Influence of topography and vegetation cover on soil organic carbon stocks, soil loss, water balance and greenhouse gas fluxes in wooded grasslands of Laikipia County, Kenya

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DECLARATION

This thesis is my original work and has not been submitted for the award of a degree in any other institution of learning.

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DEDICATION

To my family: Husband Camalas Kipchirchir Keiyo and children (Lauryn Chelangat Keiyo and Larsen Kiplangat Keiyo).

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GENERAL ABSTRACT

Soil carbon stocks (SOCs), soil water balance and greenhouse gas fluxes measurements in wooded grassland are often done in a single assessment. This is oblivious of its heterogeneous nature and asymmetric distribution that characterizes wooded grassland and thence inaccurate results are captured. This information is essential, albeit lacking, for designing sustainable strategies important for management of the fragile wooded grassland ecosystems. The present study investigated topographical and vegetation cover types effects on SOCs, soil water balance (SWB) and greenhouse gas fluxes in wooded grasslands of Laikipia County, Kenya. This study was conducted during the short and long rainy seasons of 2016 in Ilmotiok group ranch of Laikipia County. Soil organic carbon stocks (SOCs), soil water balance (SWB) and greenhouse gas fluxes across different topographical positions and vegetation cover were quantified. The experimental design was a RCBD with a split plot layout. The main plots were topographical zones (TZ); mid slopes (MS), foot slope (FS) and toe slope (TS). The subplots were vegetation cover (VC) types: tree (T), grass (G) and bare (B). Sampling of soil was done at intervals of 10 cm to a depth of 50cm in a zigzag manner using a soil auger. The sampling was done along a transect line of 150m after every block of 50m forming three replicates. The sampled soil was analyzed for texture, bulk density (BD) and soil organic carbon. Runoff plots were set up across the TZ and VC types to monitor runoff (RO) and soil loss (SL). To measure Greenhouse Gas (GHGs) fluxes (methane (CH_4), carbon dioxide (CO_2), and Nitrous Oxide (N_2O) static chamber frames were installed across the topographic zones and vegetation cover types. GHGs were measured every 7-10 days in the dry season, intermediate and rainy season between 0800hrs and 1200hr local time. TZ, VC, depth and TZ*VC significantly ($p<0.05$) influenced BD and SOCs. There was a significantly higher bulk at MS (1.03 g/cm^3 and 1.00 g/cm^3) but not significantly different from TS (1.02 and 0.92 gcm^{-3}) with FS having the lowest value (0.97 and 0.88 gcm^{-3}) for LRS and SRS respectively. Vegetation cover significantly ($P <0.05$) influence with highest bulk density recorded under BR (1.04 and 0.96 gcm^{-3}) which was not significantly different from TR (1.01 and 0.92 gcm^{-3}) and significantly higher than GR (0.97 and 0.92 gcm^{-3}) for LRS and SRS respectively. The interaction of topography and vegetation significantly influence bulk density with highest value recorded under FS*BR (1.11 and 1.03 gcm^{-3}) for LRS and SRS respectively. Highest soil organic carbon stocks were recorded at the TS (6.40 and 6.51 MgHa^{-1}) as compared to other zones though not significantly different from MS (6.16 and 6.46 MgHa^{-1}) but significantly different from FS (5.29 and 5.93 MgHa^{-1}). SOCs under GR (6.31 and 6.53 MgHa^{-1}) were slightly higher than other vegetation cover, the lowest was recorded under BR (5.76 and 6.02 MgHa^{-1}) for LRS and SRS respectively. The upper soil depth (0-10) had (8.70 and 8.74 MgHa^{-1}) compared to the lower depth (40-50) with (3.52 and 4.07 MgHa^{-1}). There were significant [P<.001] differences in evapotranspiration, runoff and soil loss across the three topographical zones and vegetation cover types. The run off was significantly higher in mid slope*bare [175.90 and 168.75 mm] and mid slope *grass [172.00 and 164.85mm] compared to toe slope *bare [169.79 and 162.64 mm] and Toe Slope* Grass [165.89 and 158.74 mm] during the LRS and SRS. Whereas Soil water balance was highest at the toe slope*grass [279.46 and 119.49 mm] than Foot slope*Grass [273.51 and 113.54 mm] and Mid Slope*Grass [267.23 and 104.76 mm] during the LRS and SRS respectively. The Run off Coefficient was significantly lower in the Toe slope*Grass [0.30 and 0.45] than Foot slope*Grass [0.31 and 0.46] for LRS and SRS). During the wet months, CH_4, N_2O and CO_2 emission were significantly higher than the dry season. Methane fluxes ranged from -0.32 mg.m^{-2}.h^{-1} to 0.24 mg.m^{-2}.h^{-1} with the lowest (-0.32 mg.m^{-2}.h^{-1}) recorded under TS*T whereas CO_2 was highest under TS*G (47 mg.m^{-2}.h^{-1}) as compared to MS*G (19 mg.m-2.h-1). TZ*VC significantly influence N_2O with MS*B recording the lowest (0.008) as compared to TS*B (2.228 mg.m^{-2}.h^{-1}). CO_2, N_2O and CH_4 In the month of January and February emissions were low and it increased in March and April in all the TZ*VC. Topography and vegetation have an effect on soil organic carbon stocks and bulk density. Toe slope and grass significantly increased soil organic carbon stocks and reduced bulk density. Toe slope with grass significantly reduced both runoff and soil loss thus increased Soil water balance and improved runoff coefficient. Therefore, protection of slopes from raindrops can effectively reduce soil loss and runoff and enhance deposition in the mid slope and toe slope. The trends of soil CO_2, N_2O, and CH_4 fluxes were principally controlled by topography and plant cover, with larger soil CH_4 uptakes and CO_2 emissions on the toe slopes and foot slopes than in MS.

Keywords: bulk density, runoff, soil loss, soil water balance, soil organic carbon stocks, topographical zones, vegetation cover

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LIST OF ACRONYMS AND ABBREVIATIONS

GHG	Greenhouse Gases
IPCC	Intergovernmental Panel on Climate Change
SOCs	Soil Organic Carbon stocks
FAO	Food Agricultural Organization
DayCent	Daily Century
DNDC	Denitrification Decomposition
CO_2	Carbon dioxide
CH_4	Methane
N_2O	Nitrous oxide
UNFCCC	United Nations Framework Convention on Climate Change
ETS	Emissions Trading Scheme
UNDP	United Nations Development Programme

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background information

Climate change globally is a factor of increased emissions of greenhouse gasses (GHG); such as nitrous oxide (N_2O), methane CH_4) and carbon dioxide (CO_2) largely contributed through anthropogenic activities (IPCC 2007). Soil carbon change is the key to climate variability and therefore, estimates of wooded grassland soil carbon stocks changes over the next century are of critical importance (Smith *et al*., 2005). In Africa, grasslands cover ~50%, they play a vital role in C cycle and biodiversity. Nevertheless, contribution of African grasslands to human welfare and potential to fix carbon, remain poorly researched in comparison to other ecosystems (Jeltsch et al. 2017).

Most of the carbon storage studies have been done in natural forests (Shirima, 2009) and in agroforestry systems (Mugasha, 2009) and in forest plantations (Wesaka, 2009). Additionally, carbon stocks are often measured homogeneously at a point assessment but in contrast, wooded grasslands are heterogeneous (Nori 2006). An average measurement from diverse sample points to distinguish diverse environments is misrepresentative since the asymmetric distribution of carbon that characterizes wooded grassland is not captured (Kratli and Schareika 2010). Wooded grasslands are frequently characterized as spots in small catchments and within each spot; there is a spatial distinction of SOC determined by topographic properties (Tan *et al*. 2004). Wooded grasslands have experienced soils and vegetation degradation resulting from human encroachment and associated land use activities (Manjarrez- Dominguez *et al.*, 2015). Hence, wooded grassland ecosystem as carbon sinks has shrunk in size due to continuous degradation (Bai *et al*., 2008).

Soil GHGs fluxes change basically over space and time driven by soil biological activities, ecological surroundings, heterogeneousness of soil properties as well as spatial variability in available nutrients and root distribution (Butterbach-Bahl *et al*., 2013). However, research on the exchange greenhouse gases (methane CH_4, carbon dioxide CO_2, and nitrous oxide N_2O) remains still scanty for wooded grasslands compared to other ecosystems known to sequester significant amounts of carbon (Merbold and Wohlfahrt 2012). Reliable evaluations of soil carbon stock are required in light of the fact that soil carbon stock changes are a portion of the national GHG inventories guided under UNFCCC and Kyoto Protocol (Rantakari *et al 2007).* Determination of fluxes using soil chamber techniques (non–steady-state) contribute towards uncertainty in gas concentration measurements due to sampling and analytical error

(Parkin *et al* 2010). Therefore, quantification of N_2O, CH_4 and CO_2 emissions from grasslands is important for a more accurate assessment using other methods justify (Saggar *et al*., 2007).

Laikipia County Government (2013– 2017) demonstrates that most vulnerable territories to climate change event are the semi-arid lands of Kenya. Erratic and low rainfall and high levels of potential evapotranspiration, poor plant growth and productivity characterize these areas. (García *et al*., 2014). Climatically, wooded grasslands in semi-arid lands are described by outrageous high temperatures (D'Odorico and Porporato, 2006) and unpredictable precipitation incidences that are of high intensity and brief length(Wei *et al*., 2007). However, few studies have been done to evaluate the water balance in the wooded grassland on account of its heterogeneous vegetative nature, therefore the capability of the respective vegetation to water storage is limited and hence undermining conservation measures (Gremer *et al*., 2015). Thus far, measurements of SOC stock changes in the field are limited by their inherent spatial variability at numerous scales (Conant and Paustian, 2002). Therefore, climatic parameters - due to their easy availability - and remotely sensed data are mostly employed by researchers at various scales, to estimate SOCs (Liu *et al*. 2012). Models have also been applied to forecast GHG emissions for different soils, climatic conditions and farm management in a number of regions across the world (Leip *et al*., 2008). Therefore, not much is known on possible carbon storage, water balance and greenhouse gases emissions in wooded grassland ecosystems of Laikipia County. Against these backdrops, this study investigated the influence of topography and vegetation cover on soil organic carbon stocks, water balance and greenhouse gas fluxes in wooded grasslands of Laikipia County, Kenya.

1.2 Statement of the problem

Climate change globally has been associated with increased emissions of greenhouse gases due to anthropogenic (human) activities (IPCC 2007). Wooded grassland ecosystem as carbon sinks to alleviate greenhouse gases emissions have reduced due to degradation (Bai *et al*., 2008). Soil carbon stocks measurements in wooded grassland are often done in a single assessment oblivious of its heterogeneous nature (spatial and temporal) (Nori 2006) and thence inaccurate asymmetric distribution of carbon that characterizes wooded grassland is not captured (Kratli and Schareika 2010). Few studies have been done to evaluate the water balance in the wooded grassland on account of its heterogeneous vegetative nature, therefore the capacity of the respective vegetation to store water is limited and hence undermining conservation measures (Gremer *et al*., 2015).

In addition, direct measurement of SOC is destructive to the soil, time-consuming and experimental determination of SOC changes in the field is also limited by its inherent spatial variability(Conant and Paustian, 2002). Information on fluxes of the major greenhouse gases (nitrous oxide N_2O) carbon dioxide CO_2, and methane CH_4 still scanty for wooded grasslands (Merbold and Wohlfahrt 2012) and hence lack of reliable estimates of greenhouse gases that is mandatory as part of the national GHG records recorded under Kyoto Protocol and UNFCCC (Rantakari *et al., 2007).* Large uncertainty exists in monitoring of gas fluxes (CO_2, CH_4 and N_2O) at a regional scale (Chapuis-Lardy *et al*., 2007), the non–steady-state soil chamber technique of GHGs measurements over a fixed time interval contribute towards uncertainty in gas concentration measurements due to sampling and analytical error (Parkin *et al* 2010) and further requires repeated measurements hence expensive and time-consuming (Tuomi *et al*. 2011). Topography influences climatic conditions, soil formation runoff, erosion seed migration and soil water infiltration, and thus affects vegetation distribution (Moeslundetal., 2013, Grzyl, Kiedrzyński, Zielińska, and Rewicz, 2014)

1.3 Justification of the study

It is important to determine carbon storage capacity of wooded grassland taking into account the heterogeneity of wooded grassland and thus determinations of SOCs changes in wooded grassland are of perilous importance since they are the key drivers of climate change. Therefore, accurate measurement of the soil organic carbon and GHGs fluxes is critical in assessment of SOCs, SWB and GHG budget of terrestrial ecosystems for interventions. Good understanding of the relationships between SOCs, SWB and GHGs fluxes with wooded grassland topography and vegetation cover types would be helpful in the management of wooded grassland for improved carbon sequestration and development of global warming mitigation measures, soil water balance management.

1.4 Objectives

1.4.1 General objective,

To determine the influence of topography and vegetation cover types on soil organic carbon stocks, soil water balance and greenhouse gas fluxes for accurate reporting and sustainable management of wooded grasslands

1.4.2 Specific objective,

i. To determine the influence of topography and vegetation cover on soil organic carbon stocks in wooded grasslands

ii. To determine the effects of topography and vegetation cover on soil water balance in wooded grasslands

iii. To determine topographical and vegetation cover influence on carbon dioxide, nitrous oxide and methane, gas fluxes

1.5 Hypothesis

i. Topography and vegetation cover have an influence on soil organic carbon stocks in wooded grasslands

ii. Topography and vegetation cover have an influence on soil water balance in wooded grasslands

iii. Topography and vegetation cover have an influence on methane, carbon dioxide, and nitrous oxide , gas fluxes in wooded grasslands

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Wooded grassland

Wooded grasslands are ae characterized by a continuous grass cover with dwarf trees, palm trees trees(≥ 7 m tall), and or shrubs (≤ 2 m) covering between 10 and 40 percent of the ground, with growth patterns that are closely linked to sporadic rainy and dry periods ((Eldridge 2011, Kindt *et al*., 2015) (Fig. 2.1)..

Figure 2. 1:Wooded grassland (source Eldridge 2011)

In Eastern Africa, 75% of the grassland is dominated by either grassland or grassland with changing measures of woody vegetation inside or over the grass layer giving ascend to wooded grassland (Reid *et al*., 2005). Woody plant intrusion into grass-dominated ecosystems has been vital driver to global land cover changes over a century(Asner et al., 2003). Throughout the world woody plants have increased in savannas and grasslands , and this has altered the abundances of woody due to the interactive changes in climatic, fire regimes and grazing and a (Jackson *et al*. 2002). Woody encroachment and thickening have converted grassland to woodland (Van Auken, 2009). Increase in woody plant density has been a problematic issue in grassland and savanna, ecosystems trees, shrubs and thicket species occupy open grasslands condense up in wooded areas forming woodlands (Saintilan and Rogers 2015). Woody plant invasion has taken place in many parts of the world; Africa included (Sankaran *et al.* 2005). Recently, intensification in woody cover has been detected in savannas globally (De Boer *et al*., 2011). Wood plants increase has been owed to overgrazing, thus increasing grass impermanence and favoring woody vegetation (Kindt *et al*., 2015) (Table 2.1). Soil water use rises with CO_2 (De Boer *et al*., 2011), , increased concentration of CO_2 leads to a change in grass –tree water competition (Kgope *et al*., 2010). In African savannas, ecological condition, alters CO_2 concentration in turn affects woody plant growth (Bond *et al*., 2010). These alterations have a greater effect on overall precipitation and biogeochemical cycles and overall productivity of grasslands (IPCC, 2007).

Table 2. 1 Classification of woody vegetation found in grasslands Source (Kindt et. al., 2015)

Type of woody vegetation	**Stand**	**Height of trees**	**Location**	**land coverage**
Closed forest	Continuous stand	10m	Central region, Rift Valley of Kenya and few in the coastal and western region	1,247,400ha
Woodlands	Open stand	<8m	Transition Between semi-humid and semi-arid -Rift Valley, Coastal region and traces in North-eastern region	2,092,600 ha
Bushland	Open stand	3-7 m	North Eastern, Coast, Rift Valley, and Eastern regions	24,629,400 ha
Shrub lands	Open/closed	2m	Unknown	Unknown
Wooded grassland	Trees	≥ 7 m	ASALs of Rift Valley, North Eastern and Eastern regions	10,600,000 ha
	Bushes	3 - 7 m		
	trees/shrubs /Dwarf trees	≤ 2 m		

2.2 Vegetation types in wooded grassland savannah and their distribution

Vegetation cover types can be classified based on through reference to its traits but their distribution spatially is primarily determined by rain and soil features (Stavi *et al.*, 2008*)*. Remote sensing technology providesa concrete and efficient means of studying changes in vegetation cover, in larger areas (Langley *et al.* 2001). Mapping and classification of vegetation are key for ecological resources management since it provides the basis for human and thus have a key role in climate change globally by affecting GHG emissions (Xiao *et al.* 2004). Woody cover mapping over huge areas is achievable through the use of remotely sensed data and techniques. In addition, the only feasible technique of mapping and monitoring woody vegetation cover over large zones are Earth Observation (EO) technologies . On the other hand, to map and monitor the extent of woody cover and its temporal changes landsat data have been employed (Symeonakis and Higginbottom, 2014). Grassland mapping and detection is mainly integrated in land cover classification initiatives at global, national and regional scales (Halabuk 2015**)**. Mapping of vegetation cover types via remotely sensed data could then be a good start for documentation of the vegetation categories that exist and it requires less time as compared to when only field investigations are used (Schmidt et al. 2004). Advantages of remote sensing coupled with Geographic Information Systems (GIS) in mapping, monitoring and detecting land use land cover dynamics was acknowledged by other Researchers (Rouchdi et. al., 2008). In ecosystem mapping approach factors, such as; landform, climates, floral and faunal are often emphasized (Olson *et al*., 2001). Remote sensing method in combination with satellite imagery approach is often used in global land cover datasets creatin describing spatial patterns in vegetation, abiotic and anthropogenic features (Bontemps *et al*., 2011).

2.3 Soil organic carbon stocks, soil water balance and GHGs fluxes in wooded grasslands

2.3.1 Soil organic carbon stocks

Soil organic carbon is the constituent part organic matter that contains plant and animal residues produced by soil microbes at exclusive stages of decomposition (Esmaeilzadeh and Ahangar, 2014). Soil organic carbon (SOC) plays essential position in improving soil quality in ecosystems and mitigating global warming through soil carbon (C) sequestration (Zornoza et al., 2015). SOC is of significantly importance in soils due to its high cation exchange capability (CEC) which impacts plant nutrients availability and microbes' activity (Liao et al., 2015). Soil carbon storage plays a key part on lowering global warming and climate change (Singh and Ryan, 2015). Soil consists of the third largest global carbon stock and releases approximately 4% of its pool into environment yearly (Li et al., 2014).

Generally, wooded grassland soils can sequester approximately 194 billion tons Carbon, accounting for 8 percent of the world soil carbon (IPCC, 2001). Carbon sequestered in soils is the major C pool in most terrestrial systems sequestering approximately 1500 Pg C doubling the entirety of carbon in the atmosphere and thrice the amount in vegetation (Lal, 2004). Large acreage covers of perennial vegetation in grasslands account for the potential to sequester carbon due to high residue inputs and reduced turnover (Blair *et al*., 2006). Soil organic carbon concentration is the main constituent of soil organic carbon stock (Don *et al*., 2007), and its spatial distribution is linked to variations in ecological aspects (Wheeler *et al*., 2007; Throop and Archer, 2008).

Though most of the studies give emphasis to the spatial variability of the soil organic carbon stock (Fang *et al*., 2010; Matsuura *et al*., 2012), there is still insufficient data in this respect, particularly wooded savannah biomes. In wooded grasslands, the type and diversity of plant species play a key role in carbon transfer into the soil (Steinbeiss *et al*., 2008). The topography collectively with elevation, performs vital role in respect to temperature and moisture content because of variations in microclimate impacts the distribution of plants and soil properties (Bochet, 2015). The temperature reduction with slope decreases organic matter decomposition rates than litter production, and consequently increases the buildup of SOC that plays a key part as sink for atmospheric CO_2 that is stored in soils as SOC (Banwart et al., 2015). Topographical position can also affect stocks in that it increases along the toe slope because of the deposition of soil eroded from higher topographic positions or decrease at higher topographical positions because of erosion or, in the case of significant elevation adjustments, corresponding changes in the climatic situations (Fernández-Romero et al., 2014).

Topography, climate and soil factors as drivers of spatial heterogeneity of SOC content in Semi-Arid grassland ecosystems are misinterpreted (Yang *et al*., 2014). Garcia-Pausas *et al*. (2007) stated that topographic zones are vital factors for accurate estimates of soil carbon stocks in grassland. Carbon sequestration is responsible for moderation of the increase in atmospheric carbon dioxide but the exact size and distribution of this sink for remain unclear (Janssens *et al*., 2003). To offer governments and other stakeholders with the fundamentals for operative policy drafting with regard to Emissions Trading Scheme (ETS) soil researchers are faced with the challenge of ascertaining and computing the fluxes of soil GHGs, therefore, steady, implementable and cheaper methodologies and procedures for monitoring SOC stocks need to be developed (Eleanor and Willgo 2010).

Additionally, IPCC 2007 report projected that approximately 5 $GtCO_2$-$eqyr^{-1}$ is stored in soils (Smith *et al.* 2007). SOCs has been taken as part of a resolution to increasing atmospheric levels of CO_2 (Lorenz *et al.* 2007). Reduction of carbon dioxide emissions could be reduce the effects of global warming and thus increased SOCs globally (Solomon *et al*., 2007). Assessing soil carbon changes is difficult due spatial variability of carbon stocks (Tuomi *et al*. 2011). Procedures should be implemented to minimize the influence of spatial variability with repetitive sampling over time (Conant and Paustian, 2002). Gas concentration measurements errors results from errors arising from both sampling and analysis\ (Parkin *et al*., 2010).

2.3.2 Soil water balances

Calculating the hydrological balance in ASALs is critical as climate variability and water shortage bring about water use conflicts (G¨untner *et al*., 2004). The soil water balance of ASALs catchment is expressed using direct and base flow factors from topography, soils, plants, land use and weather (G¨untner and Bronstert,2004). Soil water infiltration is an element of aboveground biomass (increase with biomass) and precipitation, water is dispersed from top soil to the diverse layers whereas excess water is drained to subsoil (Falloon 2001). Soil characteristics have an effect on soil water content but direct measurement of soil water content is hard, costly and consumes time for researchers particularly on a relatively large scale (Wang *et al*., 2018). Most regional investigations of SOC dynamics also overlook exchanges between spatial units, which are important for procedures such as water, soil erosion and vaporous element transmissions (Conant and Paustian 2002). soil moisture content changes over time are higher under tree coverage than grasses (Wilson 2000). Soil water content temporal patterns differ among various types of vegetation nonetheless the magnitude and direction of different vegetation types is uncertain(Sarah *et al*., 2003). For a good strategic management of water resource for sustainable land use in arid and semi-arid zones, as well as for soil and water conservation it is important to Estimate of soil water content in deep soil profiles (Aijuan *et al*., 2016). Soil water content, have an effect on GHG emission rate (Alejandro *et al*., 2010).

Measuring the water budget in ASALs is vital as climatic variability and water scarceness often lead to fights concerning water uses (Benke *et al*., 2008). Water resources in ASALs have received little attention mainly due to lack of experimental data (Andersen, 2008). Numerous approaches have been applied to estimate the components of water phases with varying degrees of success (Song *et al.*, 2009).

The hydrological procedures are normally determined by way of vegetation, topography and soil characteristics (Pellant *et al.*, 2005). The plants, landscape and soil are closely linked to infiltration, soil loss and runoff (Wilcox, *et al*., 2006). Increasing the plant cover has been widely endorsed for its various benefits, which include soil loss regulation, runoff and sediment decrease, as well as hydrological regime regulation (Yu *et al*., 2013). The plant droppings, roots and cover are believed to have an upshot on the soil loss by using obstructing crust formation, leading to an increase in the extent of interception, a lowering in raindrop power, and a growth within the soil's capacity to absorb up rain (Durán, *et al*., 2008). Vegetation decreases runoff by improving the surface roughness and soil pore spaces. Additionally, plants stabilize the soil with their roots and decrease the raindrops impact with their cover (Aghabeigi Amin *et al*., 2014). Moreover, vegetation creates a bodily barrier that could retain sediment on the soil (Martínez, *et al*., 2011). Improving plant cover can led to runoff generation and erosion manipulate (Cantón, *et al*., 2011). The quantity of water infiltrating the soil surface has a direct impact on soil and groundwater recharge and the runoff (Liu et al., 2012). Aghabeigi Amin *et al*., (2014) showed that topography have strongly and significantly affected runoff and sediment yield. Slope period and steepness and rainfall depth, are crucial factors influencing runoff and soil loss.

2.3.3 Greenhouse gas fluxes

In spite of the fact that the affects vegetation cover on the global average surface albedo and on the environmental concentration of CO_2,N_2O) andCH_4 has been incorporated into international climate change appraisals (IPCC, 2001). Less consideration has been paid to the role different in local temperatures, precipitation, vegetation and other climatic factors, especially in ASALs (Keppler et al., 2006). Grasslands play part in climate and overall C. cycle globally (Saggar *et al*., 2007). CO2 and CH4emissions resulting from the break-down of organic matter in soil contributes to about 20% of the global warming (Thum *et al.*, 2011). Facts on the conversation of GHGs; CO_2,N_2O) andCH_4 still remains inadequate for wooded savannah, while other ecologies sequestering huge quantities of carbon have been explored (Merbold and Wohlfahrt 2012) and thus monitoring gas fluxes at a regional scale result exists large uncertainty (Chapuis-Lardy *et al*., 2007). Henceforth, it was important to quantify N_2O, CH_4 and CO_2 emissions from grasslands for a more precise assessment and to gain a better understanding of the grassland ecosystems potential for climate change mitigation in future (Saggar *et al*., 2007).

GHG emissions changes approximation procedures have been developed, nevertheless, the commended Tier I, resulted to substantial faults from certain conditions and other factors emission (IPCC, 2006). Tier II developed for agricultural systems in some countries, depending on specific measurements of a country-provided a more accurate estimations of emission but may not apply for climate change projections since they were developed from specific climatic conditions (Smith *et al*. 2010). Soil biomass estimation can be a significant component of biomass studies of grassland but field-based measurements are laborious and difficult (IPCC 2004). With the help of organic matter turnover simulation models, allow forecasting of SOCs changes as a result of climate change (Knorr *et al*. 2005) will be possible. Soil carbon models are used as an substitute to counterpart repetitive SOC records and report soil carbon stock changes (Peltoniemi 2006**)**.

Nitrous oxide flux rates and production of from the soil are determined basically by reactive N availability , soil aeration and diffusivity (Balaine et al. 2013), which can be associated with soil water content and texture. Soil pH, carbon and temperature, , changes with land-use slope position and soil texture (Baggs and Philippot, 2010), thus effect N_2O production. soil emissions have proceeded to increase annually and therefore should be taken into consideration as one among the most important contributors of CO_2 emission to the atmosphere (Bond-Lamberty and Thomson, 2010). The surroundings within have unique variables which increases soil respirations (Raich and Tufekcioglu, 2000). Soils rich in organic carbon have an increased decomposition rate thus increasing the soil respiration (Bailey *et al*., 2009). SOC provides essential power for soil microorganisms responsible for denitrification (Farquharson and Baldock, 2008), and has been related to elevated soil N2O emissions (Mander *et al*., 2008). SOC in addition creates condition best for anaerobic microbial through reduction O_2 via growing cardio microbial activity (Farquharson and Baldock, 2008).

Plant cover effectively slows down microbial denitrification, through absorption of the available nitrogen and reducing soil temperature (Fortier *et al*., 2010). But according to Picek *et al*. (2007) GHG emissions increased due to vegetation and increased microbial decomposition of the root exudates. Denitrification is driven by the carbon within the soil (Mander et al., 2008). Moreover, increased N_2O emissions have been reported in grassed as compared to tree cover (Kim et al., 2009). Vegetation is the primary nitrogen sinks and influencer of soil NO_3-concentration (Compton *et al*., 2003). Soil CH_4 emissions in natural systems had been proven to differ with vegetation cover (Smith *et al*., 2003). few studies have been conducted on soil CH_4 emissions from wooded grasslands; but depending on the soil moisture act as sinks and source of Methane (Teiter and Mander, 2005). Vegetation cover and \ density magnitude have led to an influence on soil CO_2-C emissions, since reduced vegetation cover results into favorable conditions for soil respiration, and density improves on root respiration (Shresthra et al., 2009). Increased plant litter and organic residues lead to improved decomposition and thus CO_2 emissions (Oelbermann et al., 2015). Reduced vegetation cover also leads to increased soil CO_2 emissions, as reduced vegetation cover result into favorable soil situations for respiration (Shresthra et al., 2009).

CHAPTER THREE

3.0 BULK DENSITY AND SOIL ORGANIC CARBON STOCKS AS INFLUENCED BY TOPOGRAPHY AND VEGETATION COVER AT DIFFERENT SOIL DEPTHS WOODED GRASSLANDS

Abstract

Data on soil organic carbon stock (SOCs) in wooded grassland is important for assessing its contribution towards offsetting greenhouse gas emissions through carbon sequestration. Understanding the topographical and vegetation cover effect on SOCs and bulk density is therefore essential for adopting suitable strategies for reducing greenhouse gases emissions but little has been done to ascertain this. A study was therefore conducted during the short (SRS)and long rainy (LRS) seasons of 2016 in wooded grasslands of Ilmotiok community ranch in Laikipia County to determine the topographical and vegetation cover effects on soil organic carbon stocks (SOCs) and bulk density (BD) at different depths. Randomized completely block design was used; the main plot was topographical zones (TZ); mid slopes (MS), foot slope (FS), toe slope (TS) and subplots vegetation cover (VC); tree (TR), grass (GR), bare (BR). Three transect lines (replicates) of 150 m across the different topographical zones was drawn, blocking was done after every 50m.   Soil sampling was done on 1m^2 along the transect zigzag style to a depth of 50 cm at an interval of 10 cm using soil auger. The samples analysis for texture, bulk density (BD) and soil organic carbon (SOC) concentration was done in the lab. SOCs were calculated from BD and SOC concentration and respective depths.TZ, VC, depth and TZ*VC significantly ($p<0.05$) influenced BD and SOCs. There was a significantly higher bulk at MS (1.03 g/cm^3 and 1.00 g/cm^3) but not significantly different from TS (1.02 g/cm^3 and 0.92 g/cm^3) with FS having the lowest value (0.97 g/cm^3 and 0.88 g/cm^3) for LRS and SRS respectively. Vegetation cover significantly ($P < 0.05$) influence with highest bulk density recorded under BR (1.04 and 0.96 gcm^{-3}) which was not significantly different from TR (1.01 and 0.92 gcm^{-3}) and significantly higher than GR (0.97 and 0.92 gcm^{-3}) for LRS and SRS respectively. The interaction of topography and vegetation significantly influence bulk density with highest value recorded under FS*BR (1.11 and 1.03 gcm^{-3}) for LRS and SRS respectively. Highest soil organic carbon stocks were recorded at the TS (6.40 MgHa^{-1} and 6.51 MgHa^{-1}) as compared to other zones though not significantly different from MS (6.16 MgHa-1 and 6.46 MgHa-1) but significantly different from FS (5.29 MgHa-1 and 5.93 MgHa-1). SOCs under GR (6.31 MgHa-1 and 6.53 MgHa-1) were slightly higher than other vegetation cover, the lowest was recorded under BR (5.76 MgHa-1 and 6.02 MgHa-1) for LRS and SRS respectively. The upper soil depth (0-10) had (8.70 MgHa-1 and 8.74 MgHa-1) compared to the lower depth (40-50) with (3.52 MgHa-1 and 4.07 MgHa-1). Topography and vegetation have an effect on soil organic carbon stocks and bulk density. Toe slope and grass significantly increased soil organic carbon stocks and reduced bulk density.

Keywords: carbon sequestration; topographical zones; vegetation cover; wooded grassland

3.1 INTRODUCTION

Wooded grassland holds great potential for carbon sequestration that is vital in global climate change mitigation through removal of atmospherically carbon by higher than ground biomass and transferred into vegetation and soil pool for future storage (Yafeng et al., 2011). In Kenya, wooded grasslands savanna is primarily placed within the ASALs that represent over 80 percent of the entire area (UNDP, 2009). Data on SOCs by vegetation type is vital for the enactment of policies for reducing emissions from forest degradation and deforestation (REDD+) but, unfortunately, there is no data on SOCs and biomass (Amara *et al*., 2019). They therefore are vital in mitigating global climate change. Currently there is a widespread acknowledgement that exploiting soil C storage offers a theoretically essential way of offsetting atmospheric C levels and thus aid in alleviating the effects of climate change induced by anthropogenetic (Smith, 2012; IPCC, 2014). However, their potential has not been totally assessed because wooded grasslands are heterogeneous, each in temporal and spatial dimensions (Yafeng et al., 2011). The spatial heterogeneousness results from the changes in micro-climate, physical landforms and precipitation which creates an inclined distribution of soil wetness and nutrients that influence carbon sequestration whereas time-based heterogeneousness arises from seasonal distinction in productivity influenced by variation in vegetation patterns (Nori 2006).

The spatial pattern of SOC concentration is influenced by topography through their influence on soil and vegetation cover distribution (Nori 2006). Topographic positions are therefore necessary factors for precise estimates of C stocks in wooded grassland savanna. In addition, vegetation is taken into account as a main factor regulating SOC stocks in ASAL wooded grasslands savanna. In this savanna, the plant species type and variety play a key role in soil carbon transfer (Steinbeiss et al., 2008). Often estimations of soil carbon stocks in wooded grassland savanna seldom take into account the difficulties ensuing from wooded grassland non-uniformity and therefore adopt homogeneity (Dabasso et al. 2014). Past studies conducted in wooded grasslands of Arid and Semi-arid areas took them as uniform zones aside from heterogeneous zones with completely different geographic zones and vegetation cover types (Dabasso et al. 2014).

Hence, most studies done at numerous scales to approximate SOC exploitation simply obtained., environmental condition, and remotely perceived information. Thus, results in inaccurate reporting of the carbon sequestration and false illustration of the wooded grasslands savanna. Additionally, most analysis has primarily targeted on the relation of SOC stocks to environmental conditions, changes of SOC stocks underneath ever-changing climate conditions and management (Don et al. 2011). To enhance on the accurate value of regional carbon budgets and development of effective ecological restoration measures hence it is necessity to include and perceive wooded grassland as non-uniformity and thus have different spatial pattern characteristics (Wang et al., 2018). Therefore, this study determined the influence of topography and vegetation cover of wooded grassland savannah on soil organic carbon stocks at different soil depths.

3.2 Materials and method

3.2.1 Study Site

3.2.2 Geography and topography

The research was carried out in Kenya's Laikipia County's Ilmotiok community ranch. The ranch lies between latitudes (00 17 S) and (00 45 N) and longitudes 36015E and 37020 E. The County is located across the Equator (Figure 3.1) and covers 9500 km^2 and is part of the larger Ewaso Ng'iro Ecosystem. The ecosystem stretches from the slopes of Mt. Kenya (5199 m) in the south to the margin of the Great Rift Valley. Its escarpment descends into the parched terrain of northern Kenya in the west [Ojwang et al., 2010, Lalampa et al., 2016].

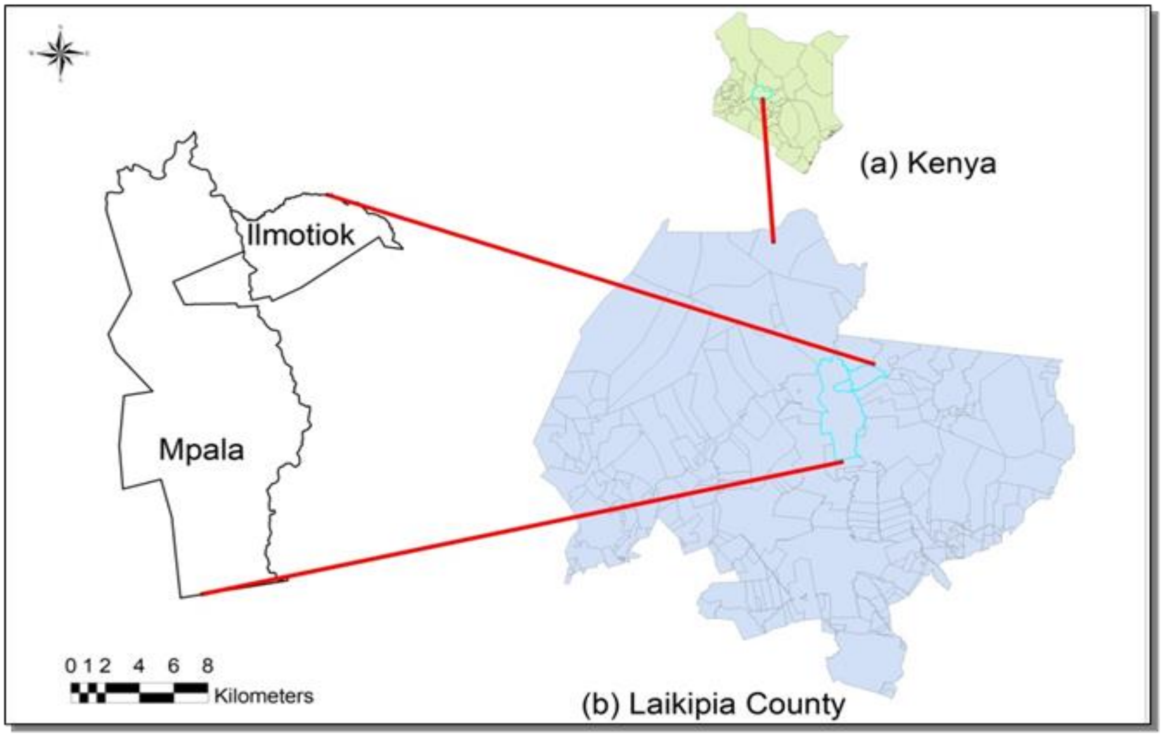

Figure 3. 1 Map of Kenya showing position of Laikipia County and the study site Ilmotiok community ranch Source Ojwang et al., 2010

Laikipia County has a two rainfall patterns, with long rains forecasted from April to May and short rains expected in August and October (Jaeztold and Schmidt 2006). The rain, on the other hand, is highly erratic and could fall at any moment during the year. The rainfall in Laikipia is relief-type, with Mt. Kenya and the Nyandarua Ranges exerting significant effect [Aberdare Ranges].

The rainfall distribution and pattern during the study period was recorded using a rain gauge placed at Mpala research Centre (Fig. 3.2), 1 km away from the exploratory plots [Ilmotiok community ranch].

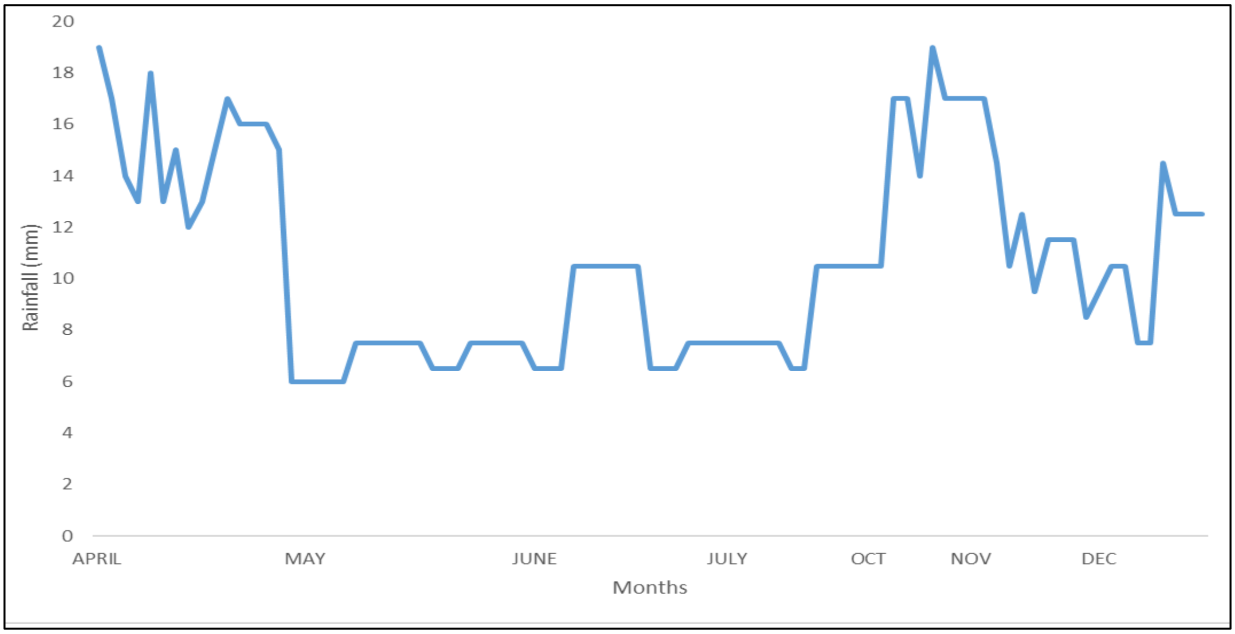

Figure 3. 2: Rainfall amounts received over the experimental period

The vegetation of the area is a mosaic of dry forests, woodland, wooded grassland and grasslands, which is a reflection of rainfall, soil, topographical gradients and human activities. Ranching, ranching and wildlife, farming, pastoralism and cultivation, pastoralism and wildlife, woodlands, wetlands, and urban centers are among the area's socioeconomic activities. The wetter southern parts of the county are mostly occupied by small-scale arable farmers, while commercial cattle ranchers occupy the intermediate areas, and pastoralists use the dry north [Ojwang et al. 2010].

3.2.3 Study approach

The study consisted of soil sampling and analysis.

3.2.5 Experimental layout and sampling

RCBD with split plot arrangement was used; with variation in topographical levels; mid slope (MS), foot slope (FS) and toe slope (TS) as the main plots and the subplots were the vegetation cover types; Tree (T), Grass (G) and Bare (B) as the control. Blocking was done along the transect line after every 50m. A total three transect line measuring 150m long were drawn for each topographical zone as replicates (Table 3.1). The assessments of soil BD, SOC concentration and SOCs were done for two consecutive rainy seasons of long (LRS) and short rain seasons (SRS) in of 2016.

Table 3. 1: Experimental design

150 m transect line

Zone	**Rep**	**Block 1**	**Block 2**	**Block 3**
		50m	**50m**	**50m**
Mid slope	**Rep 1**	**GTGGTG BGTTG**	**TGBTTGTGTGBB**	**GTGGTG BGTTG**
	Rep 2	**GTGBBGTGTGB**	**TTGTGTGBBBG**	**TGBTTGTGTGBB**
	Rep 3	**GTGGTG BGTTG**	**GTGBBGTGTGB**	**TGBTTGTGTGBB**
Foot slope	**Rep 1**	**GTGGTG BGTTG**	**TGBTTGTGTGBB**	**GTGGTG BGTTG**
	Rep 2	**GTGBBGTGTGB**	**TTGTGTGBBBG**	**TGBTTGTGTGBB**
	Rep 3	**GTGGTG BGTTG**	**GTGBBGTGTGB**	**TGBTTGTGTGBB**
Toe slope	**Rep 1**	**GTGGTG BGTTG**	**TGBTTGTGTGBB**	**GTGGTG BGTTG**
	Rep 2	**GTGBBGTGTGB**	**TTGTGTGBBBG**	**TGBTTGTGTGBB**
	Rep 3	**GTGGTG BGTTG**	**GTGBBGTGTGB**	**TGBTTGTGTGBB**

Table 3. 2: Land cover determination

Land cover type	Abbrev.	Units	How and tools used
Tree	T	% Area	Visual estimate based on the (20x20 m) subplot area
Grass	G	% Area	Visual estimate based on the (20x20 m) subplot area
Bare	B	% Area	Visual estimate based on the (20x20 m) subplot area

3.2.2 Topography (% slope and elevation)

Percentage slope was estimated using clinometer and dynamic telescopic measuring rod, while elevation was measured using GPS receiver.

3.2.6 Soil sampling and analysis

Sample were taken at 50 m intervals in the transect line 3 sampling points were identified from an area of 1 m^2. Samples were taken from a depth of 0-50 cm at an interval of 10 cm in in a Zigzag style using a soil auger. 500 g sample was pooled into a small paper bag from three sub-samples collected from the sampling points then mixed, and labeled to indicate vegetation type and topographical position. The samples were analyzed for soil texture, pH and Soil Organic Carbon (SOC).

3.2.7 Soil texture determination

Hydrometer method was used to determined soil texture. The samples with Calgon solution were shaken for 6 hours in a mechanical shaker**.** After 40 seconds measurement of silt plus clay was done and after 2 hours clay. the difference obtained from the two became sand fraction. USDA textural triangle was used to read textural classes (Fig.3. 2)

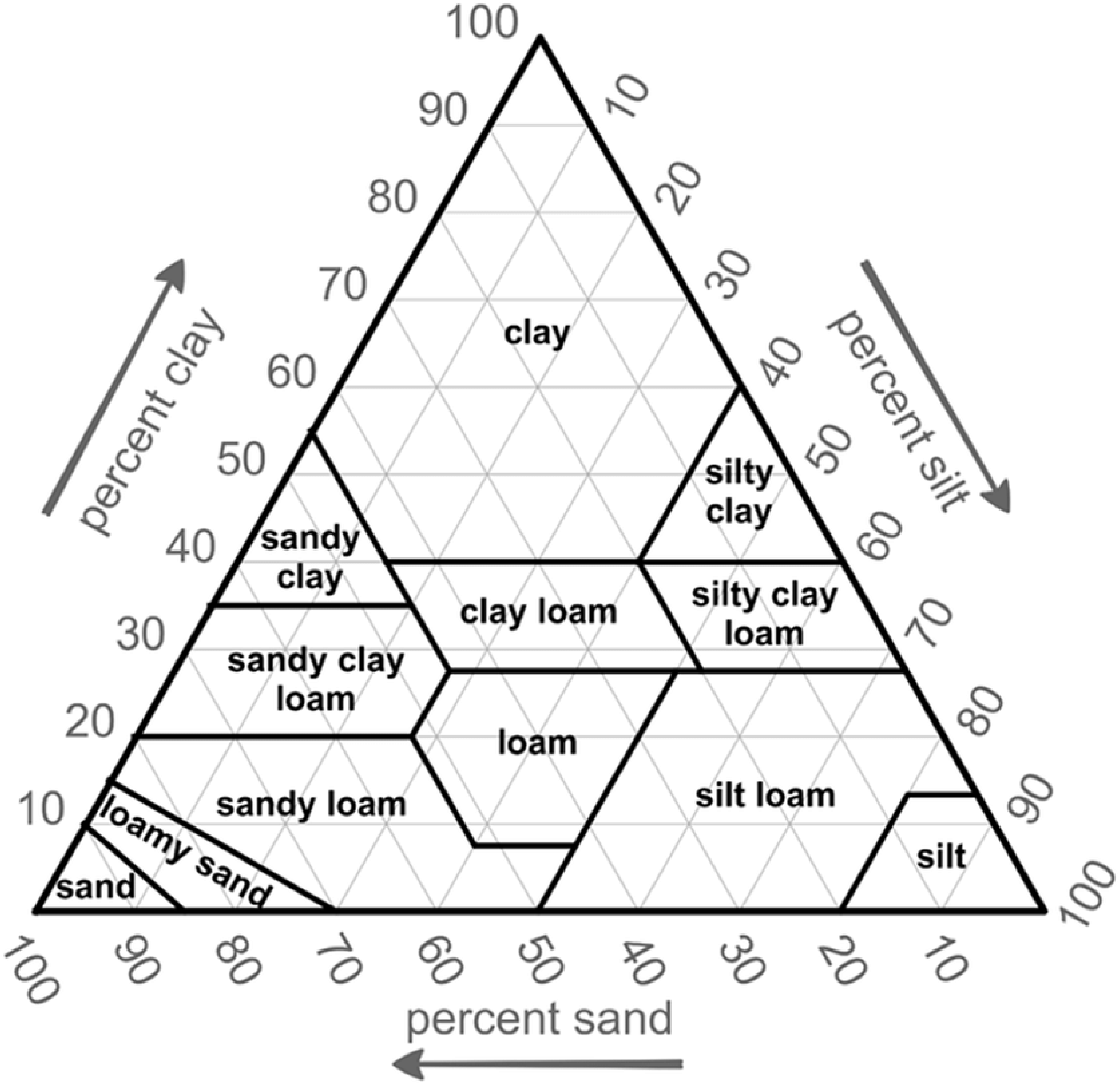

Figure 3.2: Soil textural triangle (Source: Okalebo 2002)

3.2.8 Bulk Density (BD) determination

Core rings with known dimensions were used to collect the samples. Coring ring were driven the into the soil using hand sledge and a block of wood to take the soil samples at each depth. Methodology described by Cresswell and Hamilton (2002) was used to analyze soil BD. Oven dried container was weighed before the soil was transferred. Then the container and soil were dried for 24 hours in the oven at 105^o C. The soil and container were cooled after removing from the oven in a desiccator then weighed and recorded.

Soil BD (g/cm^3) then calculated as shown (Eq 3.1):

$$\text{BD Sample} = \frac{\text{ODW Sample}}{\text{CV Sample}} \qquad \text{(Equation 3.1)}$$

Where;

BD Sample is the bulk density (g cm^{-3}) of the soil sample, ODW Sample the mass (g) of oven dried soil core and CV Sample core volume (cm^3) of the soil sample.

3.2.9 Soil reaction (pH) determination

Glass electrode pH meter was used to measure the pH on 1: 2.5 ($^w/_v$) soil suspended of in water, shaken for 30 minutes (Okalebo et al., 2002).

3.2.10 Organic carbon (%OC) determination

Walkley-Black method was used to estimate% OC (Black, 1965). 1 g of ground soil sieved through 0.5mm was weighed into a labeled digestion tube of 100 ml. 10 ml potassium dichromate 5% solution was added and till the soil became wet. 5 ml H_2SO_4 was carefully and slowly using burette and the mixture was then swirled gently to mix. digestion of the mixture was done for 30 min at 150 ^{O}C. cooling of the mixture was then allowed, then 50 ml of barium chloride 0.4% added, swirled to mix thoroughly, and the volume was made to 100 ml mark. A supernatant aliquot of the solution was transferred into a colorimeter cuvette, absorbance of the standard, the blank and sample were measured.

Total organic carbon was calculated as follows equation 3.2;

$$\text{Total Organic carbon \%} = \frac{(a-b) \times 0.10}{W} \qquad \text{(Equation 3.2)}$$

W - Weight of Sample, a - Blank Titre value, b - Titre value of the Sample

Soil organic carbon stock calculations

SOC stock (Mgha^{-1}=SOC (%) X Bulk density (gcm^{3}) x soil depth (cm) x cf (Equation 3.3)

Where:

SOC – concentration of soil organic carbon (%); BD– bulk density (g/cm^{3}); SD – topsoil depth (cm). *cf* is the conversion factor = (kg cm^{-3}) × (10,000 cm^{2} m^{-2}) × (10,000 m^{2} ha^{-1}).

3.3 Statistical analysis

analysis of variance (ANOVA) for the obtained data was done using General Statistics (GENSTAT) package version 19. The differences among the treatment means of the interaction of different topographical zones and vegetation cover types was compared using Fisher's Protected LSD test at 5% probability level.

3.4 Results and discussions

3.4.1 Influence of topography and vegetation cover types on soil bulk density (BD)

There was significant ($P < 0.05$) effect of topography, vegetation cover and depth and topography vegetation cover interaction on soil bulk density (Table 3.3). There was a significantly higher bulk at MS (1.03 g/cm3 and 1.00 g/cm3) but not significantly different from TS (1.02 and 0.92 gcm^{-3}g/cm3) with FS having the lowest value (0.97 and 0.88 gcm^{-3}) for LRS and SRS respectively. Vegetation cover significantly ($P < 0.05$) influence with highest bulk density recorded under BR (1.04 and 0.96 gcm^{-3}) which was not significantly different from TR (1.01 and 0.92 gcm^{-3}) and significantly higher than GR (0.97 and 0.92 gcm^{-3}) for LRS and SRS respectively. The bulk density was highest at 40-50 cm with a mean of (1.11 and 1.04 gcm^{-3}) and lowest bulk density was observed at 0-10 cm (0.90 gcm^{-3} and 0.81 gcm^{-3}) for LRS and SRS respectively. The interaction of topography and vegetation significantly influence bulk density with highest value recorded under FS*BR (1.11 g/cm3 and 1.03 g/cm3) for LRS and SRS respectively as compared to other interactions.

Table 3. 3: Soil bulk density (BD) as influenced by topographical zone (TZ) and vegetation cover types (VC) at different depths

		Short Rain Season			**Long Rain Season**		
T_ZONE	FS	0.97^{a}			0.88^{a}		
	MS	1.03^{b}			0.92^{a}		
	TS	1.02^{b}			1.00^{b}		
V_COVER	BR	1.04^{b}			0.96^{b}		
	GR	0.97^{a}			0.92^{a}		
	TR	1.01^{b}			0.92^{a}		
DEPTH	0-10	0.90^{a}			0.81^{a}		
	10-20	0.95^{a}			0.87^{b}		
	20-30	1.01^{b}			0.95^{c}		
	30-40	1.06^{bc}			1.00^{c}		
	40-50	1.11^{c}			1.04^{d}		
TZ*VC		BR	GR	TR	BR	GR	TR
	FS	1.11^{e}	0.83^{a}	0.95^{b}	1.03^{c}	1.00^{c}	0.96^{bc}
	MS	0.98^{bc}	1.08^{de}	1.03^{bcde}	0.96^{bc}	0.87^{a}	0.92^{ab}
	TS	1.02^{bcd}	0.99^{bcd}	1.05^{cde}	0.88^{a}	0.88^{a}	0.90^{ab}

T.Z –Topography zone, V.C –Vegetation Cover, FS-Foot Slope, MS-Mid slope, TS-Toe Slope, BR-bare, GR-grass, TR-tree

Means followed by the same superscript letter (within a column for each season separately) are not significantly different ($p \leq 0.05$) by Bonferroni LSD test.

The lower values of soil BD under grass cover were due enhanced micro porosity of the soil, soil aggregate and higher SOC concentration input, microclimate and soil structure improved comparative to bare land and tree cover. The same observations were made in Kenya by (Muya et al 2011) who reported lower bulk density in soils with a ground cover. The higher soil BD density under bare cover is accredited to low assimilation of OM in the soil, loss of vegetative and litter cover permitting rain drops impacts directly on bare soils resulting to greater splash impacts, hard layer formation, superficial seal that moderate soil water infiltration. Absence of plant growth on the bare ground resulted to reduced bulk density due to a decrease in root density whereas build-up of unconsolidated organic material on the soil surface from the presence of vegetation cover which led to increased root channels, thus lowering bulk density values at the surface, as was noted in the vegetated cover with grass and tree cover. The improved soil aggregation resulted from the input of OM from vegetation and hence improved soil structure and, and reduced bulk density (Muya et al 2011).

The differences in bulk density across the seasons can be attributed to low vegetation cover during the SRS as compared LRS this results into moderate water infiltration this thus indicates higher root biomass which in turn makes the soil porous thus reducing compaction by raindrops during the long rain season hence reduced bulk density as compared to short rain season. Gedir et al. (2002) also found bulk density was lowest in the long rain season. Several researchers have also found that the amount of compaction is reliant on soil water content at the time of contact (Gedir et al. 2002), with more compaction occurring under less wetter conditions. Soil bulk density changes demonstrate that bulk density can't be considered as a static soil property. It can likewise be seen that there is an expansion of it mean a reason during the low precipitation period as an outcome of contracting soil changes as contradicted in high precipitation period. The soil presents swelling and contracting developments amid the wetting and drying cycles along the diverse rainy and dry periods of the year. As stated by Timm *et al., 2006* that the presence of soil cracks because of wetting and drying cycles, causing a soil mass contracting and increasing bulk density of the soil between cracks.

The increases bulk density with soil depth was because subsurface layers have less organic matter and more condensed, reduced aggregation, and reduced root penetration in comparison to surface layers, there is more root growth at the top layer (0-10 cm) and improved total root length concentrated as observed by Trükmann et al. 2008. Increased bulk density down the soil profile at 50 cm can be attributed is as a result of soil compaction due to absence of roots. At depth 20-30 cm, however, there is a soil structure improvement and few roots, in. This is noted in the bulk density which increases with increasing soil depth. As noted by Eric et al. (2015), that this reflects the degree of soil compaction due to relatively homogenous soil physical conditions The same was also reported by Pande and Yamamoto 2006 who showed that loss of top soil through erosion escalates soil compaction and potentially increases the for severe run-off and erosion during rainy events.

The bulk density was significantly lower in the toe slope than other slopes. The toe slope areas, have a better soil water content, be richer in clay and organic matter, and successively have a better water holding capability than the upslope regions. The bulk density of the toe slope is decreases probably due to a rise in clay deposition and organic matter and therefore the ensuing increase in pore area. Stavi et al., 2008 argued that decreased bulk density in toe slope is attributed to increased clay content and because of the downward movement of water and organic matter from the higher zones.

3.4.2 Soil organic carbon stocks as influenced by topographical zone and vegetation cover types down the soil profile

Topographical zones, vegetation cover types and depth significantly affected ($p < 0.05$) the SOC stocks. Across all TZ, VC and Depth season significantly affected SOCs with highest value recorded during the LRS as compared to SRS. Highest soil organic carbon stocks were recorded at the TS (6.40 and 6.51) as compared to other zones though not significantly different from MS (6.16 and 6.46 MgHa^{-1}) but significantly different from FS (5.29 and 5.93 MgHa^{-1}). SOCs decreased across vegetation types (VC) in the order (grass>tree>bare) but they were not significantly different. SOC stocks under GR (6.31 MgHa^{-1} and 6.53 MgHa^{-1}) were slightly higher than other vegetation cover, the lowest was recorded under BR (5.76 MgHa^{-1} and 6.02 MgHa^{-1}). With regards to soil depth, the total soil organic carbon stock content varied considerably. SOC stocks significantly decreased with depth. The upper soil depth (0-10) had (8.70 MgHa^{-1} and 8.74 MgHa^{-1}) compared to the lower depth (40-50) with (3.52 MgHa^{-1} and 4.07 MgHa^{-1}) (Table 3.4).

Table 3. 4: Soil organic carbon stocks (Mg/ha) as influenced by vegetation cover types (VC) and topographical zone (TZ) down the soil profile

			Short Rain Season			Long Rain Season	
T_ZONE	FS		5.29^{a}			5.93^{a}	
	MS		6.16^{b}			6.46^{a}	
	TS		6.40^{b}			6.51^{a}	
V_COVER	BR		5.759^{a}			6.02^{a}	
	GR		6.313^{a}			6.53^{a}	
	TR		5.770^{a}			6.35^{a}	
DEPTH	0-10		8.70^{d}			8.74^{c}	
	10-20		6.90^{c}			7.22^{b}	
	20-30		5.94^{c}			6.35^{b}	
	30-40		4.67^{b}			5.10^{a}	
	40-50		3.52^{a}			4.07^{a}	
		BR	GR	TR	BR	GR	TR
TZ*VC	FS	5.32^{a}	5.63^{ab}	4.90^{a}	5.39^{a}	6.05^{ab}	6.33^{ab}
	MS	6.14^{ab}	6.22^{ab}	6.10^{ab}	6.50^{ab}	6.44^{ab}	6.44^{ab}
	TS	5.85^{ab}	7.08^{b}	6.28^{ab}	6.16^{ab}	7.09^{b}	6.27^{ab}

T.Z –Topography zone, V.C –Vegetation Cover, FS-Foot Slope, MS-Mid slope, TS-Toe Slope, BR-bare, GR-grass, TR-tree

Means followed by the same superscript letter (within a column for each season separately) are not significantly different ($p \leq 0.05$) by Bonferroni LSD test.

Higher soil organic carbon recorded within the toe slope zone was due to increased production of litter that is assimilating into the soil resulting to greatest vegetation growth at the toe slope because of longer periods of saturation giving rise to high concentrations of organic matter. Zhang et al. (2015) reported that vegetation cover changes influence SOC sequestration. The upper soil organic carbon concentrations are owed to the improved vegetation production, litter quality and nutrient sport as indicated by Zhang et al. (2015). Topography levels, defines the microclimate and therefore great determinant of vegetation distribution and therefore soil organic carbon concentration. Paul et al. (2016) conjointly linked difference in SOC concentration at totally different topography zones to the heterogeneous nature of vegetation and microclimate at different topographical zones. Various vegetation on changeable topography zones even has distinct soil surface coverage that deeply impacts SOC input, hydrological processes and thus the effect on SOC distribution (Seibert et al., 2007).

The variation SOC concentration across the seasons is owed to changes in plant biomass throughout the two-rain season (SRS and LRS. With increased biomass production throughout the LRS this translates to increased organic matter reservoir that holds the nutrients which can be decomposed by soil microorganisms therefore translating higher organic carbon content in the soil. Reeder *et al., 2004* reported that plant root residues supply soil organic matter and thus increase of below ground biomass that enhance soil organic carbon within the soil.

Higher SOC stocks were ascertained at the toe slope than different topographic zones. This might result the deposition of eroded organic carbon from the mid slope and foot slope. Toe slope are water accumulating zone thus has deeper and porous soils that encourage faster vegetation growth and thus increased biomass production thus leading to increased SOC. Schwanghart and Jarmer (2011) showed that prime SOC stocks in toe slope is attributed to enlarged status and as a result of the downward movement of water from the higher zones. Fernández-Romero et al., 2014 also reported that variation in topography means that totally different climate conditions, that hamper the vegetation cowl varieties, poignant productivity of vegetation, and more influence the organic carbon input quantity into the soil. On the one hand, it should result from SOC distribution because of the processes of deposition and s erosion, SOC depletion from wearing sites on the topography, and depositing them at the toe slope zone (Seibert et al., 2007). On the contrary, SOC enrichment at the toe slope promoted vegetation growth, increased residues and growth of the roots, hence

SOC accumulation at the toe slope (Zhu et al., 2014).

The low mean values of SOC ascertained for bare may be due to; vegetation loss ensuing to low carbon inputs from plant litter and roots, microorganism activity enlarged because of favorable soil temperature relative to tree and grass cover. Higher SOCS recorded below grass cover may also be due to increased production of litter incorporated in the soil compared to bare ground. Wang et al 2018 reported that accumulative root biomass not simply will increase soil C and N inputs retention inside the soil as a result of each organic N and C dynamics.

Higher soil organic carbon stock within the higher (0-10 cm) is as a results of leaf litter decomposition. Moreover, as a result of most organic residues area unit incorporated in, or deposited on the surface, organic matter tends to accumulate within the higher layers. This study results conforms to the research by Yimer et al. (2006), who recorded a decrease in SOC stock with increasing of soil depth implying that a lot of carbon is sequestered within the prime 25 cm with a modification in vegetation varieties.

3.5 Conclusions

Topography, vegetation cover and depth had a great effect on soil bulk density. SOC stocks decreased with increasing depth in all topographical zones and vegetation cover type. The upper soil depth (0-10) had the highest soil organic carbon stock compared to the lower depth (40-50) in all topographical zones and vegetation cover types. Interaction of grass and topography increased SOCs for instance SOCs increased within the toe slope with grass vegetation as opposed to other interactions. Wooded grassland therefore can be revegetated with grass to increase SOCs for improved carbon sequestration especially in the bare ground which recorded the lowest SOCs.

CHAPTER FOUR

4.0 TOPOGRAPHY AND VEGETATION COVER INFLUENCES SOIL LOSS AND WATER BALANCE IN A WOODED GRASSLAND OF ARID AND SEMI ARID LANDS

Abstract

To promote appropriate soil and water conservation techniques for adoption in semi-arid lands, requires in depth understanding of the influence and role of topography and vegetation cover on soil loss [SL] and water balance [SWB]. In this study we investigated the influence of topography and vegetation type on SL and SWB in a wooded grassland of Laikipia County, Kenya. An in-situ experiment was conducted in 2016 during the) short rainy season (SRS) and long rainy season (LRS). A RCBD [RCBD] with split plot layout was USED where; Topographical Zones [mid slope [MS], foot slope [FS] and toe slope [TS] were the main plots. The sub plots were vegetation cover types; tree [TR], grass [GR] and bare [BR]. Runoff plots measuring were installed to monitor runoff [RO] and soil loss [SL]. There were significant [P<.001] differences in evapotranspiration, runoff and soil loss across the three topographical zones and vegetation cover types. The run off was significantly higher in mid slope*bare [175.90 and 168.75 mm] and mid slope *grass [172.00 and 164.85mm] compared to toe slope *bare [169.79 and 162.64 mm] and Toe Slope* Grass [165.89 and 158.74 mm] during the LRS and SRS. Whereas Soil water balance was highest at the toe slope*grass [279.46 and 119.49 mm] than Foot slope*Grass [273.51 and 113.54 mm] and Mid Slope*Grass [267.23 and 104.76 mm] during the LRS and SRS respectively. The Run off Coefficient was significantly lower in the Toe slope*Grass [0.30 and 0.45] than Foot slope*Grass [0.31 and 0.46] for LRS and SRS. Toe slope with grass significantly reduced both RO and SL thus increased SWB and improved runoff coefficient. Therefore, protection of slopes from raindrops can effectively reduce soil loss and runoff and enhance deposition in the mid slope and toe slope.

Keywords: Runoff coefficient, Soil loss, Soil water balance

4.1 Introduction

Soil degradation through soil erosion impacts approximately one-sixth of the world's land surface area, with water erosion contributing to about 55.6 percent of the affected land area (Hurni and Portner 2008). The ASALs are the most vulnerable to soil degradation (Bobadoye et al. 2016). Climatically, wooded grasslands in these ASALS are characterized by extreme temperature conditions (Lalampa et al. 2016) that aggravate the agents of soil erosion. Several researches in arid and semi-arid environments have shown that vegetation is one of the most efficient techniques for reducing soil erosion threats (Veron et al 2010). By modifying heat and moisture transmission from the soil surface to the air, vegetation cover has an impact on soil erosion and the soil water balance (Acharya et al 2016). Runoff and soil loss are influenced by vegetation in a variety of ways; through vegetation structures, levels of plant diversity, and distribution patterns . Structures of vegetation, such as plant roots, litter layers, and vegetation canopies, , alter hydrological processes, patterns of rainfall redistribution, and characteristics of the soil, which affect runoff production and soil loss and water balance directly or indirectly (Li et al., 2014).

Soil water balance plays a significant role in the wooded grasslands and usually has very changeable patterns that are impacted by rainfall, vegetation cover and topography all at the same time (Vereecken et al. 2007). Vegetation and topography have been shown to have a major impact on the temporal and geographical changes in soil water balance (Lv et al 2011) with the shape and function of vegetation having an impact on RO and SL (Zhu et al., 2015). Aghabeigi Amin *et al.*, (2014) showed that topography significantly affect runoff and sediment yield. Slope period and steepness and rainfall depth, are reported to be crucial factors influencing runoff and soil loss (Bautista et al., 2007; Aghabeigi Amin *et al.*, 2014). Therefore, knowledge on the effects of Topography and vegetation cover types on soil loss and water balance is pivotal in designing sustainable management of the ASALs

Most of the earlier research focused on the role of vegetation in relation to a specific feature, failing to clearly describe how vegetation and topography interact to affect runoff, soil erosion and soil water balance (Aghabeigi Amin *et al.*, 2014). Assessing soil water balance is critical for effective water resource management in dry and semi-arid zones (Aijuan et al. 2016). This study was done to determine the effects of topography and vegetation cover on soil loss, runoff, and soil water balance in a wooded grasslands for informed management of degraded the ASALs.

4.2 Materials and methods

4.2.1 Study Site

Refer to section 3.2.1

4.2.2 Research design

The study employed a RCBD with a split plot layout. The primary plots were variations in topographical levels; mid slope [MS], foot slope [FS], and toe slope [TS], and the subplots were vegetation cover types; Tree [T], Grass [G], and Bare [B] as the control. As duplicates, three 150-meter-long transect lines were created for each topographical zone.

4.2.3 Vegetation cover types delimitation

Vegetation cover types (Tree. Grass and Bare) were determined as the percentage of the selected area through visual estimate based on the [20x20 m] subplot area.

4.2.4 Topography [% slope and elevation]

Percentage slope (Table 4.1) was estimated using a clinometer and dynamic telescopic measuring rod, while elevation was measured using GPS receiver.

Table 4. 1: Description of the Topographical zones

Topographic Zones	Slope [%]	Soil texture	Vegetation cover	Surface characteristics
Mid slope [MS]	>10	Sandy-silt, loams, gravel and stones	High coverage of bare grounds	Gravel and stones, erosion features, removal of top soil
Foot slope [FS]	5-10	Sandy clay soils	High grass vegetation cover and medium tree/woody vegetation cover	Medium bare ground areas
Toe slope [TS]	<2	Sandy clay, Wet soils,	High coverage by tree/woody vegetation, high canopy shade cover	Deposited soil materials from upstream

4.2.5 Experimental plot, Runoff and soil loss measurements

Twenty-seven test runoff plots measuring [4m by 8m] were set up in three topographical zones on different vegetation cover types replicated three times. A concrete stone build barrier was put in place to ensure that only the soil loss and runoff from the plot were collected [Figure 4.1]. At the base of the plot, a canal, intended to slant towards one end, was introduced to gather and pass on spillover into a 200-liter tank for overflow and soil loss capture via drainpipe. Two tanks were put in place in the event of heavy rainfall, the second tank served as an overflow basin, collecting the runoff overflowing from the first tank via a slot division. To assess soil loss, one-liter discharge from each erosive rainfall event was taken and converted to Kgha^{-1}. The runoff sample was then filtered using WhatmanTM paper, dried for 24 hours in an oven- at 105°C, and weighing balance was used to determine the weight. The laboratory analysis was carried out at the University of Nairobi's Kabete soil chemistry and physics laboratory. Total seasonal RO [in liters] was calculated from each runoff plot by weighing total runoff collected from each erosion event from the runoff plot's base .

Figure 4. 1 Runoff plots a] runoff plot b] drainpipe c] construction of the runoff plots d] water tank

4.2.6 Evaporation/Evapotranspiration determination

Seasonal evaporation was measured in mm using a Standard Evaporation Pan [Pan A] having a protective wire mesh. A pan was placed under each vegetation cover including the bare ground. The data consisted of seasonal total evaporation estimates and the total rainfall recorded.

It was then calculated as difference in water level in the pan using equation 4.1:

$$E = P \pm \Delta d \quad \text{Equation 4.1}$$

where P is precipitation during the period, and Δd is water added [+] to or removed [–] from the pan.

4.2.7 Soil water balance determination

Soil water balance was calculated for each vegetation cover type under different topographical zones by subtracting the total seasonal runoff and evaporation from the total seasonal rainfall using the formula given by equation 4.2

$$SWB = P - SROFF - QE \quad \text{Equation 4.2}$$

Where;

SWB-soil water balance, P-precipitation/rainfall, SROFF –Soil runoff, E -evapotranspiration.

4.2.8 Runoff coefficient calculation [Rc]

The ratio of runoff to rainfall, tabulated from dividing total seasonal RO by total seasonal rainfall, is known as the runoff coefficient. The proportion of rainfall that produces runoff, as well as the infiltration and retention capacity of transpiration and evaporation, is known as the runoff coefficient. Equation 4.3 is used to express it as a percentage.

$$\text{Runoff Coefficient [Rc]} = \frac{\text{Total Runoff [mm]}}{\text{Total Rainfall [mm]}} \times 100 \quad \text{[Equation 4.3]}$$

4.2.9 Statistical analysis

Using GenStat 14th version, the effects of topography and vegetation cover on RO SL, SWB, and runoff coefficient were investigated using two-way ANOVA. The significance of differences in runoff, soil loss, soil water balance, and runoff coefficient and soil water balance between treatments was tested using Fisher's LSD test.

4.3 Results

4.3.1 Evapotranspiration, Runoff, soil loss and water balance

There were significant [P<.05] difference in evapotranspiration, runoff [RO] and soil loss [SL] across topographical zones and vegetation cover types (Table 4.1).

Evapotranspiration: evapotranspiration was significantly higher in (interactions between) foot slope*tree and for Mid slope*tree compared to toe slope*tree and other interactions during both long rain season and short rain season [Table 4.1].

Runoff: The run off was significantly higher in (interactions between) mid slope*Bare and for Mid slope*Grass compared to Toe slope*Bare and Toe slope* Grass in both long rain season and short rain season [Table 4.1].

Soil loss: Soil loss was significantly higher at foot slope*bare as compared to other interactions (Table 4.1)

Soil water Balance: Whereas SWB was highest in the TS*G than FS*G and MS*G than the interaction of TZ with T and B during the LRS and SRS respectively [Table 4.1].

Table 4.2: Runoff, soil loss and soil water balance as influenced by topography and vegetation cover across the rainy seasons

Topography zone	Vegetation cover	Evapotranspiration (mm)		Run off (mm)		Soil water balance (mm)		Soil loss (Kg/m^2)	
		LRS	SRS	LRS	SRS	LRS	SRS	LRS	SRS
MS	B	116.23	73.85	174.78*	168.75	271.01	111.04	0.062*	0.053*
	G	117.63	75.25	172.00	164.85	273.51	113.54	0.036	0.026*
	T	118.53	76.15	175.90*	167.63	269.83	109.86	0.038	0.028*
FS	B	121.67*	76.99	172.76	165.61	263.55*	104.76*	0.094*	0.085*
	G	120.77*	78.39*	168.86	161.71*	267.23	107.26	0.041	0.032
	T	119.37	79.29*	171.64	164.49	264.73*	103.58*	0.056*	0.046*
TS	B	113.26*	70.88*	169.79	162.64*	276.96	116.99*	0.040	0.031
	G	114.66*	72.28*	165.89	158.74*	279.46*	119.49*	0.028*	0.018*
	T	115.56	73.18	168.66	161.51*	275.78	115.81	0.033	0.024*

Means with * are significantly different ($p < .05$) by Bonferroni LSD test

B-Bare, G-Grass, T-Trees, MS-Mid Slope, FS-Foot Slope, TS-Toe Slope, LRS-Long Rain Season, SRS-Short Rain Season

4.3.2 Runoff coefficient during the long and short rainy seasons

Runoff coefficients were highly variable during the two study seasons, with values ranging from 0.30 to 0.31 and 0.45 to 0.48 during the LRS and SRS respectively but not significantly different. In all the topographical zones, runoff coefficient was highest in FS compared to MS and TS in both seasons (Fig.6). RC was significantly lower at the TS*G (0.30 and 0.45) than FS*G (0.31 and 0.46) and MS *G (0.31 and 0.48) for LRS and SRS respectively.

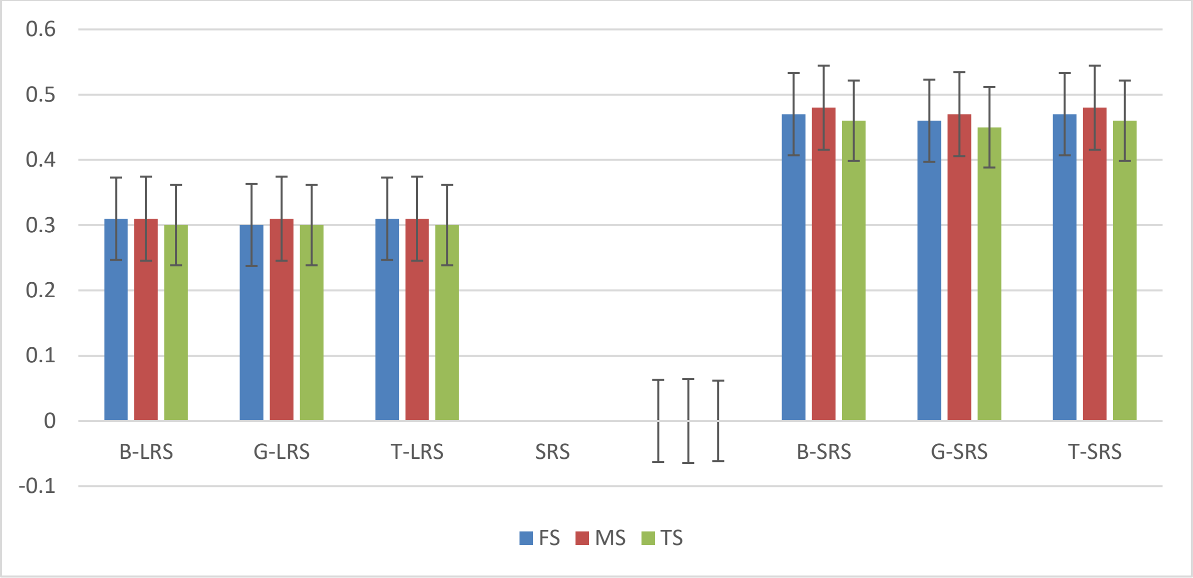

Figure 4. 2 Runoff coefficient as influenced by topographical zones and vegetation cover across the LRS and SRS

FS-Foot slope, LRS-Long Rain Season, MS-Mid slope, TS-Toe slope, TZ-topographical zone, SRS-Short Rain Season.

4.3.3 Correlations

There was a linear correlation +(R=0.46) between soil loss and runoff (Fig.4.3) and a -ve correlation (R=-0.93) for evapotranspiration and soil water balance (Fig.4.4). There was also a +ve correlation (R=0.27) for run off and rainfall (Fig.4.5).

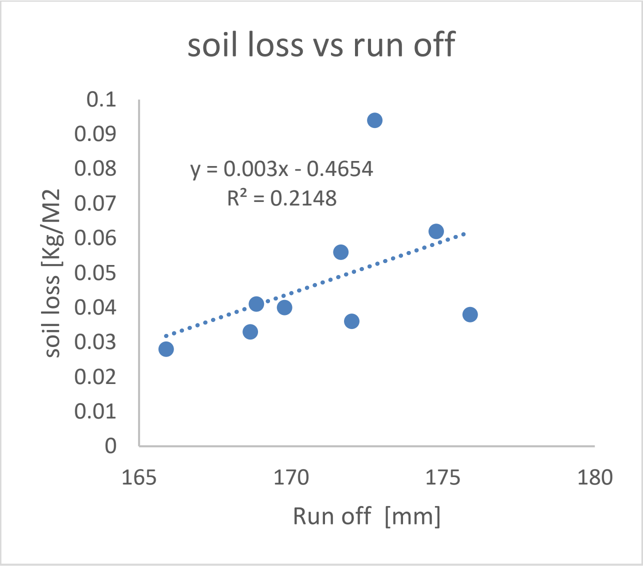

Figure 4. 3: soil loss vs runoff

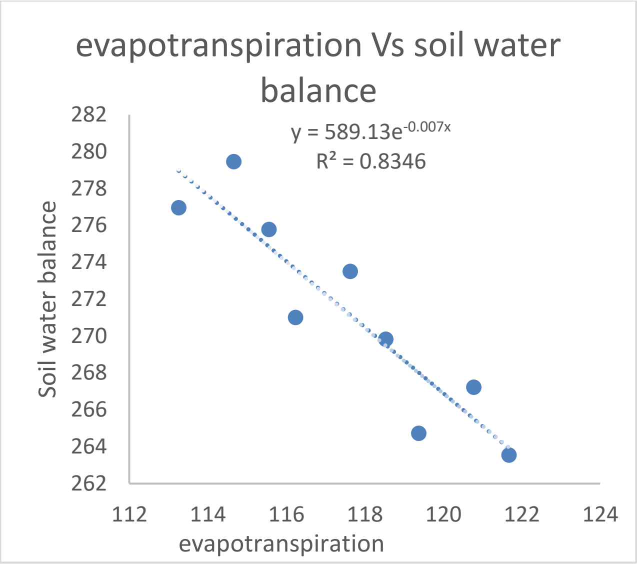

Figure 4. 4: soil water balance vs evapotranspiration

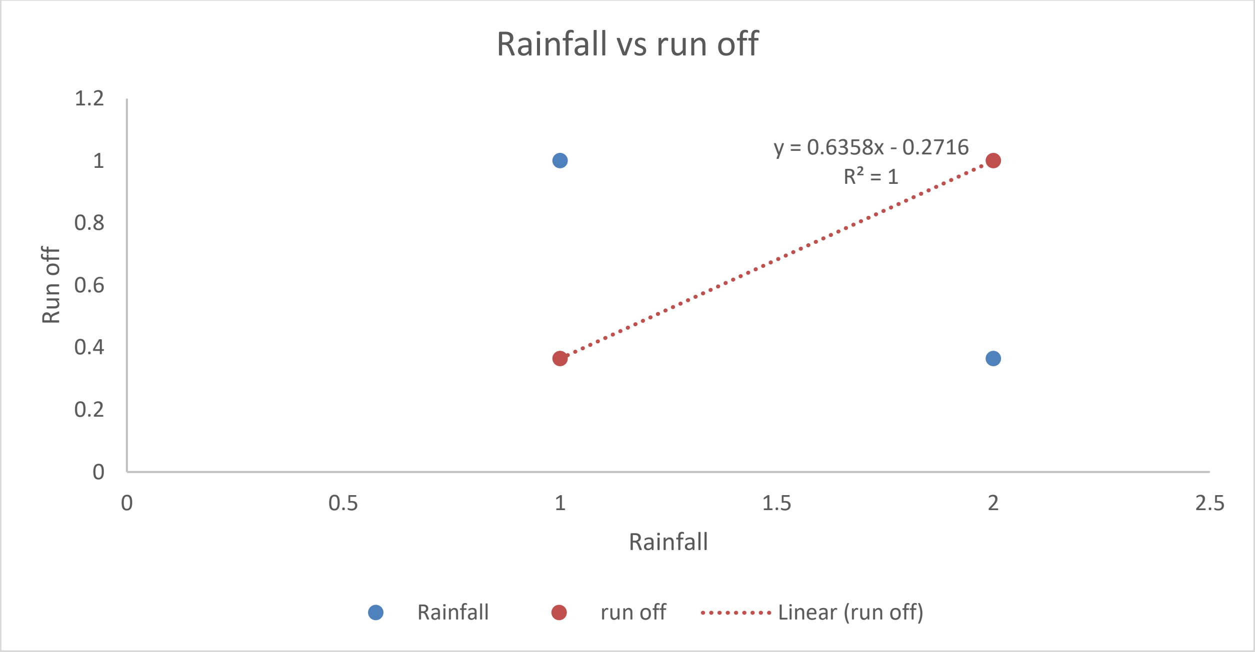

Figure 4. 5: Rainfall Vs Run off

Table 4. 3: Correlations

	Evapotranspiration (mm)	Run off (mm)	Soil water balance (mm)	Soil loss (Kg/m2)
Evapotranspiration (mm)	1	0.787709715	0.982615398	0.294292251
Run off (mm)	0.787709715	1	0.744130658	0.484922671
Soil water balance (mm)	0.982615398	0.744130658	1	0.19081323
Soil loss (Kg/m^2)	0.294292251	0.484922671	0.19081323	1

4.4 Discussions

4.4.1 Evapotranspiration, Runoff, soil loss and water balance

Evapotranspiration: Tree cover had greater evapotranspiration in both seasons, trees have the ability to use more water than most other types of vegetation due to high consumption and thus highest soil temperatures, corresponding to greater moisture losses. This agreed to the study by Cao et al. [2009] who established that woody species take up more water by evapotranspiration than other vegetation types. Furthermore, Dai et al. [2006] found that the most important factor affecting evapotranspiration was vegetation cover was. Grass and bare ground showed lesser evapotranspiration than trees.

Run off and soil loss: The quantity of RO and SL from bare ground was significantly higher than that from tree and grass cover. The effects of vegetation on runoff and soil loss is determined by structure and function of vegetation. Vegetation on the soil surface enhances the roughness of the soil surface and operates as a series of barriers that obstruct surface runoff and lengthen infiltration time. Thus, land cover minimizes soil loss by intercepting rainwater runoff, increasing soil surface roughness, and boosting rainfall infiltration.

Runoff, soil water balance and soil loss were significantly influenced by rainfall season. When compared to the SRS, the LRS had the most runoff, soil loss, and soil water balance because rainfall was both the cause and the source of RO. Runoff and SL are primarily dependant on rainfall when the intensity and other factors are fixed. The interception effect is diminished when rainfall intensity is high, and the presence of a biological crust on the soil has an impact on runoff generation. The link between runoff, sediment, and rainfall intensity was also discovered to be a power function in Wang et al. 2016 investigation. According to Farhan and Nawaiseh [2015], the higher the rainfall intensity, the wider the center diameter of raindrops, which favors runoff formation and soil loss. Run off and soil was higher under the bare ground this since there is no vegetation cover to intercept the rain drops making their soils more sensitive to RO and SL. Because of the vegetation's interception effect, a raindrop cannot directly contact the ground surface when the plant covering on the land surface is quite high. This supports the findings of Méndez et al. [2010], who found that, compared to bare ground, more ground cover reduces runoff and soil loss. This concurs with the findings of Collins et al., [2015], who discovered that vegetation cover had a direct impact on RO and SL. Vannoppen et al. [2015] similarly documented a reduction in soil loss as a result of the combined effects of t roots and vegetation cover in their study. Toe slope vegetation worked as a deposit trap by trapping soil particles in its roots, slowing surface runoff and maintaining better pore space, resulting in increased soil water balance and hence reduced runoff. According to Voepel et al. [2011], the building effect of runoff causes soil water content to progressively increase from the mid slope to the toe slope. Additionally, Dosskey et al., 2010 reported that toe slope plants have been found to be responsible for higher amount of the organic matter.

Soil water balance: The values of the SWB beneath tree and grass were much greater than those on barren land. In comparison to bare land, trees influence soil parameters through soil-vegetation interaction, resulting in higher infiltration rate and soil water retention capacity. Zhang et al. [2012] discovered that vegetated land has a greater capacity for soil water retention than non-vegetated ground. Soil organic matter distribution varies depending on the vegetation cover, which is a crucial factor determining soil bulk density, soil water content, and water retention. Wang et al. [2018] observed similar results, claiming that the upper soil layer under high vegetation cover had pronounced litter cover, which boosted water infiltration and water retention capacity. Keim et al., 2006 study showed that vegetation alters the soil water balance through transpiration and interception.

There was a slight difference in soil water balance through the topographic points, toe slope positions had higher soil water balance than foot slope and mid slopes, demonstrating the significance of texture and rooting depth on determining soil water balance.

4.4.2 Runoff coefficient during the long and short rainy seasons

The highest runoff coefficient occurs in the bare this indicates that increased vegetation cover decreases the runoff coefficient. This is as a result of decreased rain drop and run off due to interception of rain drop by vegetation cover. This concur with the study by Zhang et al., 2010 who found out that the major factor affecting the runoff coefficient is vegetation cover. When rainfall intensity exceeds the soil's infiltration capacity, runoff increases, resulting to an increase runoff coefficient during the LRS than SRS. According to Rebeca et al. [2010], the amount of rain has a direct comparable effect on the runoff coefficient. The results indicates that there is a difference in runoff coefficient at different topographical zone with higher run off coefficient for mid slope than foot slope and toe slope in both seasons this indicates that run off coefficient decreased down the slope. This is because run off is at the peak at the mid slope due to gained momentum as compared to foot slope and toe slope. In their study, Haggard et al. [2005] discovered that the association amid slope and runoff coefficient suggested that superficial runoff output will continue to increase at mid-slope slopes.

4.4.3 Correlations

From the correlation analysis it is evident that soil loss increased as runoff. increases This is because with increased runoff more soils are detached from the surface and carried away. This is the same with the studies done previously by (Gholami et al., 2013) who found with a larger amount of energy there is greater runoff, with detachment soil aggregation and movement the soil particles. The results are also agreeing with the findings of Adimassu et al. (2014) and Adimassu and Haile (2011), who found out that there is a good relationship between RO and SL. Rainfall and runoff also had a significant correlation. Previous studies suggested that runoff generation rate increased as rainfall increases. It has been found that the relationship of runoff and rainfall is always positive by (Cerdà et al., 2017).

4.5 Conclusions

It is evident from the study that vegetation and topography influence runoff, soil loss, soil water balance and runoff coefficient. The results from this study shows that run off ***and soil loss was significantly higher in MS*B and MS*G as compared to TS*B and TS* G. grass*** vegetation-reduced the soil loss and runoff control. Soil water balance increased at the toe slope with grass vegetation. Therefore, from this study proper protection of slopes from surface disturbances from raindrops can effectively reduce soil loss and runoff by using grass and tree covers to enhance deposition in the mid slopes. However, the study suggests that more research be done on the dynamics of soil water balance in bare soils in forested grasslands to better understand the soil water needs of these places. Wooded Grassland soils have the potential to increase soil water balance and reduces soil loss and runoff that promoted rejuvenation of grass vegetation for soil water conservation and improvement of livelihoods

CHAPTER FIVE

5.0 GREENHOUSE GAS FLUXES AS INFLUENCED BY TOPOGRAPHY AND VEGETATION COVER IN WOODED GRASSLANDS OF LAIKIPIA COUNTY, KENYA

Abstract

Wooded grasslands are a little-studied ecosystem that contributes an unknown amount of GHGs to global warming. The study was to see how topography and vegetation cover influenced CO_2, CH_4 (CH4), and N_2O (nitrous oxide) flux. The research was carried out in Laikipia County's Ilmotiok community ranch 2016. Randomized complete block design (RCBD) with main plots topographical zones (mid-slope (MS), foot slope (FS), and toe slope (TS)) and subplots vegetation cover (VC) (tree (T), grass (G) and bare (B)). Static chamber frames were installed for the three VC (B, G, and T) in three TZ (MS, FS, and TS). GHGs were measured every 7-10 days between 0800hrs and 1200hr. Sampling was done after fitting the lid at time (T0), 10 min. (T1), 20 min (T2) and 30 min (T3). During the wet months, CH_4, N_2O and CO_2 emission were significantly higher than the dry season. Methane fluxes ranged from -0.32 mg.m-2.h-1 to 0.24 mg.m-2.h-1 with the lowest (-0.32 $mg.m^{-2}.h^{-1}$) recorded under TS*T whereas CO_2 was highest under TS*G (47 $mg.m^{-2}.h^{-1}$) as compared to MS*G (19 $mg.m^{-2}.h^{-1}$). TZ*VC significantly influence N_2O with MS*B recording the lowest (0.008) as compared to TS*B (2.228 $mg.m^{-2}.h^{-1}$). CO_2, N_2O and CH_4 emissions were low in January and February and it increased in March and April in all the TZ*VC. Soil CO_2, N_2O, and CH_4 fluxes patterns of are principally controlled by topography and plant cover, with larger emissions of soil CO_2 and uptakes of CH_4 on the toe slopes and foot slopes than in MS.

Keywords: climate change; greenhouse gases; topography; vegetation cover

5.1 Introduction

Global warming is caused by increased GHG gases concentrations such as methane (CH_4), nitrous oxide (NO_2) and carbon dioxide (CO_2). These GHGs are all created and consumed by biological processes such as photosynthesis, decomposition, nitrification, denitrification, methanogenesis, and CH4 oxidation, and terrestrial ecosystems are key sources and sinks for them (IPCC, 2013). Soils are the primary source of CO2 and N2O in the atmosphere (Butterbach-Bahl et al., 2013).

Total yearly soil emissions are predicted to contribute 35 percent to CO2, 53 percent to N2O, and 21% to CH4 in their respective atmospheric budgets (IPCC, 2007). However, livestock part contributes about 15 % of worldwide greenhouse gas emissions (Gerber et al., 2013), and consequently escalate land degradation, environmental pollution, and decline in biodiversity (Bellarby et al., 2013). The semi-arid wooded grasslands of Laikipia County are friable to climate change due to encroachment of the rangelands due to unsustainable land uses resulting from increased human population (Georgiadis *et al. 2007*). Climate change will affect livestock production due to competition for ecosystem resources as animal products demand is predicted to rise by 10 percent by the twenty-first century (Garnett, 2009). Therefore, it is difficult to strike a balance between household food security, productivity, and protection of environmental (Wright et al., 2012). The magnitude of soil N_2O and CO_2 emissions in these semi-arid rangelands vary considerably across spatial and temporal scales (Butterbach-Bahl et al., 2013). Soil CO_2, CH_4 and N_2O fluxes differ considerably as it is driven by biological processes, ecological conditions, non-uniformity of soil properties *(*Butterbach-Bahl *et al., 2013*). Root respiration and microbial decomposition of soil organic matter produce CO2, some of which is released into the atmosphere and part of which is fixed during photosynthesis (Paterson et al., 2009).

Although various studies have examined the variability of CH4 fluxes, most of them have covered large regional scales, capturing crucial environmental factors at such scales, but sample locations have been scarce (Teh et al., 2014). The smaller-scale outlines of Methane fluxes within these ecosystems have not been adequately examined at ecosystem size gradients, due to its problematic nature of such patterns but important for projecting GHG fluxes (Nicolini et al., 2013). Similarly, a lot of effort has gone into analyzing carbon dioxide fluxes in a range of biomes using eddy covariance and chamber measurements approaches (Allaire et al., 2012), although estimates of

GHG emissions from soils include a lot of uncertainty. Practical approaches to measure soil GHG fluxes are necessary for better understanding of the magnitudes, spatial and temporal variations of soil-atmospheric trace-gas emissions (Allaire et al., 2012). Due to the importance of terrestrial ecosystems as GHG producers and sinks (IPCC, 2007) and the need to counteract climate change, new management techniques aimed at lowering soil GHG emissions are urgently needed. There are few studies that incorporate topographic irregularity into ecological scale forecasts of in situ chamber flux measurements of a variety of GHGs (Merbold and Wohlfahrt 2012). Owing to the substantial spatial-temporal variability of fluxes in forested grasslands, understanding topography and vegetation cover effects on soil GHG fluxes remains difficult. As a result, research was conducted in the forested grasslands of Laikipia County, Kenya, to assess GHG gas CO_2, CH_4 and N_2O fluxes as impacted by topography and vegetation cover types.

5.2 Materials and methods

5.2.1 Study Site

Refer to section 3.2.1

5.2.2 Research design

The main plot was variation in topographical zones; mid slope (MS), foot slope (FS), and toe slope (TS), and the subplots were vegetation cover Tree (T), Grass (G), and Bare (B) as the control. A total three transect line measuring 150m long were drawn for each topographical zone as replicates (Table 5.1). Blocking was done along the transect line after every 50m. Measurements of GHGs was done from January to April 2017.

Table 4. 4: Research design

150 m transect line

Zone	**Rep**	**Block 1** **50m**	**Block 2** **50m**	**Block 3** **50m**
Mid slope	**Rep 1**	**GTGGTG BGTTG**	**TGBTTGTGTGBB**	**GTGGTG BGTTG**
	Rep 2	**GTGBBGTGTGB**	**TTGTGTGBBBG**	**TGBTTGTGTGBB**
	Rep 3	**GTGGTG BGTTG**	**GTGBBGTGTGB**	**TGBTTGTGTGBB**
Foot slope	**Rep 1**	**GTGGTG BGTTG**	**TGBTTGTGTGBB**	**GTGGTG BGTTG**
	Rep 2	**GTGBBGTGTGB**	**TTGTGTGBBBG**	**TGBTTGTGTGBB**
	Rep 3	**GTGGTG BGTTG**	**GTGBBGTGTGB**	**TGBTTGTGTGBB**
Toe slope	**Rep 1**	**GTGGTG BGTTG**	**TGBTTGTGTGBB**	**GTGGTG BGTTG**
	Rep 2	**GTGBBGTGTGB**	**TTGTGTGBBBG**	**TGBTTGTGTGBB**
	Rep 3	**GTGGTG BGTTG**	**GTGBBGTGTGB**	**TGBTTGTGTGBB**

B-Bare G-Grass, T-Tree,

5.2.3 Land cover determination

Vegetation cover types was determined as the percentage of the selected area through visual estimation.

Table 4. 5: Land cover determination

Land cover type	Abbrev.	Units	How and tools used
Tree	T	% Area	Visual estimate based on the (20x20 m) subplot area
Grass	G	% Area	Visual estimate based on the (20x20 m) subplot area

5.2.4 Static chamber installation

For the three-vegetation cover in each of the three topographical zones, static chamber frames were placed (two weeks prior to the first sample date to avoid soil damage that could affect greenhouse gas emissions). The chamber anchor was buried 10 cm into the soil, leaving 15 cm of chamber space above the surface. (Fig.4.6).

Figure 4. 6: Static GHG chamber

5.2.5 Flux measurements

To capture the observed time-based variability of GHG gas emissions, sampling was done across the four months (January to April) to catch the dry (January), intermediate (February and March), and wet (March/April) seasons. Gas samples were collected between 0800hrs and 1200hr local time. Gas sampling was done immediately after fitting the lid at time zero (T0), after 10 min (T1), 20 min (T2) and lastly after 30 min (T3). Other measurements taken included soil moisture, soil temperature, air temperature and chamber temperature, air pressure and chamber height from soil surface. Above ground at 1.5 m air temperatures and inside the base chamber were taken concurrently in each sampling event using an Ein stich—TFA digital probe thermometer. soil moisture content (SM, %v/v) and soil temperature (°C) were taken at 5 cm surface soil depth using a probe sensor model 5MT, Decagon Devices Inc. which measured both soil moisture and temperature. Once the systems were operational and set i.e., thermometers and chamber lids, gases were collected using Luer-Lok syringe and stored in 20ml evacuated vials which were later transported to mazingira Laboratory, International livestock research institute LRI, Kenya for CO_2, N_2O, and CH_4 analysis using an Agilent 6890 Gas chromatograph (Lutes *et* al., 2016).

The CH4, CO2, and N2O fluxes vs chamber closure duration was calculated using linear regression of standard concentrations as described by Lutes et al., (2016), and corrected for soil moisture and temperature using equation 5.1 below (computerized).

$$F= (P/Po)\ x\ (M/Vo)\ x\ (dc/dt)\ x\ (To/T)\ x\ H \qquad \text{(Equation 5.1)}$$

Whereby: F= (for) CO_2 - C Linear flux ($mg.m^{-2}.h^{-1}$), CH_4-C Linear flux ($mg.m^{-2}.h^{-1}$) and N_2O- N Linear flux ($ug.m^{-2}.h^{-1}$), P= atmospheric pressure of study site (Pa), P_o= atmospheric pressure (Pa), M= gas mass (g/mol), V_o= molar volume (ml), dc/dt = rate of change in concentrate,

T_o = absolute chamber temperature (°C), T= absolute chamber temperature at time of sampling (°C), H= height of static chamber at the time of sampling.

5.3 Statistical analysis

Using GenStat 14th version, the effects of topography and vegetation cover on runoff, soil loss, soil water balance, and runoff coefficient were investigated using two-way ANOVA. The significance of differences in runoff, soil loss, soil water balance, and runoff coefficient and soil water balance between treatments was tested using Fisher's LSD test.

5.4 Results and discussion

5.4.1 Rainfall and temperature data

Rainfall and air temperature over the four months study period ranged from 7 mm to 400 mm per month (Table 2), which was closely similar to the long-term average annual rainfall (560 mm) of the study site. Mean annual air temperature ranged from 19-29°C, whereas minimum and maximum ranged from (9-15°C) and 24-32 °C respectively.

Table 5. 1: Rainfall, maximum, average and minimum temperature

		Jan	**Feb**	**Mar**	**April**
Rainfall (mm)		17	7	250	400
Temperatures (°C)	Min	9	10	12	15
	Mean	19	20	19	19
	Max	28	32	28	24

5.4.2 CO2, CH4, and N2O flows as a influenced by soil moisture

The amount of moisture in the soil has a substantial (p0.05) impact on GHG emissions (CO2, CH4 and N2O). Wet soil had considerably higher CO2 levels (79.39 mg.m^{-2}.h^{-1}) than dry soil (p0.05) (12.79 mg.m^{-2}.h^{-1}). Wet soil has (-0.00662 mg.m^{-2}.h^{-1}) CH4, whereas dry soil had (-0.00662 mg.m^{-2}.h^{-1}) CH4 (-0.01742a mg.m^{-2}.h^{-1}) (Table 3).

Table 5. 2: CO2, CH4, and N2O flows as influenced by soil moisture

Soil condition	CO_2 - C (mg.m^{-2}.h^{-1})	CH_4-C (mg.m^{-2}.h^{-1})	N_2O- N (mg.m^{-2}.h^{-1})
Dry	12.79^{a}	-0.01742^{a}	0.822^{a}
Wet	79.39^{b}	-0.00662^{a}	18.543^{b}

Fisher's LSD test finds that means with the same superscript letter (within a column) are not substantially different (p0.05).

When the soil becomes wet, CO2 fluxes increase dramatically. Because of their impacts on microbial activity and plants, soil aeration, substrate availability, and redistribution, soil temperature and moisture content have an immediate impact on CO2 production and intake. Soil moisture is important for soil CO2 fluxes; wetter soils exhaled more CO2 due to enhanced microbial respiration conditions (Zhou et al., 2013).

Dry soils have both methanogenesis and methanotrophic, which increase emissions from the soil to the environment without coming into contact with an oxidizing soil environment; nonetheless, higher methanogenesis will have a greater effect, and the net result may be an increase in CH4 emissions. These findings support previous claims by (Angel et al., 2012) that CH4 emissions are turned on and off in extremely dry soils. Because methanogenesis increases in anaerobic environments, populations of methanogenic organisms rise with increased soil moisture in previously dry soils, and methanogenesis is introduced (Le Mer and Roger, 2001). However, when soils are damp, methanogenic activity is abridged (Inubushi et al., 2003). Throughout the research period, the temporal and geographical variation of CH4 fluxes decreased depending on soil temperature and moisture variations. This is similar to the ones investigated by Zhu et al (2013).

As a result, the effects of wetness on soil nitrous oxide fluxes are due to the restrictions of O2 diffusion into the soil, which leads to an increase in soil anaerobiosis, which encourages reductive microbial strategies as well as denitrification. According to, soil water is a major using component for N2O collection (Christiansen et al., 2012). Pennock and Corre (2001) suggested that higher soil moisture content resulted in better N2O fluxes, which were linked to increased denitrifying bacteria owing to lower O2 dispersion into the soil (Yanai et al., 2007). Wet conditions encourage the growth of soil microbial populations and inorganic nitrogen, resulting in increased N2O emissions at some point during the wet season. Particularly microbial denitrification, and nitrification in, are responsible for Nitrous oxide emissions from soils, even when the soil is wet Katayanagi and Hatano (2012). Moisture and temperature are the primary regulators of nitrous oxide and methane fluxes in soils. Wu et al. (2010) discovered that seasonal changes in soil moisture and temperature closely correspond to temporal patterns in nitrous oxide and methane fluxes.

5.4.3 Effects of topographical zones and vegetation cover type on Methane (CH_4) fluxes

Topography and vegetation significantly ($P<0.05$) influenced CH_4 emissions. Methane fluxes ranged from -0.021 mg.m^{-2}.h^{-1}to 0.026 mg.m^{-2}.h^{-1}with the lowest (-0.021 mg.m^{-2}.h^{-1}) recorded under FS*B. TZ*B were all negative for all the months (January-April) with April recording more negative values but not significantly different with March values. Methane (CH_4) emissions in January and February were low and it increased in March and April in all the TZ*VC (Table 5.3). The positive values for methane were recorded under TZ*G with the highest value during the month of April under (TS*G 0.026 mg.m-2.h-1) and lowest during the month of February (FS*G 0.003 mg.m^{-2}.h^{-1}) in comparison to other zones.

Table 5.3: Effects of topographical zones and vegetation cover type on Methane (CH4) emissions

TZ	VC	JAN	FEB	MAR	APR
FS	**BARE**	-0.006^{c}	-0.020^{b}	-0.009^{c}	-0.021^{b}
	GRASS	0.003^{e}	0.007^{fg}	0.009^{fgh}	0.013^{j}
	TREE	0.003^{e}	-0.001^{d}	-0.002^{d}	-0.020^{b}
MS	**BARE**	-0.003^{d}	-0.010^{c}	-0.09^{a}	-0.017^{b}
	GRASS	0.005^{f}	0.011^{hi}	0.011^{hi}	0.022^{l}
	TREE	0.001^{d}	0.003^{e}	0.005^{f}	0.007^{fg}
TS	**BARE**	-0.001^{d}	-0.08^{a}	-0.07^{a}	-0.013^{c}
	GRASS	0.007^{fg}	0.014^{j}	0.016^{k}	0.026^{l}
	TREE	0.006^{f}	0.008^{fg}	0.009^{fgh}	0.011^{hi}

Fisher's LSD test shows that means preceded by a distinct superscript letter (within a column for each month separately) are substantially different (p0.05).

The reduction of vegetation covers increased CH_4 emissions Sturtevant and Oechel, 2013 suggested that Plant biomass and stem density have been extensively associated with CH4 emissions. Vieira et al. (2012) found that vegetation type had an impact on methane emissions in the aggregate. This study also found that vegetation cover, soil features, and climate change all had an impact on CH4 emissions, demonstrating that vegetation cover is an important factor in CH4 emissions.

Increased CH4 emissions have been linked to accelerated root biomass production, as well as increased breakdown of plant material due to aerobic soil conditions by (Yun et al. 2012).

The toe slope, showed increasing CH_4 fluxes than foot slope and mid-slope in all vegetation cover types. The assumption is that topography controls soil water redistribution, which affects soil aeration and thus soil microbial activities. Yvon-Durocher et al., 2014 also found out that zones containing soils that aid microbial activities and the net CH_4 flux at the soil surface. The soil in the toe slope area is saturated, and the hydrologic flow from the foot slope allows dissolved organic carbon to migrate downslope. The modest CH4 fluxes are in line with findings from other research, which show methane produced in soil is reacted before it reaches the subsoil (Vidon et al., 2015). The watershed's toe and mid slopes have slower drainage, creating a soil environment that may be more favourable to CH4 generation, or may have a better balance of methanogenic and methanotrophic techniques. Soil CH4 flow is caused by active soil methanotrophic and methanogenic bacteria that rely on the presence of oxygen (Kim, 2015).

CH4 fluxes ranged from net emission to net uptake, indicating that the soil microbial ecology contained both methanotrophs and methanogens bacteria. Due to soil microbial synthesis and consumption of CH4 occurring simultaneously, CH4 flow is highly variable both geographically and temporally.

Because of changes in gas transport and decreases in aerobic zones in the soil, CH4 absorption typically decreases as soil moisture increases. This is fueled by resumed mineralization and the easy availability of decomposable organic materials for reactivated microorganisms' metabolism (Borken and Matzner, 2009). With more frequent wet-dry cycles, the Birch effect is reduced (Borken and Matzner, 2009). Then again, the absorption of CH_4 by using soil became enhanced by using rainfall due to CH_4 flux response to increase in soil moisture. CH_4 fluxes shifted from uptake during dryer conditions to slight emissions under wet conditions (Teh et al., 2014).

5.4.4 Effects of topographical zones and vegetation cover type on carbon dioxide (CO_2)

Topography and vegetation significantly ($P < 0.05$) influence carbon dioxide. Toe slope had the highest soil CO_2 fluxes than the other topographical mid slope and foot slope. Average CO_2 fluxes in all topographical zones were between 2.8 to 48 mg.m^{-2}.h^{-1} (Table 5.4). The highest emissions were recorded under TZ*G as compared to other interactions throughout the seasons with significantly higher emissions under MS*G month of April (48.56 mg.m^{-2}.h^{-1}) and the lower under MS*B month of February 2.88 mg.m^{-2}.h^{-1}. In January and February, carbon dioxide (CO2) emissions were modest, but climbed in March and April.

Table 5. 4: Effects of topographical zones and vegetation cover type on carbon dioxide (CO2) mg.m-2.h-1

	MS			FS			TS		
Month	**BARE**	**GRASS**	**TREE**	**BARE**	**GRASS**	**TREE**	**BARE**	**GRASS**	**TREE**
JAN	4.41^{a}	5.77^{a}	7.73^{ab}	5.98^{ab}	12.08^{cde}	25.05^{fgh}	7.27^{ab}	8.78^{bc}	9.83^{bc}
FEB	4.63^{a}	11.97^{bcd}	13.73^{cde}	2.88^{a}	11.70^{bc}	7.64^{ab}	6.24^{ab}	7.34^{ab}	7.87^{ab}
MAR	13.79^{cde}	24.49^{efg}	11.38^{bc}	8.21^{bc}	68.56^{m}	55.64^{l}	16.50^{def}	31.47^{j}	23.42^{efg}
APR	21.89^{efg}	36.70^{k}	28.32^{ghi}	9.94^{bc}	69.94^{mn}	63.18^{m}	25.51^{fgh}	80.29^{o}	24.88^{efg}

Means followed by the different superscript letter are significantly different ($p < 0.05$) by Fisher's LSD test.

Topography influences soil CO_2 fluxes by way of influencing the soil moisture condition. Inclined soils are normally properly aerated and properly drained, for this reason, providing conditions favorable for aerobic heterotrophic. Previous studies have indicated that toe slopes have superior soil CO2 fluxes than foot slopes or mid-slope locations due to enhanced soil nutrient depositions and soil moisture cand (Arias-Navarro et al. 2017).

Vegetation has impacts on CO_2 emissions and undoubtedly correlates with net ecosystem production. Metcalfe et al., 2007 demonstrated that decrease root density or litter content material correspond with decreased CO2 fluxes. Increased CO2 concentrations in soils can also be attributed to improved root mass as a result of higher CO2 levels in the atmosphere. Increase in ground cover also can impact C and nutrient cycling approaches and regulate the ecosystem-environment exchange of CO_2 (Buckeridge *et al* 2010). Despite the fact that growth in leaf area with more vegetation cover increases gross ecosystem production and uptake of CO_2 (Shaver *et al 2000*).

Higher soil CO_2 concentrations were recorded in moist periods of March and April; our results correspond that excessive $C0_2$ emissions throughout wet durations was due to $C0_2$ displacement in the soil due to increased rainwater. Increase in CO_2 flux during the wet season are most probably due to an aggregate of factors occurring simultaneously – will increase in soil temperature and soil moisture that can additionally induce higher carbon (C) availability as reported by (Hubbard et al., 2006). In addition, at some point of the observation period of this study, the large quantity of litter that had gathered all through the dry period became intensively decomposed with the onset of rainfall. Soil water content also can impact rates of CO_2 by diffusing soluble C substrates in thin water as suggested by Davidson et al. 2006. Addition of water to the soils as precipitation through infiltration can elicit vast increases in total respiratory reflecting greater decomposition of the organic layer and growth in substrate availability. Increased precipitation is predicted to reduce rates of O2 penetration into the soil, lowering carbon oxidation (Liptzin et al., 2011). Precipitation variability is a well-known key driver of seasonal variations in soil CO2 flow in a various environments (Stielstra et al., 2015, Vargas et al., 2012). In rainy season respiration is likely to increase with increased vegetation covers because of the increased insulating ability of the plants-trapped snow developing warmer soil surroundings (Sturm *et al 2015*).

5.4.5 Effects of topographical zones and vegetation cover type on Nitrous oxide (N_2O)

The results showed that topography and vegetation had a positive influence on N_2O fluxes. The mean N_2O emission for toe slope ranged from 0.475 to 43.026 $ug.m^{-2}.h^{-1}$, these values were significantly higher than at mid slope (-2.63-15.016 $ug.m^{-2}.h^{-1}$) and foot slope (-1.311-10.759

ug.m^{-2}.h^{-1}) ($P < 0.05$) (Table 5.5). In all topographical zones, bare soil exhibited the lowest average fluxes from all vegetation cover categories.

Nitrous oxide (N2O) emissions were higher in March compared to other months in all topographical zones and vegetation cover types.

Table 5. 5: Effects of topographical zones and vegetation cover type on Nitrous oxide (N2O)

	VC	JAN	FEB	MAR	APR
FS	**BARE**	-0.578^{b}	-1.311^{a}	-0.378^{bc}	1.088^{de}
	GRASS	1.377^{fg}	1.117^{def}	0.673^{de}	9.224^{jk}
	TREE	0.835^{de}	1.305^{def}	0.802^{de}	10.759^{jk}
MS	**BARE**	-1.053^{b}	-1.321^{a}	-2.630^{a}	-0.712^{de}
	GRASS	1.311^{def}	1.583^{fg}	5.426^{j}	15.016^{l}
	TREE	1.300^{def}	1.181^{def}	5.557^{j}	8.629^{jk}
TS	**BARE**	0.475^{d}	1.004^{de}	0.489^{d}	6.946^{j}
	GRASS	1.098^{de}	2.156^{h}	22.155^{m}	43.026^{n}
	TREE	3.432^{hi}	0.032^{d}	2.596^{h}	28.477^{m}

Means followed by the same superscript letter at different months are not significantly different ($p < 0.001$) by Fisher’s LSD

The bare soil had N_2O accumulated emissions near zero this due to reduced soil moisture content, soil temperature and soil aeration, therefore, affecting the emissions. Soil moisture will increase as a result of stomata starting as a consequence growing situations for N_2O emissions through denitrification force (Ding et al., 2003). Van der Nat and Middelburg (2000) observed that N2O emissions have been affected collectively by vegetation cover percentage. Soil N_2O emissions are increased in the toe-slope than in foot slope or mid-slope positions this is because of moisture content in the different positions along the slope commonly explaining well the located variability in N_2O fluxes. The differences in moisture content material among the different topographic positions explaining well the determined changeability in N_2O fluxes with the highest soil N2O fluxes at the toe slope intently correlated with the highest soil moisture in these positions (Negassa et al., 2015). Extensive consequences of topographic position on a couple of components of the N cycle were proven by using Weintraub et al. (2014), who indicated that there is lower N and a less open Nitrogen cycle in toe-slopes. Increased N_2O fluxes occur in the soil with a high moisture content that is because patterns of N_2O flux is controlled via soil moisture variability. Soil moisture affects earthworm casts that produce nitrous oxide. Geng et al 2017 in his study in tropical soils reported that N_2O emissions can be sporadic and brief, for example, after heavy rains and are characterized via short pulses of emissions related to better nitrogen inputs or excessive precipitation occasions. As an example, an increase in soil temperature can directly stimulate nitrifies and denitrifies that produce N_2O, however greater fast soil drying (Bijoor et al. 2008). Temperature increases could also stimulate plant boom and N uptake, thereby decreasing the effect of N being lost as N_2O. However, warming boost N_2O emissions due to increased microbial activity and N deliver via accelerated N mineralization (Dieleman et al. 2012).

5.5 Conclusion

Topography and vegetation cover primarily control the patterns of soil CH_4, CO2 and N_2O fluxes therefore, topography and vegetation structures are essential in soil carbon fluxes tpredictions of. Toe slope had the highest soil CO_2 and N_2O fluxes than the other zones mid slope and foot slope. Carbon dioxide (CO_2) and N_2O emissions increased in March and April and very in January and February.

CHAPTER SIX

6.0 GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

6.1 General discussion

In this research, approximately 50 percent of Soil Organic Carbon were found in the upper horizon, whereas 30 percent in the mid horizon and 20 percent in the lower horizon. This might be as a result of constant addition of partially decomposed plant residue and undecomposed on top soils. Other scientists have also found that top horizon have accumulated more OM than lower horizon. SOC concentration also vary because of different vegetation types locally. Higher SOCS recorded below grass cover due to increased litter production that is added into the soil compared to tree and bare ground. Vegetation is one the many influencing factors of SOC stocks (Oueslati et al. 2015). SOC concentration were also significantly higher at toe slope and foot slopes than at the mid slope. The burial of soil in the depositional position (toe slope) may result in a relative gain in SOC, because there would be less carbon mineralization than when exposed to the higher oxygen conditions at the mid slope. This is attributable to the effects of topography on moisture content, erosion and deposition. It controls rates of redistribution of soil along the slope locations and have an effect on the amount and soil organic carbon quality (Oueslati et al. 2013). Runoff in bare ground increases, as there is no vegetation cover and if any it is more disperse and thus their soils are susceptible to run off. Topography through the redistribution of soil organic matter and soil particles controls processes of soil erosion. The slope and the ratio of runoff to rainfall relationship between suggested that surface runoff production increase at toe slopes. Vegetation cover regulates runoff and soil loss processes by responsibly intercepting rainfall and decrease the effect of raindrop while promoting rainfall penetration into the soil thus reducing surface flow velocities, thus diminishing the runoff and soil loss. There is a strong effect of vegetation on surface runoff (Chen et al., 2007).

Potential soil CO_2 mean fluxes declined along the slope with toe slope having significantly higher fluxes than the mid slope and foot slope positions. Several researchers point out that the spatial differences in soil CO2 fluxes have been associated with slope characteristic. Soil N_2O emissions are higher in toe slope than mid slope or foot-slope sites due to differences in moisture content at different positions in the slope thus explaining well the observed differences in N2O fluxes with the maximum soil N2O fluxes found in toe slope positions correlating with the highest soil moisture in such positions. Substantial effects of topographic slope and landscape position on greenhouse gases have been shown as well by Weintraub et al. (2014).

6.2 Conclusion

- Results from this study have shown that different topographical zones and vegetation cover types of wooded grassland savanna had a great influence on soil organic carbon, soil water balance and greenhouse gas fluxes. There was high variability in soil organic carbon stocks for the different vegetation cover types with high soil organic carbon stocks observed in vegetated cover than bare ground.
- The study has established that interaction of toe slope and grass cover, resulted into higher SOCs and SWB than in interaction of mid slope and bare cover. Such positive results are beneficial for GHGs emission reduction and soil water conservation, especially for water-constrained and degraded wooded grasslands of Laikipia County.
- SOC stocks decreased with increasing depth in all topographical zones and vegetation cover type. The upper soil depth had the highest soil organic carbon stock compared to the lower depth in all topographical zones and vegetation cover types.
- Toe slope-grass cover, also resulted to reduced soil loss and run off when compared to other interaction. Specifically, mid slope-bare stood out with highest soil loss and run off. Therefore, toe slope with grass cover was the most effective in reducing both RO and SL thus increased soil water balance.
- Proper protection of slopes from surface disturbances from raindrops can effectively reduce soil loss and runoff by using grass and tree covers to enhance deposition in the mid slopes.
- From the study results, soil greenhouse gas emissions were significantly influenced by topography and vegetation cover. Topography and vegetation cover primarily control the patterns of soil CH4, CO2 and N2O fluxes, therefore, topography and vegetation features must be included in the predictions soil carbon fluxes.
- Toe slope had the highest soil CO2 and N2O fluxes than the other zones mid slope and foot slope. Carbon dioxide and N_2O emissions were lowest in January and February and

it increased in March and April. The results from this study outlined the role of topography and vegetation covers on runoff, soil loss and soil water balance.

6.3 Recommendation

- Proper protection of slopes from surface disturbances can effectively reduce soil loss and runoff by using grass and tree covers to enhance deposition in the mid slopes.
- It will be recommendable that a policy that considers proper vegetation cover management be set up.
- Conservation measures for improvement of carbon sequestration should take into consideration the topography and the differences in vegetation cover for successful interventions.
- For better accurate and understanding, evaluation of soil management practices to reduce Greenhouse gas emission measurement of soil CO2 emissions should be done from different topographical zones and vegetation cover types allows the s.
- To help reduce global GHG emissions and maintaining or increasing crop productivity, there is a need to develop and implement measures that increase grass and tree cover to reduce emissions directly through carbon sequestration in the semi-arid wooded grasslands of Laikipia County.

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APPENDICES

Appendix 1: ANOVA for the effects of topographical zones and vegetation types on BD, %OC and SOCs

BD_LRS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
T_zone	3	0.419639	0.139880	24.68	<.001
V_cover	2	0.045678	0.022839	4.03	0.020
Depth	4	0.611158	0.152789	26.95	<.001
T_zone.v_cover	6	0.132362	0.022060	3.89	0.001
T_zone.depth	12	0.217430	0.018119	3.20	<.001
V_cover.depth	8	0.058707	0.007338	1.29	0.253
T_zone.v_cover.depth	24	0.195573	0.008149	1.44	0.104

BD_SRS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
T_zone	3	0.181261	0.060420	9.67	<.001
V_cover	2	0.110489	0.055245	8.84	<.001
Depth	4	0.653806	0.163451	26.15	<.001
T_zone.v_cover	6	0.609964	0.101661	16.26	<.001
T_zone.depth	12	0.078030	0.006503	1.04	0.417

V_cover.depth	8	0.067309	0.008414	1.35	0.228
T_zone.v_cover.depth	24	0.091642	0.003818	0.61	0.919

%OC_LRS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
T_zone	3	0.56655	0.18885	7.10	<.001
V_cover	2	0.51120	0.25560	9.61	<.001
Depth	4	7.32126	1.83031	68.84	<.001
T_zone.v_cover	6	0.23230	0.03872	1.46	0.199
T_zone.depth	12	0.61918	0.05160	1.94	0.036
V_cover.depth	8	0.31509	0.03939	1.48	0.171
T_ZONE.V_COVER.DEPTH	24	0.90825	0.03784	1.42	0.110

%OC_SRS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
T_zone	3	0.24632	0.08211	3.41	0.020
V_cover	2	0.31587	0.15793	6.56	0.002
Depth	4	8.30194	2.07549	86.19	<.001
T_zone.v_cover	6	0.39709	0.06618	2.75	0.015
T_zone.depth	12	0.04303	0.00359	0.15	1.000
V_cover.depth	8	0.07467	0.00933	0.39	0.925
T_zone.v_cover.depth	24	0.16652	0.00694	0.29	1.000

SOCs_LRS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
T_zone	3	21.911	7.304	2.88	0.039
V_cover	2	31.489	15.745	6.20	<.001
Depth	4	501.070	125.268	49.31	<.001
T_zone.v_cover	6	24.870	4.145	1.63	0.144
T_zone.depth	12	55.383	4.615	1.82	0.053
V_cover.depth	8	34.733	4.342	1.71	0.103
T_zone.v_cover.depth	24	90.008	3.750	1.48	0.089

SOCs_SRS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
T_zone	3	60.608	20.203	8.26	<.001
V_cover	2	46.666	23.333	9.54	<.001
Depth	4	747.273	186.818	76.35	<.001
T_zone.v_cover	6	12.842	2.140	0.87	0.516
T_zone.depth	12	13.753	1.146	0.47	0.930
V_cover.depth	8	13.380	1.673	0.68	0.705
T_zone.v_cover.depth	24	27.792	1.158	0.47	0.982

Appendix 2: ANOVA for the effects of topographical zones and vegetation types on evapotranspiration, runoff and soil water balance

Evapotranspiration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
T_ZONE	2	336.439	168.219	40.35	<.001
season	1	24246.869	24246.869	5816.21	<.001
V_COVER	2	21.910	10.955	2.63	0.086
T_ZONE.season	2	0.000	0.000	0.00	1.000
T_ZONE.V_COVER	4	10.580	2.645	0.63	0.641
season.V_COVER	2	5.290	2.645	0.63	0.536
T_ZONE.season.V_COVER	4	10.580	2.645	0.63	0.641

Runoff

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
T_ZONE	2	336.439	168.219	40.35	<.001
season	1	690.154	690.154	165.55	<.001
V_COVER	2	138.760	69.380	16.64	<.001
T_ZONE.season	2	0.000	0.000	0.00	1.000
T_ZONE.V_COVER	4	2.527	0.632	0.15	0.961

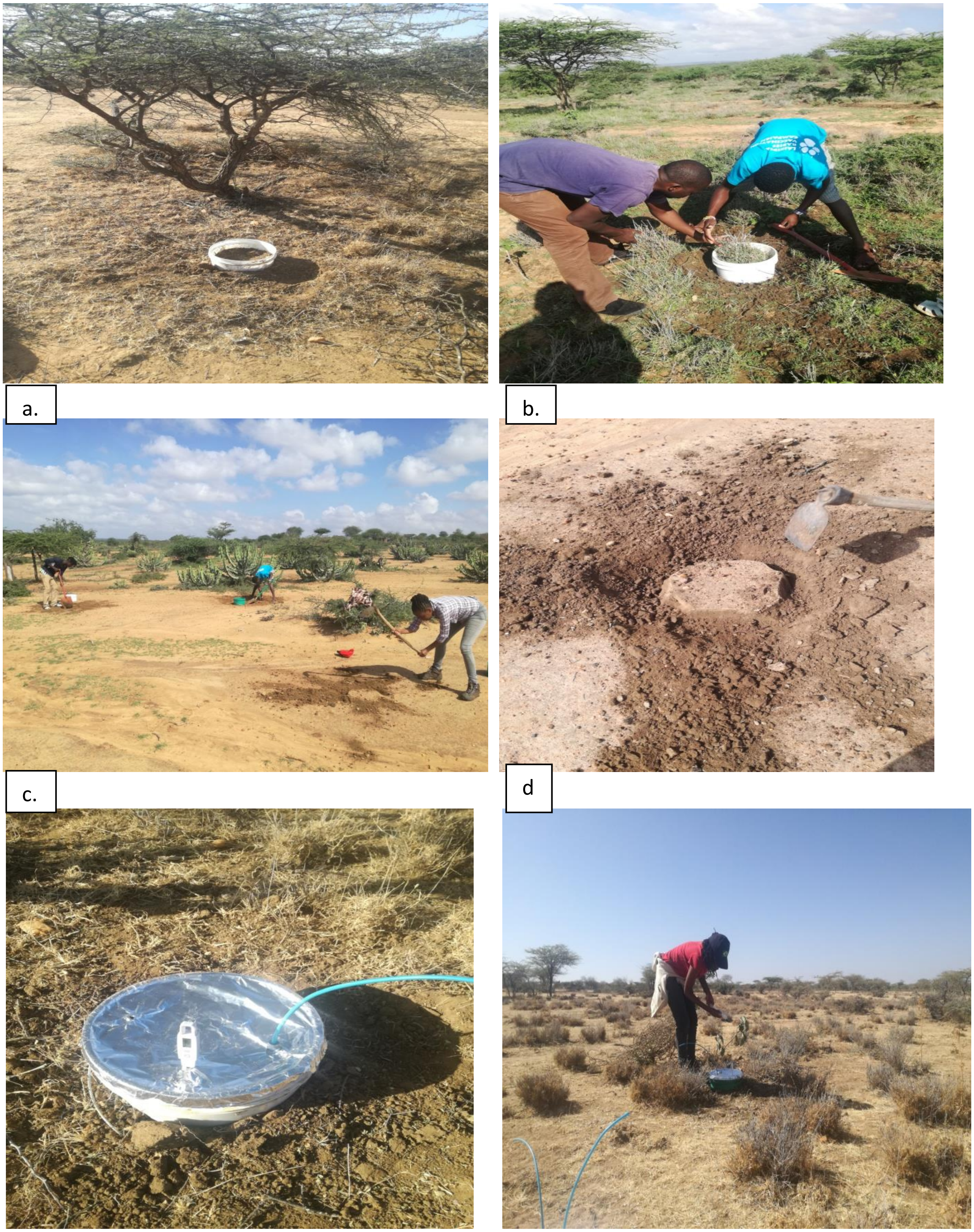
season.V_COVER	2	1.263	0.632	0.15	0.860
T_ZONE.season.V_COVER	4	2.527	0.632	0.15	0.961

Soil water balance

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
T_ZONE	2	1345.76	672.88	40.35	<.001
season	1	345470.41	345470.41	20717.40	<.001
V_COVER	2	119.96	59.98	3.60	0.038
T_ZONE.season	2	0.00	0.00	0.00	1.000
T_ZONE.V_COVER	4	2.77	0.69	0.04	0.997
season.V_COVER	2	1.38	0.69	0.04	0.959
T_ZONE.season.V_COVER	4	2.77	0.69	0.04	0.997

Annex 1: Field demarcation and soil sampling

Annex 2: Run-off plots



Annex 3: GHGs chambers installation