

The values of carbon obtained in litter 1.08 ± 0.04 t ha^{-1} for flood plain grasslands are consistent with the values obtained of 1 t ha^{-1} in Philippine upland grasslands by Delaney (1999) using 50% as conversion factor (Table 2). The value of carbon 2.11 ± 0.07 t ha^{-1} obtained in upland grasslands in this study are higher compared to that of (Delaney, 1999).

4.3 Below Ground Carbon in Herbaceous Roots in Floodplain and Upland Grasslands Ecosystems

The carbon stock in roots was 6.22 ± 0.25 t ha^{-1} in floodplain grasslands and 7.82 ± 0.57 t ha^{-1} in upland grasslands (Table 3). There was no significant difference (P> 0.05) (Appendix 10) for carbon stored by roots in these two ecosystems. This may be due to the fact that the root system for grass species may likely have similar capacity to accumulate biomass and carbon. Grass roots are believed to store substantial amounts of carbon (Nelson and Sommers, 1996). However, root carbon in the floodplain and upland grasslands was lower compared to that of shoot indicating that shoots accumulate larger amounts of biomass in grasslands compared to roots.

Table 3: Average biomass and carbon content in herbaceous roots

Site	Biomass(t ha^{-1})	LOI percent	Carbon (t ha^{-1})^{1}	Carbon (t ha^{-1})^{2}
Flood plain grassland	8.17 ± 0.37	78	6.22 ± 0.25	4.08 ± 0.18
Upland grassland	11.12 ± 0.81	70	7.82 ± 0.57	5.56 ± 0.41

^{1}Carbon by loss on Ignition (LOI)

^{2}Carbon estimated by multiplying biomass (t ha^{-1}) by a factor of 0.50

The carbon stock of the roots of herbaceous vegetation in flood plains grasslands (6.22 ± 0.25 t ha^{-1}) and highland grasslands (7.82 ± 0.57 t ha^{-1}) (Table 3) obtained by converting biomass using percentage LOI was slightly higher compared to the values obtained from open grasslands of Philippines of 5.1 t ha^{-1} (Delaney, 1999) but lower than that of 11.4 t ha^{-1} in semi arid grasslands and thickets of South Africa (Millis *et al*. 2009). The difference was probably due to the conversion factor of 0.50 used. On the other hand the carbon stocks obtained by converting biomass using 50% as conversion factor for flood plain grassland of 4.08 ± 0.18 t ha^{-1} and 5.56 ± 0.41 t ha^{-1} for upland grassland (Table 3) are consistent with values obtained by Delaney (1999).

4.4 Carbon Storage in Flood Plain and Upland Grasslands Soil

The soil carbon density in flood plain at 0 – 15 cm, 15 – 30 cm, 30 – 45 cm and 45 – 60 cm was 33.63 ± 1.27 t ha^{-1}, 24.98 ± 0.82 t ha^{-1}, 20.77 ± 0.69 t ha^{-1} and 19.13± 0.76 t ha^{-1} respectively. Carbon stored by upland soil was 51.51 ± 1.49 t ha^{-1}, 43.5 ± 1.23 t ha^{-1}, 35.86 ± 0.95 t ha^{-1} and 30.18 ± 1.02 t ha^{-1} for soil layer 0 – 15 cm to 45 – 60 cm. Carbon stored in the soils of two sites decreased with depth with the top soil 0 - 15 cm having more organic carbon per hectare and decreased downward to 45 - 60 cm (Table 4 and Fig. 5). This difference was significant ($P<0.05$) as indicated in Appendix 11 and in Appendix 12.

Table 4: Average soil organic carbon in floodplain and upland grasslands ecosystems

Site	Carbon density t ha^{-1}				
	0 – 15 cm	15 – 30 cm	30 – 45 cm	45 – 60 cm	Mean
Floodplain grassland	33.63 ± 1.27	24.98 ± 0.82	20.77 ± 0.69	19.13± 0.76	24.63 ± 0.88
Upland grassland	51.51 ± 1.49	43.5 ± 1.23	35.86 ± 0.95	30.18 ± 1.02	40.26 ± 1.17

The difference in carbon storage within the layers was due to accumulation of herbaceous residues on top soils as compared to the subsequent layers (Biswas and Mukherjee, 1987). The highest values of carbon in top soil for both site was due to more roots at this layer than in the sub soil. Also depositions of high organic matter once decomposed from litter, dead herbaceous shoots and roots contribute to more carbon on top soils. It has been argued that below ground carbon dominates in grasslands, and is mainly contained in roots and soil organic matter (FAO, 2010; Louis *et al*., 2006). However carbon stored in the 0 – 15 cm soil layer at floodplain grassland (33.63 ± 1.27 t ha^{-1}) and upland grassland (51.51 ± 1.49 t ha^{-1}) were lower compared to that found by Fisher *et al.* (1994) for savannas (64.0 t ha^{-1}) and pasture grown with *Andropogon gayanus* (71.1 t ha^{-1}) at a soil depth of 0 – 20 cm but carbon storage at the subsequent layers 20 - 40 cm and 40 – 60 cm seems to correspond well with the trend of the results obtained from floodplain and upland grasslands (Table 4). There was significant difference in carbon stock in the soils of highland grasslands and flood plain grasslands ($P<0.05$). Upland grasslands had higher mean carbon storage in soils as compared to floodplain grasslands (Table 4). The higher values for upland grasslands could be linked to high accumulation of decomposed litters in top soils and large amount of dead rhizomes in subsequent layers and also could be due to low temperatures, high moisture hence low decomposition rates (personal observation). The difference in soil properties, altitude and annual rainfall could also contribute to the observed difference (Kato, 2007).

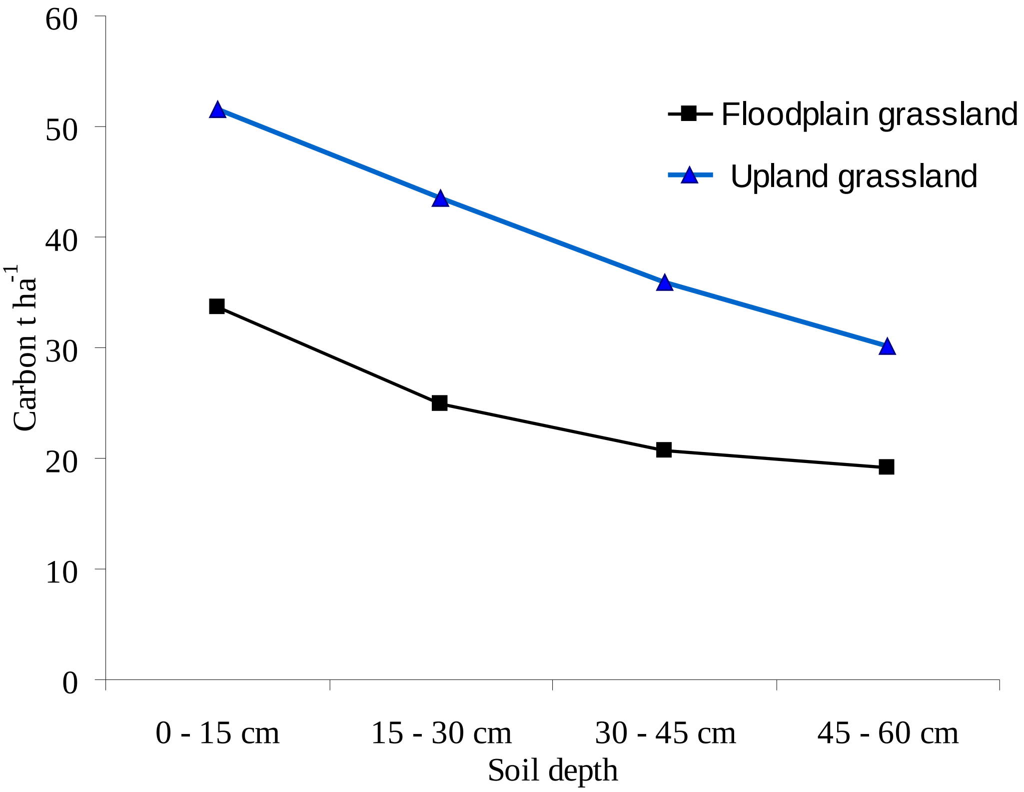

Figure 5: Carbon stored in different soil layers in floodplain and upland grasslands.

Further more the difference in management regime leads to differences in biomass hence difference in carbon storage potential. Biomass in grassland ecosystems, being predominantly herbaceous (i.e. non-woody), is small, transient carbon pool (compared to forest) and hence soils constitute the dominant carbon stock (FAO, 2010).

4.5 Total Carbon Storage in Floodplain and Upland Grasslands Ecosystems

The results obtained in different pools in grassland ecosystem are summarized in Table 5. Grasslands have an ability to store carbon in the above and below ground parts of vegetation as well as in the soil (Lal, 2003).

Table 5: Total organic carbon in floodplain and upland grasslands ecosystem

site	Carbon Stock (t ha^{-1})				
	Shoot	Root	Litter	Soil 0 – 60 cm	Total C
Floodplain	33.04 ± 1.18	6.22. ± 0.25	1.89 ± 0.08	24.63 ± 0.88	65.78 ± 2.39
Upland	12.60 ± 0.50	7.82 ± 0.57	3.09 ± 0.11	40.26 ± 1.17	63.77 ± 2.35

Total carbon storage potential of above and below ground including soils for floodplain grasslands was 65.78 ± 2.39 t ha^{-1} and in upland grasslands was 63.77 ± 2.35 t ha^{-1} (Table 5). These values are within the range of carbon stored by pasture land and grazing land reported by Lal (2003) though there was no specific information on which pools contribute more carbon in grassland ecosystem. The pools that contribute more in carbon storage potential in grasslands in this study were 33.04 ± 1.18 t ha^{-1} in shoots and 24.63 ± 0.88 t ha^{-1} in soils at flood plain and in upland grasslands the shoots have 12.60 ± 0.50 t ha^{-1} while carbon stock in soil was 40.26 ± 1.17 t ha^{-1} (Table 5 and Fig. 6). The carbon storage potential in flood plain grassland was affected by less accumulation of residues due to frequent flooding which transported the litter to the Rufiji River.

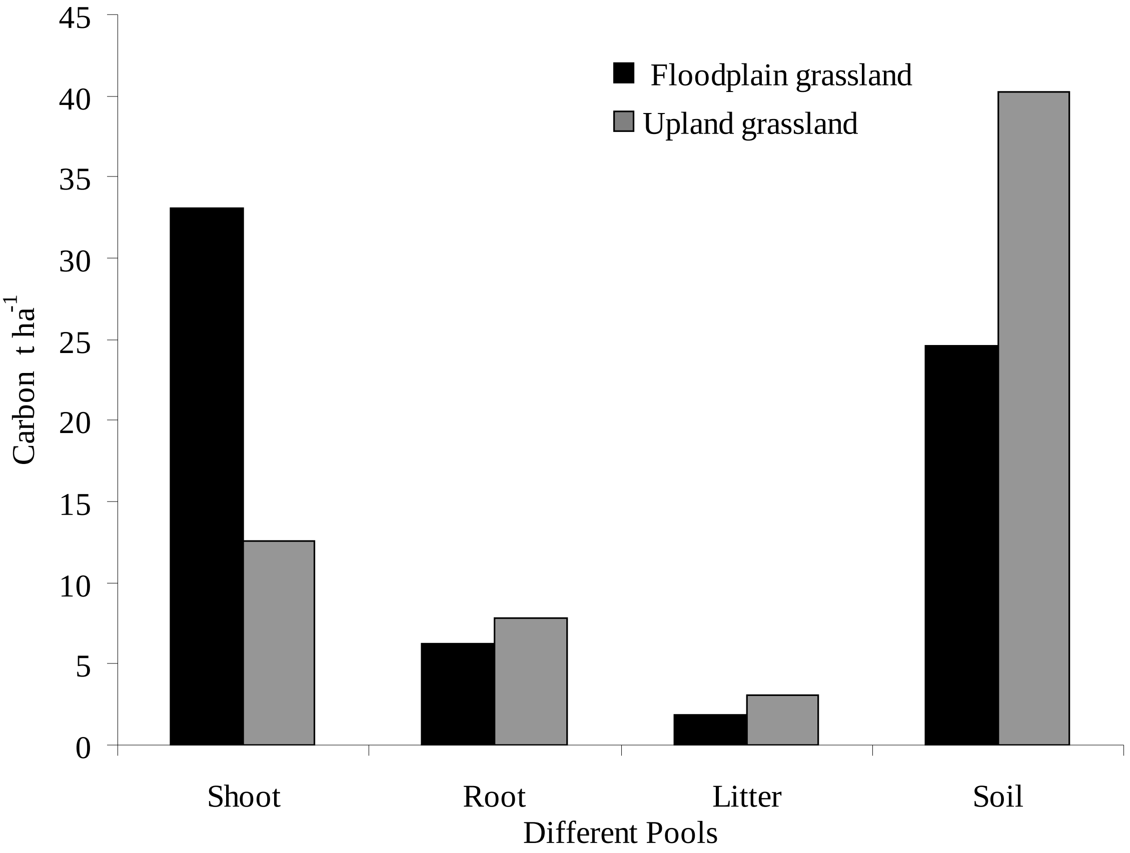

Figure 6: Carbon stored in different pools in floodplain and upland grasslands ecosystems

Total carbon stored in upland grassland 63.77 t ha^{-1} and that of floodplain grassland 65.78 t ha^{-1} (Table 5) were less compared to the amount stored by forest in eastern arc mountains 77 t C ha^{-1} obtained by Zahabu (2006) for the growing trees and also less than 418 t C ha^{-1} for Uluguru and 295 t C ha^{-1} for Usambara obtained by Munishi (2001).

4.6 Carbon Stored by Different Species in Floodplain and Upland grasslands

The herbaceous plants in flood plains and upland grasslands had different carbon storage potential in above and below ground pools (Fig. 7, 8, 9 and 10).

Table 6: Carbon storage by shoots and roots of different species in upland and floodplain grasslands

Site	Species	Carbon (t ha^{-1})*	
		Shoots	Roots
Upland grassland	*Pteris pteriodes (Masiru)*	18.731a	20.281a
	Cymbopogon (Lipelele)	17.873a	4.938b
	Hyparrhenia rufa (Nees) Stapf (Swago)	9.799b	4.050b
	Hyparrhenia spp (Nyaganga)	7.379b	3.106b
Flood plain grassland	*Cleistachne sorghoides* Benth (Swagu)	45.197a	6.069a
	Vetiveria nigritana(Benth) Stapf (Mbambata)	25.740b	5.910a
	Hyparrenia spp (Chekela)	20.761b	5.414a

*Means with the same letter are not significantly different.

4.6.1 Carbon storage in shoots of some species in upland and flood plain grassland

The carbon stored by shoots of dominant species in upland grassland differed from species to species as indicated on Fig. 7 and Table 6. *Pteris pterioides* had the highest carbon stock 18.73 t ha^{-1}, followed by *Cymbopogon spp* 17.87 t ha^{-1}, *Hyperrhenia rufa* (Nees) Stapf 9.80 t ha^{-1} and *Hyperrhenia spp*. 7.38 t ha^{-1}. There was a marked differences between carbon stored by *Pteris pterioides* with *Hyperrhenia rufa* (Nees) Stapf and *Hyperrhenia spp* and the difference was also significant between *Cymbopogon spp* with *Hyperrhenia rufa* (Nees) Stapf and *Hyperrhenia spp* ($P<0.05$) (Fig. 7).

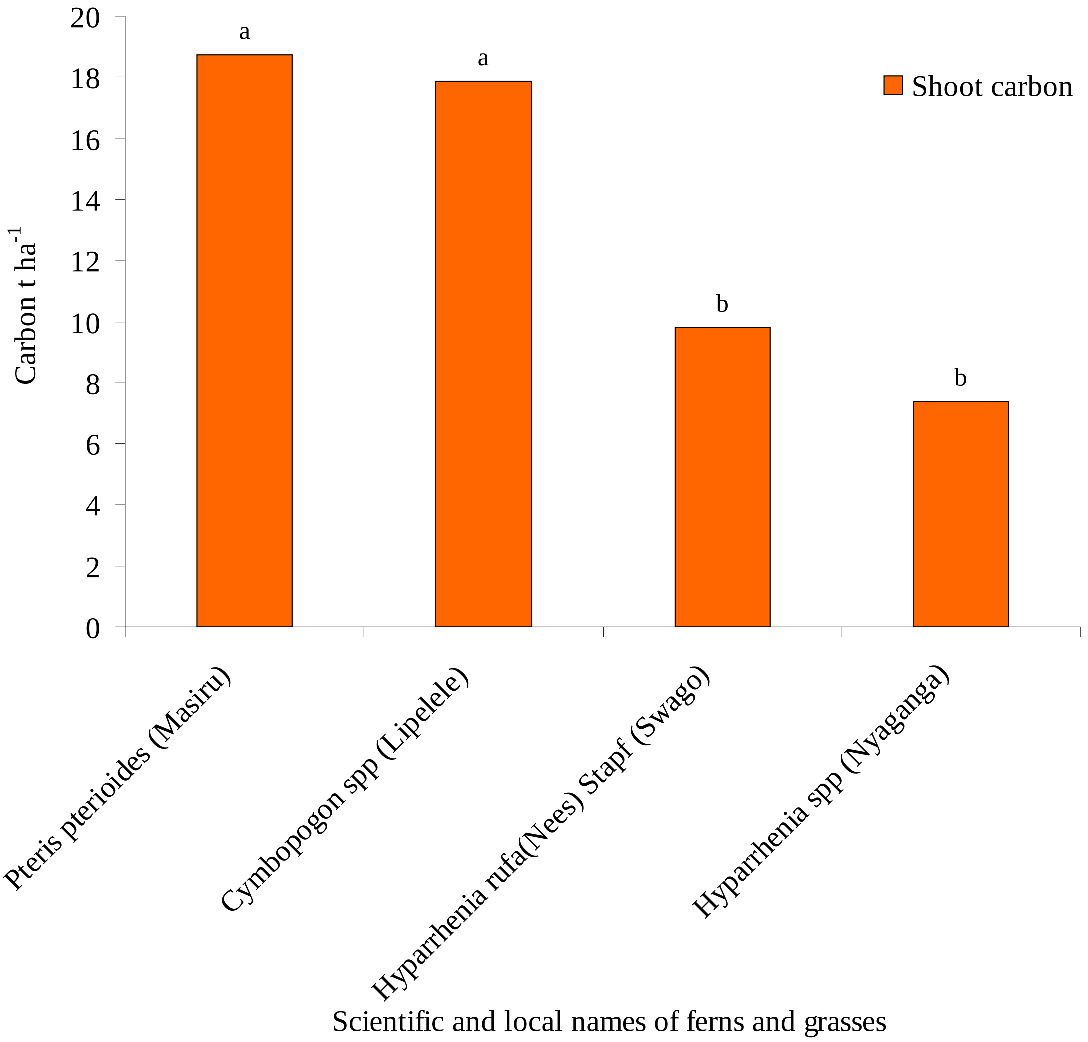

Figure 7: Carbon stored by shoots of different species in upland grasslands

Letters in (Fig. 7) indicate the levels of significant differences in carbon storage between means of shoots for ferns and different grasses in upland grasslands. Means with the same letter are not significantly different. Therefore there is no significant difference in carbon storage between *Pteris pterioides* and *Cymbopogon spp* also between *Hyperrhenia rufa* and *Hyperrhenia spp*.

In the flood plain grasslands *Cleistachne sorghoides* Benth contributed the highest carbon 45.197 t ha^{-1} followed by *Vetiveria nigritana* (Benth) Stapf with 25.740 t ha^{-1} and *Hyparrhenia spp* with 20.761 t ha^{-1} was the least in carbon stocks (Fig. 8).

There was a significant difference between carbon stored by *Cleistachne sorghoides* Benth with that of *Vetiveria nigritana* (Benth) Stapf in shoots, ($P<0.05$). No marked difference between carbons stored by *Vetiveria nigritana* (Benth) Stapf (Mbambata) and *Hyparrhenia spp* (Chekela) (Table 6). The *Cleistachne sorghoides* Benth (Swagu) is larger in size hence more biomass compared to the *Vetiveria nigritana* (Benth) Stapf (Mbambata) and *Hyparrhenia spp* (Chekela).

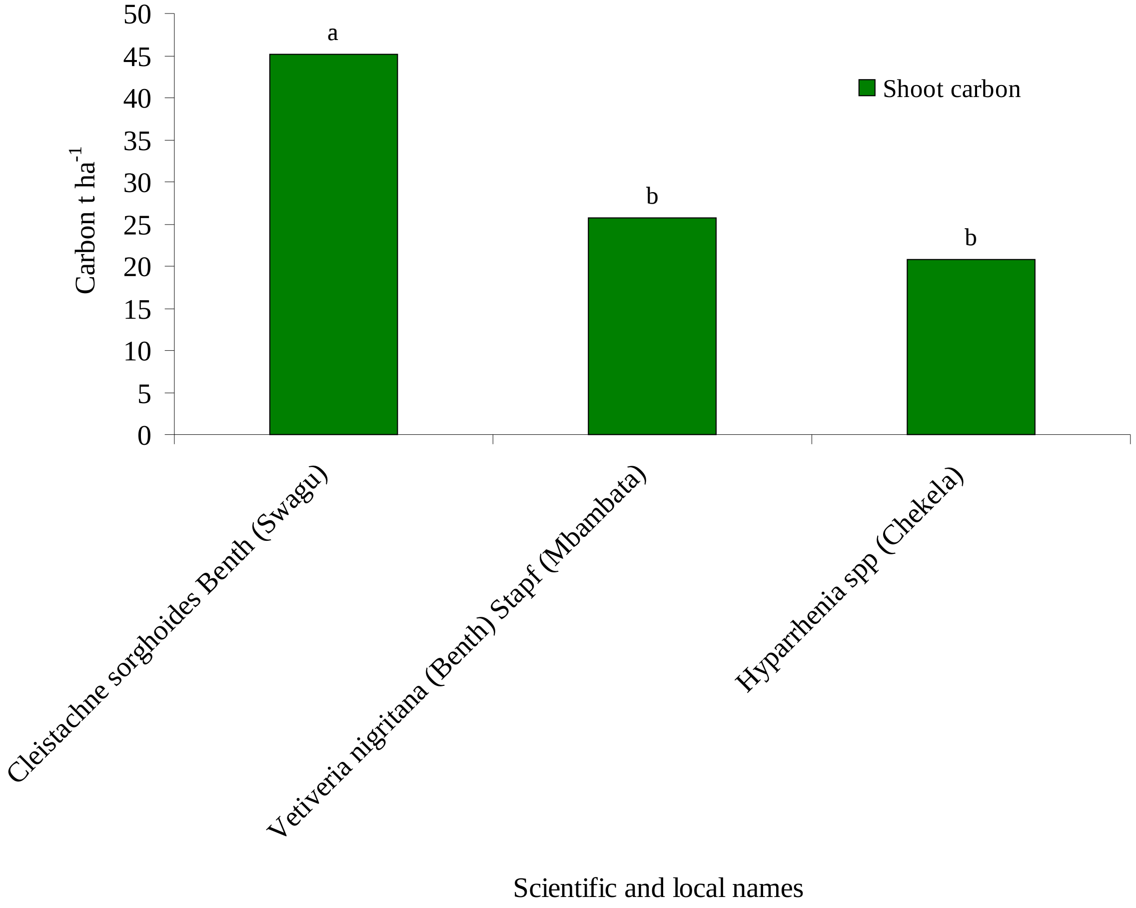

Figure 8: Carbon stored by shoots of different grass species in flood plain grasslands

Letters in (Fig. 8 and Table 6) represent the levels of significant differences of carbon stored by shoots of different grasses in floodplain grasslands. Means of *Vetiveria nigritana* (Benth) Stapf (Mbambata) and *Hyparrhenia spp* (Chekela) have same letter therefore the difference is not significant.

4.6.2 Carbon storage in roots of some plant species in upland and flood plain grasslands

The species identified as dominant species in Kilolo upland grassland differ in carbon storage potential in the roots with high values stored by *Pteris pterioides* (Masiru) 20.281 t ha^{-1} followed by *Cymbopogon spp* (Lipelele) 4.938 t ha^{-1} then *Hyperrhenia rufa* (Nees) Stapf (Swago) 4.050 t ha^{-1} and the least was *Hyperrhenia spp* (Nyaganga/masing'ang'ata) 3.106 t ha^{-1} (Fig. 9). Root of ferns (*Pteris pterioides*) was found to store more carbon relative to other species studied and the difference was significant (Table 6)

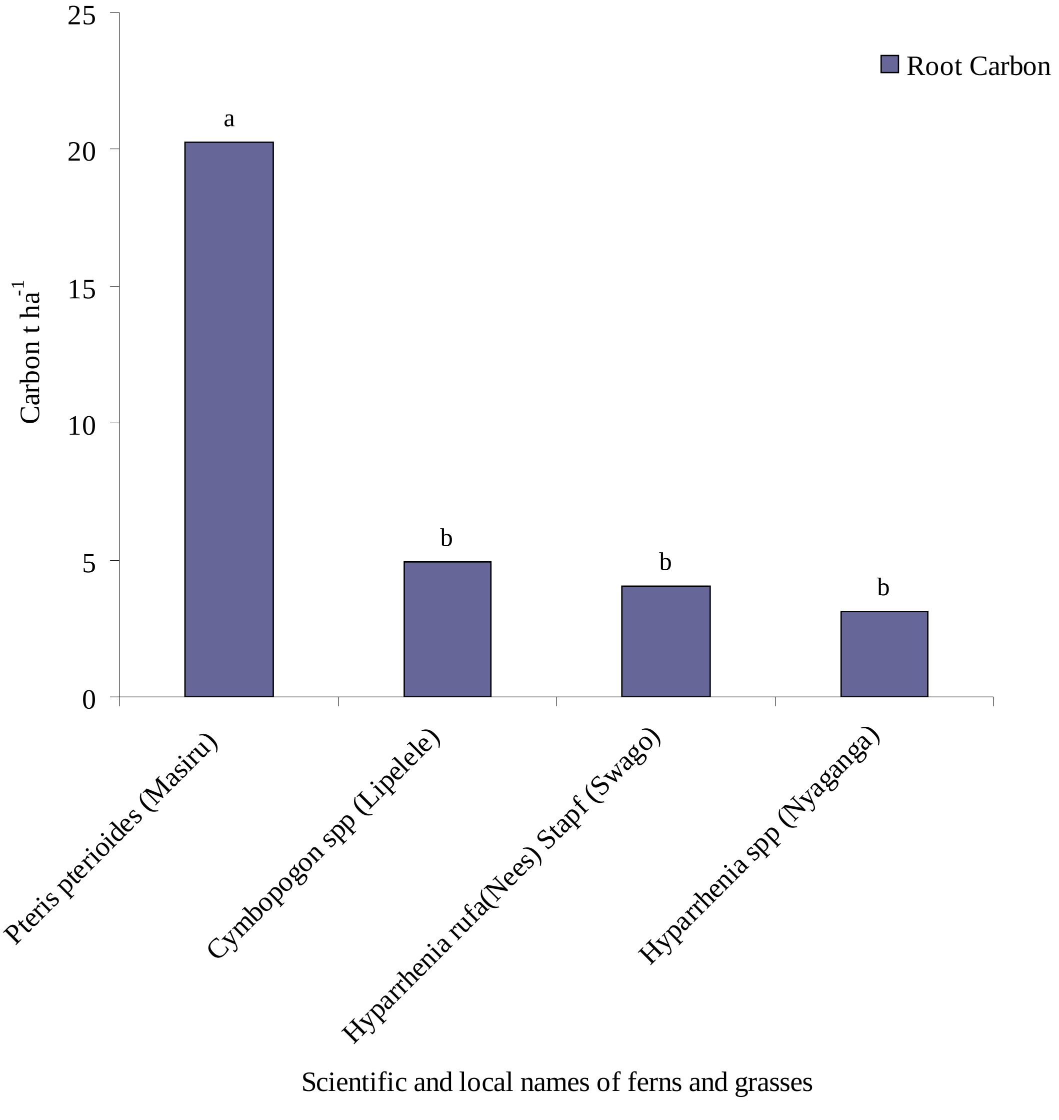

Figure 9: Carbon stored by roots of different grass species in upland grasslands

Letters in (Fig. 9) indicates the levels of significant differences between carbon stored by roots of ferns and different grasses in upland grasslands. Means with the same letter indicates that there is no significant different between the means.

The grasses in (Fig. 10) was found to store carbon in the roots differently with high values in *Cleistachne sorghoides* Benth 6.06 t ha^{-1}, followed by *Vetiveria nigritana* (Benth) Stapf 5.91 t ha^{-1} compared to *Hyparrhenia spp* with the least values of carbon 5.41 t ha^{-1}. Generally there is no significant difference between carbon stored by roots of *Cleistachne sorghoides* Benth (Swagu), *Vetiveria nigritana* (Benth) Stapf (Mbambata) *and Hyperrhenia spp* (Chekela) (Table 6).

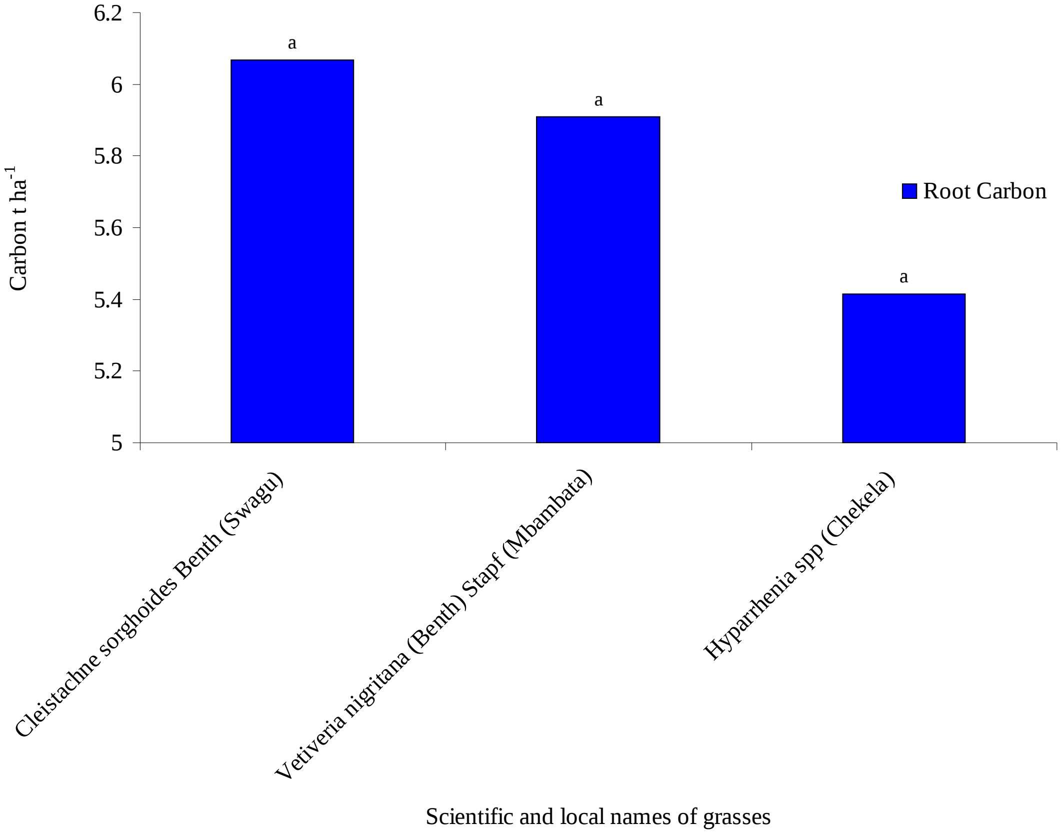

Figure 10: Carbon stored by roots of different species in floodplain grassland

The same letter in (Fig. 10) means that the different in carbon storage by roots of three grasses is not significant.

The difference in carbon storage was not significant ($P>0.05$) between *Cleistachne sorghoides* Benth 6.069 t ha^{-1}and *Hyparrhenia spp* 5.414 t ha^{-1}; also between *Vetiveria nigritana* (Benth) 5.910 t ha^{-1}and *Hyparrhenia spp* 5.414 t ha^{-1} (Fig. 10). The roots of *Cleistachne sorghoides* Benth (Swagu) and *Vetiveria nigritana* (Benth) Stapf (Mbambata) were thick and long in size which penetrates deeper in the soil than roots of *Hyparrhenia spp* hence contributed to the very minor difference observed (Table 6).

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study on carbon storage potential of grassland ecosystem was conducted at two sites representing floodplain and upland grasslands. The aim was to determine carbon stored by different pools in the flood plains and highland grasslands.

Both the floodplain and upland grasslands had high potential for carbon storage in aboveground and belowground pools. The total carbon stock in all pools being 65.78 ± 2.39 t ha^{-1} for floodplain grassland and 63.81 ± 2.32 t ha^{-1} for upland grassland.

Generally the above ground vegetation carbon in the upland grasslands was lower than in the floodplain grasslands. The potential for roots to store carbon was not significantly different ($P>0.05$) between the two ecosystems. The amount of carbon stored in litter was significantly higher in the upland grasslands than in the flood plain grassland.

The pool which was the highest in carbon storage in flood plain was the above ground vegetation (shoot) with 33.04 ± 1.18 t ha^{-1} while in upland site the highest carbon was 40.26 ± 1.17 t ha^{-1} stored in the soil. The soil carbon pool was substantial in both ecosystems but higher in the upland grasslands. The top soil (0 -15 cm) stored the highest amount of carbon and decreased with depth in both ecosystems. There was a significant difference between carbon stored in the soil ($P<0.05$) in upland and floodplain grasslands.

5.2 Recommendations

- Although grasslands offer extensive area for carbon storage, more information is needed on how variations in their composition (non-woody vegetation, shrubs, trees, and soil types) affect the quantities of carbon that they can store.

- Grasslands store considerable amount of carbon therefore should be included in the national carbon accounting.

- Grasslands burning should be avoided in order to mitigate emissions from these ecosystems which seem to store substantial amount of carbon.

- Most studies consider only above ground carbon pools, the carbon stored in the soils is significantly higher and future studies should include this important carbon pool.

- The loss on ignition method for determining carbon in herbaceous especially grasses should be used rather than using a factor of 0.5 recommended for other vegetation like trees which will under estimate carbon stored by grasses.

- In order to understand more widely on carbon storage potential in grassland ecosystems further research should be done to ascertain carbon storage potential of pure grasslands, savannas and grassland associated with shrubs in different parts of Tanzania.

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APPENDICES

Appendix 1: Carbon in 0 – 15 cm, 15 – 30 cm, 30 – 45 cm, and 45 – 60 cm soil layers for floodplain grasslands

Site	Tran	Alt m a s l	Plot	Depth	C (t ha^{-1})	Depth	C (t ha^{-1})	Depth	C (t ha^{-1})	Depth	C (t ha^{-1}))
1	3B	256	1	1	48.10	2	28.48	3	22.08	4	28.90
1	2	246	2	1	16.98	2	12.12	3	17.02	4	9.83
1	1	243	2	1	43.61	2	27.93	3	15.94	4	20.94
1	2	247	10	1	14.73	2	17.57	3	17.21	4	23.55
1	2B	245	4	1	16.66	2	21.54	3	10.97	4	15.73
1	2C	250	6	1	55.67	2	32.03	3	28.22	4	24.36
1	2	249	1	1	15.94	2	22.30	3	12.93	4	16.86
1	5	238	1	1	29.12	2	20.45	3	11.48	4	25.49
1	2	244	2	1	42.90	2	24.09	3	20.73	4	30.48
1	1	243	4	1	40.23	2	21.94	3	25.87	4	26.80
1	2C	247	4	1	21.61	2	18.51	3	17.03	4	10.02
1	2C	246	5	1	36.96	2	30.56	3	19.42	4	22.02
1	2C	245	3	1	36.58	2	14.59	3	10.49	4	26.89
1	2B	246	9	1	29.99	2	36.41	3	30.12	4	29.95
1	1	240	2	1	16.70	2	13.90	3	11.34	4	11.91
1	1	240	3	1	22.73	2	28.99	3	21.54	4	12.64
1	2	243	2	1	26.00	2	21.62	3	16.16	4	19.29
1	2C	248	9	1	54.14	2	33.45	3	33.88	4	35.81
1	3	244	5	1	19.06	2	21.69	3	21.04	4	18.93
1	2	239	1	1	44.77	2	24.99	3	13.83	4	15.28
1	2	247	5	1	55.78	2	32.20	3	30.11	4	34.91
1	2B	249	10	1	45.80	2	25.25	3	40.79	4	26.05
1	2	247	9.	1	15.32	2	21.51	3	18.68	4	14.62
1	3	242	3	1	20.48	2	25.67	3	18.72	4	15.91
1	1	244	5	1	50.57	2	45.69	3	29.79	4	18.68
1	3	260	3	1	44.85	2	31.78	3	21.68	4	9.85
1	3	255	4	1	59.87	2	37.95	3	30.97	4	34.46
1	2B	245	7	1	26.71	2	8.90	3	32.26	4	32.97
1	2B	243	1	1	28.80	2	12.02	3	28.18	4	15.70
1	2	244	**1**	1	14.59	2	7.20	3	29.83	4	23.95
1	3B	244	6	1	39.49	2	18.54	3	15.37	4	22.85
1	2	246	8	1	12.25	2	17.42	3	24.84	4	14.58
1	2C	246	7	1	21.95	2	27.33	3	20.20	4	20.36

1	3B	254	3	1	28.94	2	22.23	3	17.66	4	14.94
1	2	241	4	1	32.04	2	17.83	3	17.70	4	8.15
1	4	238	1	1	39.06	2	19.65	3	19.18	4	15.53
1	6	245	3	1	36.50	2	31.69	3	24.28	4	16.66
1	4	246	5	1	36.35	2	41.86	3	24.46	4	22.01
1	1	238	last	1	33.32	2	29.65	3	19.14	4	14.61
1	0	238	last	1	34.04	2	29.41	3	15.89	4	12.01
1	1	249	2	1	31.13	2	22.75	3	18.22	4	15.41
1	0	241	2	1	42.28	2	23.93	3	9.46	4	6.85
1	6	241	1	1	50.50	2	38.27	3	23.66	4	23.95
1	2	245	7	1	21.20	2	23.49	3	15.75	4	7.40
1	3B	256	1	1	45.60	2	30.85	3	13.36	4	8.51
1	4	247	3	1	45.22	2	33.84	3	21.65	4	14.80
1	0	239	1	1	24.20	2	18.98	3	11.51	4	12.28
1	2	255	3	1	44.87	2	29.85	3	26.27	4	14.39
Sum					1614.3		1198.9		996.97		918.16
Average					33.63		24.98		20.77		19.13
STDEV					13.02		8.32		7.04		7.73
Confidence					1.27		0.82		0.69		0.76

Site 1 means Kilombero, Depth 1 means 0 - 15 cm, Depth 2 means 15 - 30 cm Depth 3 means 30 – 45 cm and Depth 4 means 45 – 60 cm

Appendix 2: Carbon in 0 - 15 cm, 15 - 30 cm, 30 – 45 cm, and 45 – 60 cm layers for upland grasslands soil.

Site	Trans	Alt m.a.s.l	Plot	Depth	C (t ha^{-1})	Depth	C (t ha^{-1})	Depth	C (t ha^{-1})	Depth	C (t ha^{-1})
2	12	1491	2	1	46.62	2	44.92	3	37.24	4	27.44
2	7	1507	3	1	49.55	2	46.14	3	38.56	4	31.38
2	13	1497	3	1	48.96	2	46.29	3	45.65	4	36.90
2	5	1501	2	1	40.39	2	13.68	3	19.46	4	23.65
2	1	1458	2	1	33.40	2	22.09	3	23.63	4	24.74
2	9	1499	1	1	44.51	2	50.50	3	38.43	4	31.40
2	8	1497	4	1	37.88	2	24.01	3	33.16	4	34.36
2	11	1485	2	1	60.68	2	56.11	3	50.02	4	46.52
2	10	1458	1	1	69.71	2	50.63	3	46.88	4	35.72
2	2	1471	1	1	46.52	2	32.19	3	31.16	4	26.79
2	6	1502	1	1	55.02	2	38.55	3	34.39	4	24.07
2	20	1708	1	1	57.67	2	61.07	3	38.62	4	32.51
2	11	1477	5	1	36.94	2	41.71	3	42.17	4	41.26
2	8B	1498	1	1	90.24	2	56.37	3	44.90	4	37.69
2	4	1484	2	1	73.27	2	50.82	3	33.69	4	29.35
2	22	1684	3	1	51.11	2	28.58	3	19.76	4	22.61
2	21	1680	1	1	47.11	2	40.18	3	39.77	4	30.05
2	20	1699	6	1	28.71	2	27.81	3	27.69	4	48.80
2	3	1472	2	1	49.37	2	50.81	3	47.96	4	46.30
2	9B	1494	4	1	58.28	2	47.78	3	40.14	4	39.95
2	21	1693	6	1	70.34	2	51.38	3	48.71	4	48.53
2	24	1560	6	1	66.72	2	43.48	3	51.58	4	42.09
2	23	1544	6	1	53.41	2	55.05	3	41.25	4	48.18
2	8	1500	0	1	58.46	2	41.87	3	48.12	4	44.45
2	24	1555	2	1	38.27	2	32.27	3	38.99	4	49.02
2	23	1545	1	1	26.95	2	39.77	3	39.61	4	24.87
2	9	1488	5	1	45.37	2	18.86	3	42.26	4	32.99
2	20	1681	7	1	49.66	2	45.62	3	22.56	4	10.74
2	12	1490	1	1	30.19	2	46.66	3	38.18	4	25.32
2	13	1496	1	1	58.99	2	36.10	3	37.30	4	34.69
2	5	1498	4	1	49.47	2	87.94	3	30.56	4	24.59
2	9	1497	0	1	65.17	2	45.03	3	36.34	4	32.27
2	12	1490	1	1	48.47	2	33.04	3	47.28	4	30.83
2	1	1463	1	1	27.24	2	57.63	3	15.61	4	8.02
2	7	1514	1	1	69.60	2	61.02	3	45.89	4	15.45
2	13	1496	1	1	86.44	2	32.87	3	52.22	4	37.21
2	5	1500	1	1	36.18	2	38.11	3	25.10	4	18.02

2	4	1496	1	1	48.75	2	47.95	3	24.47	4	20.28
2	10	1464	2	1	54.59	2	33.85	3	46.77	4	34.12
2	9B	1470	1	1	52.11	2	51.59	3	18.01	4	17.10
2	11	1474	1	1	66.93	2	38.23	3	30.27	4	26.42
2	22	1706	1	1	56.22	2	42.50	3	22.12	4	15.70
2	3	1485	1	1	49.40	2	39.04	3	36.47	4	29.50
2	6	1512	2	1	43.90	2	40.76	3	31.09	4	20.78
2	8B	1465	3	1	63.43	2	55.88	3	24.91	4	22.83
2	23	1569	3	1	56.25	2	45.34	3	32.60	4	27.49
2	8B	1469	5	1	48.51	2	48.08	3	33.20	4	26.47
2	9B	1468	2	1	56.58	2	47.62	3	35.83	4	26.44
2	22	1609	6	1	50.57	2		3	26.59	4	12.85
Sum					2554.2		2087.8		1757.2		1478.8
Average					52.12		43.49		35.86		30.18
STDEV					13.85		12.56		9.73		10.49
CONF					1.35		1.23		0.95		1.02

Site UD 2 means Udekwa village Kilolo; STDEV means Standard deviation; CONF means Confidence interval.

Appendix 3: Biomass and carbon in shoots for floodplain grasslands.

Site	Sample type Shoot	Trans	Plot	LOI %	Biomass (t ha^{-1})	C (t ha^{-1})	Local name (Pogoro)	Scientific name
KLE 1	1	1	1	92.6	64.298	59.509	Magugu	
1	1	1	3	93.5	53.449	49.963	Magugu	
1	1	2	1	93.5	22.002	20.568	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	2	3	82.2	57.631	47.386	Magugu	
KLW1	1	0	2	96.7	43.898	42.451	Swagu	*Cleistachne sorghoides* Benth
1	1	0	3	96.7	24.009	23.217	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	0	4	95.7	32.840	31.412	Swagu	*Cleistachne sorghoides* Benth
1	1	0	5	91.3	31.834	29.065	magugu	
1	1	1	3	91.3	26.402	24.106	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	1	4	91.2	17.333	15.810	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	2	3	80.4	51.458	41.390	Swagu	*Cleistachne sorghoides* Benth
1	1	2	5	81.7	27.442	22.426	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	2	7	91.2	25.292	23.068	Swagu	*Cleistachne sorghoides* Benth
1	1	3	1	95.6	75.518	72.199	magugu	
1	1	3	4	93.5	39.726	37.163	Swagu	*Cleistachne sorghoides* Benth
1	1	3	5	95.7	22.659	21.685	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	4	2	93.5	22.990	21.490	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	4	3	88.0	52.174	45.936	Swagu	*Cleistachne sorghoides* Benth
1	1	4	4	98.9	62.356	61.685	Swagu	*Cleistachne sorghoides* Benth
1	1	4	5	92.2	34.904	32.189	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	5	1	94.6	33.704	31.872	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	5	2	87.1	26.783	23.327	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	5	3	91.3	28.604	26.117	chekela	*Hyparrhenia spp*
1	1	5	4	93.5	19.221	17.968	mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	6	1	93.5	34.267	32.057	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	6	2	90.6	29.911	27.107	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	6	3	95.7	39.744	38.034	Mbambata	*Vetiveria nigritana* (Benth) Stapf

KILMAHU 1	1	1	1	95.7	47.711	45.637	Swagu	*Cleistachne sorghoides* Benth
1	1	1	2	87.0	45.278	39.372	Swagu	*Cleistachne sorghoides* Benth
1	1	1	3	72.0	62.289	44.818	Swagu	*Cleistachne sorghoides* Benth
1	1	1	5	94.5	61.150	57.790	Swagu	*Cleistachne sorghoides* Benth
1	1	1	6	94.5	16.301	15.405	chekela	*Hyparrhenia spp*
1	1	1	7	94.6	21.726	20.546	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	1	8	95.4	71.240	67.965	Swagu	*Cleistachne sorghoides* Benth
1	1	1	9	95.7	24.705	23.631	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	1	10	91.5	20.300	18.572	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	2	2	93.5	34.874	32.599	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	2	4	76.8	48.239	37.041	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	2	5	94.6	26.325	24.910	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	2	6	93.5	54.566	51.007	Swagu	*Cleistachne sorghoides* Benth
1	1	2	7	92.4	18.076	16.701	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	2	8	91.4	33.631	30.738	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	2	9	94.6	7.742	7.326	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	2	10	91.3	54.615	49.866	Swagu	*Cleistachne sorghoides* Benth
1	1	3	1	94.5	61.102	57.745	Swagu	*Cleistachne sorghoides* Benth
1	1	3	2	94.7	23.510	22.259	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	3	3	93.5	30.444	28.480	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	3	4	95.6	38.105	36.430	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	3	5	94.6	20.872	19.738	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	2B	1	91.1	34.882	31.782	Swagu	*Cleistachne sorghoides* Benth
1	1	2B	2	94.4	56.677	53.528	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	2B	3	93.5	33.710	31.535	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	2B	4	96.7	18.867	18.239	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	2B	6	94.6	30.411	28.758	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	2B	8	95.7	19.954	19.087	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	2B	10	83.7	40.269	33.704	Swagu	*Cleistachne sorghoides* Benth
1	1	2C	2	93.5	38.093	35.609	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	2C	4	90.3	49.970	45.134	Swagu	*Cleistachne sorghoides* Benth
1	1	2C	5	94.6	30.349	28.700	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	2C	7	95.6	29.767	28.444	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	2C	8	89.4	36.384	32.513	Mbambata	*Vetiveria nigritana* (Benth) Stapf

1	1	2C	10	94.4	47.123	44.505	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	3B	1	94.5	53.769	50.815	Swagu	*Cleistachne sorghoides* Benth
1	1	3B	3	94.6	21.544	20.374	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	3B	4	98.9	17.472	17.285	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	3B	5	94.6	16.908	15.999	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	1	3B	6	91.2	10.879	9.922	Mbambata	*Vetiveria nigritana* (Benth) Stapf
	Sum			6185	2410.28	2213.7		
	Mean			92	35.97	33.04	STDEV 14.389 ; CONFIDENCE 1.185	

Site 1 means Kilombero, Sample type 1 means shoots, KLE means eastern side of main road to ferry area, KLW means western side of main road to ferry area, KILMAHU means Kilombero Mahutanga village and STDEV means standard deviation.

Appendix 4: Biomass and carbon in roots for floodplain grasslands

Site	Sample type	Transect	Plot	Biomas (t ha^{-1})	LOI%	C (t ha^{-1})	Local name (Pogoro)	Scientific name
KLE1	Root 2	1	1	25.532	66.7	17.021	Magugu	
1	2	1	2	13.291	77.8	10.338	Chekela	*Hyparrhenia spp*
1	2	1	3	21.049	71.0	14.938	Magugu	
1	2	2	1	11.550	66.3	7.658	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	2	2	2	9.716	81.3	7.901	Swagu	*Cleistachne sorghoides* Benth
KLW1	2	0	2	10.425	74.2	7.735	Swagu	*Cleistachne sorghoides* Benth
1	2	0	3	7.324	69.6	5.095	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	2	0	5	12.668	82.6	10.465	Magugu	
1	2	1	2	7.377	81.1	5.979	Swagu	*Cleistachne sorghoides* Benth
1	2	1	3	8.396	69.9	5.868	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	2	1	4	9.862	82.8	8.165	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	2	1	5	6.574	79.6	5.231	Swagu	*Cleistachne sorghoides* Benth
1	2	2	1	5.803	80.4	4.668	Swagu	*Cleistachne sorghoides* Benth
1	2	2	2	12.370	72.3	8.948	Swagu	*Cleistachne sorghoides* Benth
1	2	2	3	9.452	62.1	5.870	Swagu	*Cleistachne sorghoides* Benth
1	2	2	6	3.419	43.4	1.485	chekela	*Hyparrhenia spp*
1	2	3	1	2.890	89.1	2.576	Magugu	
1	2	3	9	8.711	82.8	7.209	Unknown	*Eragrostiella bifaria(*Vahl) Bor
1	2	4	1	4.682	83.7	3.919	Swagu	*Cleistachne sorghoides* Benth
1	2	4	2	3.278	82.6	2.708	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	2	4	4	9.277	74.4	6.906	Swagu	*Cleistachne sorghoides* Benth
1	2	4	5	7.846	83.9	6.580	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	2	5	1	7.837	73.9	5.793	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	2	5	3	7.971	82.8	6.597	chekela	*Hyparrhenia spp*
1	2	6	1	4.730	93.4	4.418	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	2	6	3	8.618	81.7	7.043	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	2	6	4	9.299	72.0	6.699	Magugu	
KILMAHU1	2	1	3	6.638	81.5	5.411	Swagu	*Cleistachne sorghoides* Benth
1	2	1	4	2.889	92.5	2.671	Swagu	*Cleistachne sorghoides* Benth
1	2	1	5	10.111	78.5	7.937	Swagu	*Cleistachne sorghoides* Benth
1	2	1	6	3.440	82.8	2.847	Swagu	*Cleistachne sorghoides* Benth
1	2	1	7	10.378	69.9	7.254	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	2	1	8	5.953	63.0	3.753	Swagu	*Cleistachne sorghoides* Benth
1	2	1	9	7.538	86.0	6.485	Mbambata	*Vetiveria nigritana* (Benth)

								Stapf
1	2	1	10	8.141	68.5	5.575	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	2	2	3	9.662	70.6	6.820	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	2	2	4	5.808	88.2	5.121	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	2	2	6	6.429	61.1	3.925	Swagu	*Cleistachne sorghoides* Benth
1	2	2	7	9.035	61.5	5.560	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	2	2	8	6.046	77.7	4.696	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	2	2	9	5.640	53.2	3.000	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	2	3	1	8.978	80.4	7.221	Swagu	*Cleistachne sorghoides* Benth
1	2	2B	1	7.054	91.5	6.453	Swagu	*Cleistachne sorghoides* Benth
1	2	2B	2	1.809	78.7	1.423	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	2	2B	3	7.889	90.1	7.109	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	2	2B	4	2.556	91.3	2.333	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	2	2B	5	6.675	89.1	5.949	Swagu	*Cleistachne sorghoides* Benth
1	2	2B	9	7.920	86.0	6.813	Swagu	*Cleistachne sorghoides* Benth
1	2	2C	1	10.826	79.6	8.614	Swagu	*Cleistachne sorghoides* Benth
1	2	2C	2	5.685	87.0	4.944	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	2	2C	4	18.514	67.7	12.542	Swagu	*Cleistachne sorghoides* Benth
1	2	2C	5	5.173	83.3	4.311	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	2	2C	6	5.558	92.3	5.130	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	2	2C	7	7.225	78.3	5.655	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	2	2C	8	6.843	73.9	5.058	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	2	2C	9	6.184	82.4	5.097	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	2	3B	2	12.430	85.1	10.579	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	2	3B	3	8.320	91.4	7.604	Mbambata	*Vetiveria nigritana* (Benth) Stapf
1	2	3B	4	3.028	87.1	2.637	Mbambata	*Vetiveria nigritana* (Benth) Stapf
		Sum		494.16	4767.3	379.28		
		Mean		8.10	78.1	6.218		STDEV 2.886; CONF 0.251

Site 1 means Kilombero, Sample type 2 means roots; KLE means eastern side of main road to ferry area, KLW means western side of main road to ferry area, KILMAHU means Kilombero Mahutanga village, STDEV means standard deviation and CONF means confidence interval.

Appendix 5: Biomass and carbon in litter for floodplain grasslands

	Site	Sample type	Trans	Plot	Biomass (t ha^{-1})	LOI%	C (t ha^{-1})	Litter mixture
	KLE1	LITTER3	1	3	1.675	84.7	1.419	Grasses
	1	3	1	0	1.491	84.3	1.258	Grasses
	1	3	2	1	1.515	87.4	1.323	Grasses
	1	3	2	2	0.513	91.2	0.468	Grasses
	1	3	2	3	3.260	91.1	2.970	Grasses
KLW	1	3	0	1	1.730	82.4	1.425	Grasses
	1	3	0	2	2.843	82.4	2.341	Grasses
	1	3	0	4	2.347	94.5	2.218	Grasses
	1	3	0	5	3.252	89.3	2.904	Grasses
	1	3	1	1	3.646	91.0	3.318	Grasses
	1	3	1	2	2.380	89.7	2.134	Grasses
	1	3	1	3	2.438	92.3	2.250	Grasses
	1	3	1	4	1.260	83.7	1.055	Grasses
	1	3	1	5	1.233	80.2	0.990	Grasses
	1	3	2	1	4.300	81.4	3.500	Grasses
	1	3	2	3	1.481	85.7	1.270	Grasses
	1	3	2	4	2.812	87.1	2.448	Grasses
	1	3	2	5	1.965	79.5	1.563	Grasses
	1	3	2	6	2.484	86.8	2.157	Grasses
	1	3	2	7	2.389	88.8	2.120	Grasses
	1	3	3	1	3.004	83.5	2.509	Grasses
	1	3	3	2	1.098	91.2	1.002	Grasses
	1	3	3	3	1.848	89.5	1.654	Grasses
	1	3	3	4	1.369	85.9	1.176	Grasses
	1	3	3	5	3.056	88.9	2.716	Grasses
	1	3	3	9	2.224	88.6	1.972	Grasses
	1	3	4	1	1.307	91.0	1.190	Grasses
	1	3	4	2	1.231	88.9	1.094	Grasses
	1	3	4	3	1.718	88.6	1.522	Grasses
	1	3	4	4	3.402	89.9	3.058	Grasses
	1	3	4	5	1.660	85.3	1.416	Grasses
	1	3	5	1	0.274	80.0	0.219	Grasses
	1	3	5	3	2.455	91.1	2.236	Grasses
	1	3	5	4	1.459	64.5	0.941	Grasses
	1	3	6	1	3.287	92.3	3.034	Grasses
	1	3	6	2	1.891	84.0	1.589	Grasses
	1	3	6	3	2.373	93.3	2.215	Grasses
	1	3	6	4	1.812	82.3	1.491	Grasses
KILMAHU	1	3	1	1	2.582	80.2	2.071	Grasses
	1	3	1	2	5.041	88.8	4.475	Grasses
	1	3	1	3	3.970	80.2	3.185	Grasses

1	3	1	4	2.607	91.1	2.375	Grasses
1	3	1	5	4.118	85.9	3.538	Grasses
1	3	1	6	3.400	84.1	2.859	Grasses
1	3	1	7	2.976	84.9	2.527	Grasses
1	3	1	8	3.574	82.7	2.955	Grasses
1	3	1	9	3.116	84.3	2.628	Grasses
1	3	1	10	5.538	87.2	4.829	Grasses
1	3	2	1	0.846	87.9	0.744	Grasses
1	3	2	2	1.986	82.4	1.635	Grasses
1	3	2	4	4.239	83.7	3.549	Grasses
1	3	2	5	2.446	88.0	2.151	Grasses
1	3	2	6	4.068	83.5	3.398	Grasses
1	3	2	7	1.351	93.2	1.259	Grasses
1	3	2	8	0.791	95.7	0.757	Grasses
1	3	2	9	3.430	88.5	3.036	Grasses
1	3	2	10	0.447	83.7	0.374	Grasses
1	3	3	1	4.480	84.5	3.787	Grasses
1	3	3	2	2.176	77.3	1.681	Grasses
1	3	3	3	1.560	90.1	1.406	Grasses
1	3	3	4	0.420	94.5	0.397	Grasses
1	3	3	5	0.919	94.4	0.867	Grasses
1	3	3	6	2.698	92.3	2.490	Grasses
1	3	2B	1	0.899	81.2	0.730	Grasses
1	3	2B	2	1.921	92.2	1.772	Grasses
1	3	2B	3	0.398	89.3	0.355	Grasses
1	3	2B	4	1.512	82.8	1.251	Grasses
1	3	2B	7	1.547	88.5	1.369	Grasses
1	3	2B	8	1.032	93.3	0.963	Grasses
1	3	2B	9	0.666	79.8	0.531	Grasses
1	3	2C	1	3.831	87.4	3.346	Grasses
1	3	2C	2	1.057	84.9	0.897	Grasses
1	3	2C	3	2.278	94.4	2.151	Grasses
1	3	2C	5	0.478	88.2	0.422	Grasses
1	3	2C	6	0.586	87.1	0.510	Grasses
1	3	2C	8	1.405	88.4	1.241	Grasses
1	3	2C	9	1.465	88.6	1.299	Grasses
1	3	2C	10	4.235	89.8	3.802	Grasses
1	3	3B	1	2.916	88.6	2.584	Grasses
1	3	3B	2	2.572	88.5	2.276	Grasses
1	3	3B	3	1.250	89.9	1.124	Grasses
1	3	3B	4	0.801	95.5	0.765	Grasses
1	3	3B	5	1.227	85.1	1.043	Grasses
		Sum		181.33	7224.8	157.569	
		Mean		2.185	87.0	1.898	
			STDEV	1.0355477	CONF	0.07713	

Site 1 means Kilombero, Sample type 3 means litters, KLE means eastern side of main road to ferry, KLW means western side of main road to ferry, KILMAHU means Kilombero Mahutanga village

Appendix 6: Biomass and carbon in shoots for upland grasslands

Site	Sample type	Trans	Plot	Biomass (t ha^{-1})	LOI%	C (t ha^{-1})	Local name (Hehe)	Scientific name
UD 2	Shoot 1	1	1	8.126	82.4	6.696	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	1	1	2	11.448	85.5	9.785	Swago	*Hyparrhenia rufa(*Nees) Stapf
2	1	1	3	10.903	83.3	9.086	Swago	*Hyparrhenia rufa(*Nees) Stapf
2	1	2	1	5.749	84.7	4.869	Swago	*Hyparrhenia rufa(*Nees) Stapf
2	1	2	2	11.398	84.4	9.625	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	1	2	3	6.611	81.1	5.364	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	1	3	1	8.813	85.5	7.533	Nyaganga	*Hyparrhenia hirta*(i) Stapf)
2	1	3	2	8.690	85.5	7.431	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	1	3	3	9.677	82.3	7.966	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	1	4	1	6.552	75.5	4.947	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	1	4	2	8.619	76.7	6.611	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	1	4	3	9.593	74.4	7.133	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	1	5	1	9.519	81.2	7.728	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	1	5	2	8.976	78.9	7.083	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	1	5	3	11.107	79.0	8.769	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	1	6	1	11.973	86.6	10.364	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	1	6	2	9.030	81.1	7.324	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	1	7	1	8.476	83.3	7.064	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	1	7	2	10.520	81.2	8.540	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	1	7	3	13.421	88.7	11.904	Lipelele	*Cymbopogon spp*
2	1	8	0	10.171	85.6	8.702	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	1	8	1	23.097	81.1	18.740	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	1	8	2	7.205	82.3	5.927	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	1	8	3	25.173	86.6	21.788	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	1	8	4	6.450	84.5	5.451	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	1	8	5	8.943	80.0	7.158	Swago	*Hyparrhenia rufa*(Nees) Stapf

2	1	8b	0	23.182	87.7	20.319	Masiru	*Pretis pterioides*
2	1	8b	1	8.158	82.3	6.710	Masiru	*Pretis pterioides*
2	1	8b	2	9.743	85.5	8.331	Masiru	*Pretis pterioides*
2	1	8b	3	22.774	85.5	19.473	Masiru	*Pretis pterioides*
2	1	9	0	12.002	86.8	10.412	masiru	*Pretis pterioides*
2	1	9	1	18.018	78.9	14.218	Masiru	*Pretis pterioides*
2	1	9	2	12.175	83.4	10.152	Swago	*Hyparrhenia rufa(*Nees) Stapf
2	1	9	3	16.896	85.7	14.484	Fern	*Pretis pterioides*
2	1	9	4	13.759	80.1	11.022	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	1	9	5	19.589	81.3	15.935	Masiru	*Pretis pterioides*
2	1	9b	1	16.894	76.7	12.958	Masiru	*Pretis pterioides*
2	1	9b	2	5.205	87.7	4.565	Masiru	*Pretis pterioides*
2	1	9b	3	19.500	80.1	15.620	Masiru	*Pretis pterioides*
2	1	9b	4	20.832	84.4	17.591	Masiru	*Pretis pterioides*
2	1	9b	5	20.640	88.8	18.329	Masiru	*Pretis pterioides*
2	1	10	1	15.730	82.2	12.933	Swago	*Hyparrhenia rufa(*Nees) Stapf
2	1	10	2	15.213	85.5	13.008	Lipelele	*Cymbopogon spp*
2	1	10	3	20.378	80.2	16.340	Masiru	*Pretis pterioides*
2	1	10	4	8.194	77.9	6.380	Lipelele	*Cymbopogon spp*
2	1	11	1	30.325	85.5	25.930	Masiru	*Pretis pterioides*
2	1	11	2	31.357	85.5	26.804	masiru	*Pretis pterioides*
2	1	11	3	31.658	86.6	27.405	Masiru	*Pretis pterioides*
2	1	11	4	32.763	82.2	26.937	Masiru	*Pretis pterioides*
2	1	11	5	29.416	89.8	26.408	Masiru	*Pretis pterioides*
2	1	12	1	26.075	84.5	22.035	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	1	12	2	15.533	85.5	13.282	Lipelele	*Cymbopogon spp*
2	1	12	3	34.568	85.9	29.676	Masiru	*Pretis pterioides*
2	1	13	1	22.046	86.7	19.106	Masiru	*Pretis pterioides*
2	1	13	2	20.649	81.2	16.764	Masiru	*Pretis pterioides*
2	1	13	3	22.689	84.4	19.159	Masiru	*Pretis pterioides*
2	1	20	1	5.495	89.8	4.936	Nyaganga	*Hyparrhenia spp*
2	1	20	2	10.310	85.5	8.816	Masiru	*Pretis pterioides*
2	1	20	3	30.752	84.4	25.956	Nyaganga	*Hyparrhenia spp*
2	1	20	4	14.444	82.2	11.877	Lipelele	*Cymbopogon spp*
2	1	20	5	21.792	76.8	16.728	Lipelele	*Cymbopogon spp*
2	1	20	6	18.168	88.7	16.122	Lipelele	*Cymbopogon spp*
2	1	20	7	17.898	79.0	14.131	Lipelele	*Cymbopogon spp*
2	1	21	1	5.667	84.6	4.793	Nyaganga	*Hyparrhenia spp*
2	1	21	2	7.362	80.0	5.891	Nyaganga	*Hyparrhenia spp*
2	1	21	3	10.135	86.7	8.784	Masiru	*Pretis pterioides*
2	1	21	4	6.330	85.5	5.411	Nyaganga	*Hyparrhenia spp*
2	1	21	5	21.752	87.7	19.066	Lipelele	*Cymbopogon spp*
2	1	21	6	9.593	82.3	7.891	Nyaganga	*Hyparrhenia spp*
2	1	21	7	36.745	83.4	30.639	Lipelele	*Cymbopogon spp*
2	1	22	1	3.809	84.4	3.217	Nyaganga	*Hyparrhenia spp*
2	1	22	2	7.474	80.1	5.987	Nyaganga	*Hyparrhenia spp*
2	1	22	3	21.316	85.5	18.226	Masiru	*Pretis pterioides*
2	1	22	4	7.832	79.0	6.189	Nyaganga	*Hyparrhenia spp*
2	1	22	5	6.193	85.6	5.303	Nyaganga	*Hyparrhenia spp*
2	1	22	6	7.873	77.9	6.136	Nyaganga	*Hyparrhenia spp*
2	1	23	1	10.606	86.6	9.185	Masiru	*Pretis pterioides*
2	1	23	2	19.568	89.7	17.561	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	1	23	3	6.053	97.6	5.908	Nyaganga	*Hyparrhenia spp*

2	1	23	4	7.008	79.0	5.538	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	1	23	5	8.286	83.3	6.905	Nyaganga	*Hyparrhenia spp*
2	1	23	6	12.160	83.3	10.133	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	1	24	1	18.360	82.5	15.149	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	1	24	2	16.400	78.9	12.938	Swago	*Hyparrhenia rufa(*Nees) Stapf
2	1	24	3	12.986	83.4	10.828	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	1	24	4	24.766	86.6	21.449	Lipelele	*Cymbopogon spp*
2	1	24	5	24.677	88.8	21.913	Lipelele	*Cymbopogon spp*
2	1	24	6	23.057	85.7	19.767	Lipelele	*Cymbopogon spp*
Sum				1321.069	735.4	1109.2		
Average				15.012	83.6	12.605		
STDEV		6.931598		CONF		0.501243922		

Site 2 means Udekwa Kilolo, Sample type 1 means shoots, STDEV means standard deviation and CONF means confidence interval.

Appendix 7: Biomass and carbon in roots for upland grasslands

Site	Sample type	Trans	Plot	Biomass (t ha^{-1})	LOI%	C (t ha^{-1})	Local name (Hehe)	Scientific name
2	ROOT 2	1	1	11.411	66.1	7.545	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	1	2	4.877	46.5	2.266	Swago	*Hyparrhenia rufa(*Nees) Stapf
2	2	1	3	4.969	79.0	3.923	Swago	*Hyparrhenia rufa(*Nees) Stapf
2	2	2	1	7.267	72.3	5.255	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	2	2	8.693	76.7	6.669	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	2	3	1.240	79.0	0.980	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	3	1	0.724	82.3	0.596	Nyaganga	*Hyparrhenia spp*
2	2	3	2	3.543	76.8	2.721	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	3	3	5.275	82.3	4.342	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	4	1	9.395	73.6	6.919	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	4	2	1.802	79.0	1.422	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	4	3	3.907	68.7	2.684	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	5	1	6.062	84.4	5.116	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	5	2	6.776	63.0	4.269	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	5	3	6.343	65.4	4.149	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	6	1	5.998	86.5	5.191	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	6	2	5.960	65.2	3.884	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	7	1	6.273	65.2	4.088	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	7	2	7.269	53.7	3.901	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	7	3	11.163	68.7	7.667	Lipelele	*Cymbopogon spp*
2	2	8	0	5.635	80.1	4.514	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	8	1	3.802	66.8	2.541	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	8	2	6.707	73.4	4.924	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	8	3	4.543	72.1	3.275	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	8	4	6.213	66.7	4.142	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	8	5	5.293	79.0	4.183	Swago	*Hyparrhenia*

								rufa(Nees) Stapf
2	2	8b	0	5.362	77.9	4.175	Masiru	*Pretis pterioides*
2	2	8b	1	5.511	78.9	4.347	Masiru	*Pretis pterioides*
2	2	8b	2	6.866	65.2	4.474	Masiru	*Pretis pterioides*
2	2	8b	3	9.290	74.4	6.907	Masiru	*Pretis pterioides*
2	2	9	0	23.819	73.3	17.452	Masiru	*Pretis pterioides*
2	2	9	1	20.119	75.6	15.201	Masiru	*Pretis pterioides*
2	2	9	2	7.350	69.8	5.132	Swago	*Hyparrhenia rufa(*Nees) Stapf
2	2	9	3	43.881	80.3	35.234	Masiru	*Pretis pterioides*
2	2	9	4	3.498	69.0	2.414	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	9	5	19.337	87.6	16.942	Masiru	*Pretis pterioides*
2	2	9b	1	24.436	73.3	17.904	Masiru	*Pretis pterioides*
2	2	9b	2	3.233	64.0	2.068	Masiru	*Pretis pterioides*
2	2	9b	3	35.718	77.8	27.776	Masiru	*Pretis pterioides*
2	2	9b	4	2.184	56.8	1.240	Masiru	*Pretis pterioides*
2	2	9b	5	38.457	65.2	25.059	Masiru	*Pretis pterioides*
2	2	10	1	6.623	74.4	4.930	Swago	*Hyparrhenia rufa(*Nees) Stapf
2	2	10	2	6.962	84.4	5.879	Lipelele	*Cymbopogon spp*
2	2	10	3	38.018	62.6	23.788	Masiru	*Pretis pterioides*
2	2	10	4	5.781	63.8	3.686	Lipelele	*Cymbopogon spp*
2	2	11	1	47.649	75.8	36.116	Masiru	*Pretis pterioides*
2	2	11	2	38.009	45.6	17.350	Masiru	*Pretis pterioides*
2	2	11	3	25.045	83.3	20.864	Masiru	*Pretis pterioides*
2	2	11	4	13.249	67.9	8.999	Masiru	*Pretis pterioides*
2	2	11	5	28.757	63.9	18.378	Masiru	*Pretis pterioides*
2	2	12	1	2.541	71.3	1.813	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	12	2	5.469	80.0	4.376	Lipelele	*Cymbopogon spp*
2	2	12	3	22.026	61.9	13.626	Masiru	*Pretis pterioides*
2	2	13	1	28.121	71.1	19.997	Masiru	*Pretis pterioides*
2	2	13	2	31.647	73.3	23.187	Masiru	*Pretis pterioides*
2	2	13	3	30.817	66.2	20.394	Masiru	*Pretis pterioides*
2	2	20	1	0.740	72.4	0.536	Nyaganga	*Hyparrhenia spp*
2	2	20	2	23.686	59.4	14.073	masiru	*Pretis pterioides*
2	2	20	3	4.634	72.6	3.363	Nyaganga	*Hyparrhenia spp*
2	2	20	4	11.550	74.5	8.607	Lipelele	*Cymbopogon spp*

2	2	20	5	9.185	75.5	6.936	Lipelele	*Cymbopogon spp*
2	2	20	6	6.895	73.2	5.048	Lipelele	*Cymbopogon spp*
2	2	20	7	3.324	60.3	2.004	Lipelele	*Cymbopogon spp*
2	2	21	1	0.492	73.2	0.360	Nyaganga	*Hyparrhenia spp*
2	2	21	2	8.387	72.1	6.043	Nyaganga	*Hyparrhenia spp*
2	2	21	3	32.164	72.1	23.187	Masiru	*Pretis pterioides*
2	2	21	4	11.405	63.8	7.279	Nyaganga	*Hyparrhenia spp*
2	2	21	5	3.861	79.1	3.054	Lipelele	*Cymbopogon spp*
2	2	21	6	5.077	78.2	3.970	Nyaganga	*Hyparrhenia spp*
2	2	21	7	2.833	68.9	1.952	Lipelele	*Cymbopogon spp*
2	2	22	1	5.999	83.3	4.997	Nyaganga	*Hyparrhenia spp*
2	2	22	2	3.436	69.8	2.397	Nyaganga	*Hyparrhenia spp*
2	2	22	3	19.110	58.9	11.254	Masiru	*Pretis pterioides*
2	2	22	4	7.543	77.8	5.870	Nyaganga	*Hyparrhenia spp*
2	2	22	5	3.528	76.7	2.705	Nyaganga	*Hyparrhenia spp*
2	2	22	6	5.899	51.7	3.048	Nyaganga	*Hyparrhenia spp*
2	2	23	1	24.306	78.9	19.179	Masiru	*Pretis pterioides*
2	2	23	2	7.720	60.3	4.654	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	23	3	1.007	68.6	0.691	Nyaganga	*Hyparrhenia spp*
2	2	23	4	2.011	83.5	1.678	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	23	5	2.669	58.8	1.570	Nyaganga	*Hyparrhenia spp*
2	2	23	6	4.220	62.5	2.637	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	24	1	8.952	73.3	6.565	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	24	2	8.014	45.7	3.664	Swago	*Hyparrhenia rufa(*Nees) Stapf
2	2	24	3	7.248	71.5	5.182	Swago	*Hyparrhenia rufa*(Nees) Stapf
2	2	24	4	6.144	81.2	4.988	Lipelele	*Cymbopogon spp*
2	2	24	5	5.367	60.6	3.250	Lipelele	*Cymbopogon spp*
	Sum			979.01	622.5	688.03		
	Mean			11.125	70.7	7.818		
	STDEV		7.93528162	CONF		0.57382316		

Site 2 means Udekwa Kilolo, Sample type 2 means roots, STDEV means standard deviation and CONF means confidence interval.

Appendix 8: Biomass and carbon in litter for upland grasslands

Site	Sample type LITTER	Transect	Plot	Biomass (t ha^{-1})	LOI%	Carbon (t ha^{-1})	Litter mixture
2	3	1	1	5.563	75.5	4.202	Grass and Fern
2	3	1	2	2.759	76.7	2.115	Grass, Fern and tree leaves
2	3	1	3	10.060	63.8	6.419	Grass, Fern and tree leaves
2	3	2	1	3.370	80.0	2.697	Grass, Fern and tree leaves
2	3	2	2	2.303	71.0	1.634	Grass, Fern and tree leaves
2	3	2	3	3.033	72.1	2.185	Grass, Fern and tree leaves
2	3	3	2	5.006	73.2	3.665	Grass and Fern
2	3	3	3	5.438	76.7	4.171	Grass and Fern
2	3	4	1	7.622	74.4	5.668	Grass and Fern
2	3	4	2	3.722	78.9	2.936	Grass and Fern
2	3	4	3	6.809	73.2	4.986	Grass and Fern
2	3	5	1	4.939	72.1	3.559	Grass and Fern
2	3	5	2	4.735	76.6	3.629	Grass and Fern
2	3	5	3	5.592	70.9	3.965	Grass and Fern
2	3	6	1	8.681	69.7	6.055	Grass and Fern
2	3	6	2	7.289	77.8	5.671	Grass and Fern
2	3	7	1	3.688	75.7	2.790	Grass and Fern
2	3	7	2	3.712	74.5	2.764	Grass and Fern
2	3	7	3	2.218	77.8	1.725	Grass and Fern
2	3	8	0	1.970	74.4	1.465	Grass and Fern
2	3	8	1	3.028	65.0	1.968	Grass and Fern
2	3	8	2	6.982	71.0	4.959	Grass and Fern
2	3	8	4	5.762	67.3	3.880	Grass and Fern
2	3	8	5	7.181	78.9	5.666	Grass and Fern
2	3	8b	0	1.830	73.2	1.340	Grass and Fern
2	3	8b	1	3.000	69.7	2.092	Grass and Fern

2	3	8b	2	6.075	72.0	4.377	Grass andFern
2	3	8b	3	5.882	73.4	4.315	Grass and Fern
2	3	9	0	7.315	80.0	5.855	Grass and Fern
2	3	9	1	11.411	66.1	7.547	Grass and Fern
2	3	9	2	6.729	63.7	4.287	Grass and Fern
2	3	9	3	7.021	63.7	4.476	Grass and Fern
2	3	9	4	3.407	53.8	1.834	Grass and Fern
2	3	9	5	2.125	74.4	1.581	Grass and Fern
2	3	9b	1	6.872	77.0	5.289	Grass and Fern
2	3	9b	2	4.025	64.9	2.613	Grass and Fern
2	3	9b	3	6.499	66.1	4.299	Grass and Fern
2	3	9b	4	3.605	70.0	2.523	Grass and Fern
2	3	9b	5	2.064	74.4	1.535	Grass and Fern
2	3	10	2	5.970	79.0	4.713	Grass and Fern
2	3	10	3	5.602	67.3	3.772	Grass and Fern
2	3	10	4	4.852	66.2	3.211	Grass and Fern
2	3	11	1	3.181	72.0	2.292	Grass and Fern
2	3	11	2	4.762	80.1	3.815	Grass and Fern
2	3	11	3	2.630	77.8	2.046	Grass and Fern
2	3	11	4	5.865	66.3	3.891	Grass and Fern
2	3	11	5	3.902	77.8	3.036	Grass and Fern
2	3	12	1	2.022	77.8	1.573	Grass and Fern
2	3	12	2	2.634	71.1	1.873	Grass and Fern
2	3	12	3	4.164	74.4	3.099	Grass and Fern
2	3	13	1	2.060	75.5	1.556	Grass and Fern
2	3	13	2	2.380	65.0	1.547	Grass and Fern
2	3	13	3	2.649	66.3	1.757	Grass and Fern
2	3	20	2	2.389	62.5	1.494	Grass and Fern
2	3	20	3	5.610	80.0	4.488	Grass and Fern
2	3	20	4	5.802	63.7	3.697	Grass and Fern
2	3	20	6	4.683	65.0	3.044	Grass and Fern
2	3	20	7	6.441	76.8	4.944	Grass and Fern
2	3	21	1	2.946	67.4	1.984	Grass and Fern
2	3	21	2	3.756	63.7	2.393	Grass and Fern
2	3	21	3	2.395	66.1	1.584	Grass and Fern
2	3	21	4	2.550	66.3	1.689	Grass and Fern
2	3	21	5	1.800	74.4	1.339	Grass and Fern
2	3	21	6	2.427	61.2	1.486	Grass and Fern
2	3	21	7	3.051	58.7	1.792	Grass and Fern
2	3	22	1	4.956	62.5	3.096	Grass and Fern
2	3	22	2	6.890	47.1	3.247	Grass and Fern
2	3	22	3	6.021	69.7	4.200	Grass and Fern
2	3	22	4	2.995	72.4	2.167	Grass and Fern
2	3	22	5	1.216	57.5	0.699	Grass and Fern
2	3	22	6	4.033	58.9	2.375	Grass and Fern
2	3	23	1	1.981	72.1	1.428	Grass and Fern
2	3	23	3	1.885	60.0	1.131	Grass and Fern
2	3	23	4	1.549	76.7	1.188	Grass and Fern
2	3	23	5	2.543	81.1	2.063	Grass and Fern
2	3	23	6	1.946	66.3	1.290	Grass and Fern
2	3	24	1	3.054	69.7	2.129	Grass and Fern
2	3	24	2	2.557	68.6	1.754	Grass and Fern
2	3	24	3	3.299	68.5	2.261	Grass and Fern
2	3	24	4	2.758	73.2	2.019	Grass and Fern
2	3	24	5	2.272	61.3	1.393	Grass and Fern
2	3	24	6	2.101	72.5	1.523	Grassand Fern

Sum		347.901	5770	224.82
Mean		4.24	70.4	2.98
STDEV	1.500952	CONF		0.108538

Site 2 means Udekwa Kilolo, Sample type 3 means litter, STDEV means standard deviation and CONF means confidence interval.

Appendix 9: Procedures for determination of carbon in the soil

i) Soil was grounded in mortar and sieved in 0.5 mm sieve ii) 0.5 g of soil sample was weighed and put into a 500 ml Erlenmeyer flask iii) 10 mls of 0.1667 M potassium dichromate solution was added to the flask and swirl gently to disperse the soil in the solution iv) 20 mls of concentrated sulphuric acid was added into the soil mixture and the mixture was swirled for one minute. Then mixture was allowed to cool for 30 minutes. Then 200 mls of distilled water was added to the mixture followed by 10mls of phosphoric acid was also added and the content was mixed by using magnetic stirrer. Then followed by addition of 1ml of diphenylamine indicator and sample was titrated against ammonium ferrous sulphate approximately 0.5N to brilliant green.

The blank was also prepared in a separate conical flask following all steps except there was no soil added. From the blank the exact normality of ammonium ferrous sulphate was calculated. The procedures are described in Nelson and Sommer, (1996).

Calculations used to find carbon content in the soil were:

i) Normality of the ammonium ferrous sulphate solution

$$N = (F \times M) / T$$

$$(F \times M) / T = 0.45$$

The Normality found was 0.45.

Where: F = Final 10 ml of potassium dichromate added to the titrated blank; M = Normality of the potassium dichromate; T = mls of ammonium ferrous sulphate used for the second titration of the blank; N = Normality of the ammonium ferrous sulphate.

ii) Organic carbon content

The percentage carbon in every soil sample was determined from the following formula by (NSS, 1990).

Percentage Organic Carbon (% O.C) = $(B-A) \times N \times 0.396 \times Mc / Wt$

Where:

B = ml ammonium ferrous sulphate used for the first blank titration; A = ml ammonium ferrous sulphate used for the sample; N = Normality of the ammonium ferrous sulphate; Wt = Weight of the sample in gram (g); Mc = Moisture correction factor and 0.396 is a constant factor.

The factor 0.396 is obtained from: a) Incomplete combustion (1.32); b) Equivalent of carbon (3); c) Conversion from millequivalents to equivalents (1000); d) Conversion to percentage (100).

That is: $1.32 \times 3 \times 100 / 1000 = 0.396$

The carbon stored by the soil in hectare basis was calculated using the products of organic carbon concentration in kg, the bulk density and layer thickness (0 - 15, 15 - 30, 30 - 45, and 45 - 60) cm or 15 cm in every layer. The following formula was also used to calculate Percentage organic carbon in the soil which gave the same results

Formula:

Percentage O.C = (m.e $K_2Cr_2O_7$ – m.e $FeSO_4$) x m.e of carbon x f) / ODWS x 100

Where:

m.e $K_2Cr_2O_7$ = ml $K_2Cr_2O_7$ x normality

m.e $FeSO_4$ / $(NH_4)_2$ $FeSO_4$ = ml $FeSO_4$ / $(NH_4)_2$ $FeSO_4$ x normality

f = 1.32, m.e of carbon = 0.003, ODWS = Oven dry weight of soil

The conversion factor f = 1.32 was used in calculation because the black Walkley method recover only 77%. That is 77 percent of carbon in the sample is oxidized.

Appendix 10: Anova for carbon stored by shoots, roots and litter in upland and floodplain grasslands

Anova: Single Factor for carbon in shoots

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	67	2213.705	33.04037	207.0457
Column 2	67	818.3325	12.21392	54.43894

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	14530.33	1	14530.33	111.1372	3.15E-19	3.912875
Within Groups	17257.99	132	130.7423			
Total	31788.32	133				

Anova: Single Factor for carbon stored by roots

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	60	372.3962	6.206603	8.465788
Column 2	60	473.5696	7.892826	66.07245

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	85.30051	1	85.30051	2.288772	0.132987	3.921478
Within Groups	4397.756	118	37.26912			
Total	4483.056	119				

Anova: Single Factor for carbon stored in litter

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	83	157.5693	1.898425	1.072359
Column 2	83	255.1083	3.073594	2.327556

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	57.31241	1	57.31241	33.71402	3.22E-08	3.898787
Within Groups	278.7931	164	1.699958			
Total	336.1055	165				

Appendix 11: Anova for carbon stored by upland and floodplain grassland soils

Anova: Single Factor for soil layer 0 - 15cm

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	48	1614.281	33.63086	169.599
Column 2	48	2520.765	52.51594	184.8692

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	8559.507	1	8559.507	48.29492	4.76E-10	3.942303
Within Groups	16660	94	177.2341			
Total	25219.51	95				

Anova: Single Factor for soil layer 15-30cm

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	48	1198.946	24.97804	69.26769
Column 2	48	2087.833	43.49653	157.8268

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	8230.422	1	8230.422	72.48457	2.64E-13	3.942303
Within Groups	10673.44	94	113.5472			
Total	18903.86	95				

Anova: Single Factor for soil layer 30-45cm

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	48	996.975	20.77031	49.53956
Column 2	48	1730.662	36.05545	92.83178

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5607.253	1	5607.253	78.7694	4.52E-14	3.942303
Within Groups	6691.453	94	71.18567			
Total	12298.71	95				

Anova: Single Factor for soil layer 45-60cm

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	48	918.1621	19.12838	59.74286
Column 2	48	1465.933	30.54027	103.7577

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3125.554	1	3125.554	38.23295	1.61E-08	3.942303
Within Groups	7684.526	94	81.75028			
Total	10810.08	95				

Appendix 12: Anova for carbon stored by shoots and roots of dominant species in floodplain and upland grasslands

Anova for shoots of dominating species in floodplain grassland

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	5155.438	2577.719	27.02	< 0001
Error	59	5628.352	95.396		
Corrected Total	61	10 783.791			

Anova for shoots of dominating species in upland grassland

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1481.600	493.867	15.15	< 0001
Error	68	2216.244	32.592		
Corrected Total	71	3697.845			

Anova for roots of dominating species in floodplain grassland

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1.204	0.602	0.120	0.887
Error	50	251.220	5.024		
Corrected Total	52	252.425			

Anova for roots of dominating species in upland grassland

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	3159.471	1053.157	65.54	< 0001
Error	67	1076.633	16.069		

Corrected Total	70	4236.105

Appendix 13: Means of carbon stored by roots and shoots of different species in upland and floodplain grasslands

Carbon storage by roots of different species in upland grasslands

Means with the same letter are not significantly different

Duncan Grouping	Mean (t C ha^{-1})	No	Species
A	20.281	15	*Pteris pterioides* (Masiru)
B	4.938	10	*Cymbopogon spp* (Lipelele
B	4.050	33	*Hyparrhenia rufa*(Nees) Stapf (Swago)
B	3.106	13	*Hyparrhenia spp* (Nyaganga/Masing'ang'ata

Carbon storage by roots of different species in floodplain grasslands

Means with the same letter are not significantly different

Duncan Grouping	Mean (t C ha^{-1})	No	Species
A	6.069	21	*Cleistachne sorghoides* Benth (Swagu
A	5.910	29	*Vetiveria nigritana* (Benth) Stapf (Mbambata
A	5.414	3	*Hyparrhenia spp* (Chekela)

Carbon storage by shoots of different species in upland grasslands

Means with the same letter are not significantly different

Duncan Grouping	Mean (t C ha^{-1})	No	Species
A	18.731	15	*Pteris pterioides* (Masiru)
B	17.873	11	*Cymbopogon spp* (Lipelele
B	9.799	33	*Hyparrhenia rufa*(Nees) Stapf (Swago)
B	7.379	13	*Hyparrhenia spp* (Nyaganga/Masing'ang'ata

Carbon storage by shoots of different species in floodplain grasslands

Means with the same letter are not significantly different

Duncan Grouping	Mean (t C ha^{-1})	No	Species
A	45.197	19	*Cleistachne sorghoides* Benth (Swagu
B	25.740	41	*Vetiveria nigritana* (Benth) Stapf (Mbambata
B	20.761	2	*Hyparrhenia spp* (Chekela)