METHANOGENIC AND CARBON SEQUESTRATION OF INDIGENOUS AND INTRODUCED GRASSES AND CATTLE METHANE EMISSIONS IN RANGELAND ECOSYSTEMS OF SOUTH EASTERN KENYA

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A Thesis Submitted to the Graduate School in Partial Fulfillment of the Requirements for the Master of Science Degree in Livestock Production Systems of Egerton University

EGERTON UNIVERSITY
OCTOBER 2022

DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been presented in this university or any other for the award of a degree.

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DEDICATION

I dedicate this thesis work to my parents Mr and Mrs Bernard Maweu Mbonge and the entire family for their invaluable financial, moral and spiritual support towards ensuring that I get the best in life and education; lovely daughter Triza Mutheu and challenge her to endeavour on achieving more. Thank you and God bless you abundantly.

ACKNOWLEDGEMENTS

Firstly, I thank Almighty God for the good physical and mental health and for seeing me through the academic journey. Secondly, I profoundly thank Egerton University's Graduate School and the Department of Animal Sciences for the opportunity to pursue postgraduate studies. Thirdly, I thank the Center of Excellence in Sustainable Agriculture and Agribusiness Management (CESAAM) for funding my master's studies. Fourthly, I thank the University of Nairobi (UoN) Animal production laboratory, National agricultural research laboratory (NARL), Arid and rangelands research Institute of Kenya Agricultural and Livestock research organization, and International Livestock Research Institute (ILRI) for allowing me to use their laboratory facilities. Fifthly, my sincere gratitude goes to my resourceful supervisors; Prof. Bockline Omedo Bebe, Dr Olivier Basole Kashongwe, and Dr Simon Gichuru Kuria for their invariable technical advice and guidance. Sixthly, I thank my parents Mr and Mrs Bernard Maweu Mbonge for their endless financial and moral support during my study period. Thank you all for making this study a success.

ABSTRACT

Predominant and adaptable grasses utilized for ruminant production in the rangelands of South Eastern Kenya are low in biomass yield and quality while their methane emission and carbon sequestration are not documented. These grasses include *Eragrostis superba* (*E. superba*), *Cenchrus ciliaris* (*C. ciliaris*), *Panicum maximum* (*P. maximum*), and *Enteropogon macrostachyus* (*E. macrostachyus*). Towards realizing improved ruminant productivity in the rangelands, some higher biomass-yielding grasses with better quality and low moisture demand (*Brachiaria* hybrid variety *Brachiaria cayman, Brachiaria cobra* and *Chloris gayana* varieties Boma rhodes and Extozi rhodes) have been introduced. However, this intervention is being implemented without the knowledge of their potential in mitigating greenhouse gas emissions in the rangeland ecosystems to support sustainable ruminant production. To resolve this knowledge gap, this study assessed the utilization of three indigenous and two introduced grass species to determine i) digestibility and methane emission using an *in-vitro* gas production technique in which rumen fluid was incubated for 72 hours and gas was sampled after every three (3) hours to determine methane concentration using gas chromatograph; ii) carbon sequestration using carbon stock method, and iii) enteric methane emission estimates from ruminant livestock grazing rangeland ecosystems using IPCC Tier I and Tier II approaches. Field and experimental data were analyzed with general linear models and the means were separated with Tukey's HSD test. Relative to the indigenous grasses, the introduced grasses had higher crude protein content (74.05 g/Kg DM vs. 52.11 g/Kg DM), dry matter digestibility (34.13% vs 31.43%), organic matter digestibility (31.70% vs 29.27%) and NDF (712.7 g/Kg DM vs. 708.0 g/Kg DM). But they also had higher methane emission (25.61 ml vs 15.93 ml) and 24% lower in total carbon stock sequestration (9.2 tons C/ha vs 11.3 tons C/ha) and 23% lower in dry matter production (14.0 tons vs 17.3 tons /ha). The estimated methane emission and associated Global Warming Potential with Tier II were 4.4% higher than the estimates with the Tier I approach (Kg CH4/year of 9,279,526.80 vs 8,889,997; kg CO2eq of 259,826,750.4 vs. 248,919,916). Results suggest that the production of ruminants utilizing introduced grasses would achieve increased productivity with trade-offs on sustainability, at increased methane emission and low carbon sequestration. Use of IPCC Tier II marginally improved estimates of enteric methane emission and associated global warming potential for zebu cattle population grazing in the rangelands ecosystems of South Eastern Kenya.

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LIST OF ABBREVIATIONS AND ACRONYMS

AEZ	Agro-ecological zone
ADF	Acid Detergent Fibre
ADL	Acid Detergent lignin
AGB	Above Ground Biomass
ANOVA	Analysis of Variance
ARLRI	Arid and Rangelands Research Institute
ASALs	Arid and Semi-Arid Lands
BGB	Below Ground Biomass
CO_2	Carbon dioxide
CH_4	Methane
DM	Dry Matter
DMD	Dry Matter Digestibility
DMI	Dry Matter Intake
ECM	Energy Content of Milk
EF	Emission Factors
FAO	Food and Agricultural Organization of the United Nations
FID	Flame Ionization Detector
GC	Gas Chromatogram
GE	Gross Energy
GEI	Gross Energy Intake
GHG	Greenhouse Gas
GPT	Gas Production Technique
IPCC	Intergovernmental panel on climate change
IVDMD	*In -vitro* dry matter digestibility
IVOMD	*In -vitro* organic matter digestibility
KALRO	Kenya Agricultural Livestock Research Organization
Kg	Kilogram
LCF	Low opportunity Cost Feeds
MCF	Methane Conversion Factor
MEF	Methane Emission Factor
NARL	National Agricultural Research Laboratory
NDC	Nationally determined contribution

NDF	Neutral Detergent Fibre
OMD	Organic matter degradability
OM	Organic Matter
SEM	Standard Error of Mean
SOC	Soil Organic Carbon
SPSS	Statistical Package For the Social Sciences
UN	United nations
VFA	Volatile Fatty Acids

CHAPTER ONE

INTRODUCTION

1.1 Background information

Sustainable pasture-based ruminant production in the rangeland ecosystems contributes to the agenda of the development of the low-carbon economy. Implementing this agenda necessitates pasture management practices that check against associated high environmental costs including increased carbon and methane emissions, deforestation, loss of biodiversity and overgrazing. Minimizing greenhouse gas emissions and increasing carbon sequestration in soils are key pathways to mitigating climate change. Livestock producers need knowledge of pasture management practices that minimize greenhouse gas emissions and increase carbon sequestration. This is because 18 % (7.1 billion tons CO_2 equivalent) of the global greenhouse gases can be traced the livestock sector (Azizi *et al.,* 2017). Of this emission, 45% is attributed to the production and processing of livestock feed while 39% represents emission from enteric fermentation of feed by ruminant livestock. An estimated Production of pastures and feed crops is estimated to utilize 70% of the global agricultural land (Gerber *et al*., 2013; Ripple *et al* ., 2014).

Grass pastures are the basal diet of ruminants in rangelands, but the variable and changing climate impacts their quality and quantity needed to support ruminant production. This results from marked rainfall seasonality, more frequent drought events and increased carbon dioxide in the atmosphere. The variable and changing climate is one reason for poor quality pasture because of high lignification and low nitrogen content, leading to low digestibility and increased enteric methane emission as a byproduct during rumen enteric fermentation (Santos *et al.*, 2017).

In the rangelands ecosystems, ruminant production is a key contributor to people's livelihoods and utilizes both indigenous and introduced grasses. *Chloris gayana* variety Boma rhodes has been introduced from high-potential areas where they yield high biomass. However, when tried in arid and semi-arid lands (ASALs), their performance was significantly higher in biomass as that of *E. superba* (Mganga *et al*., 2021) which was poor when compared to performance in high-potential areas due to their low adaptation to harsh climatic conditions. Despite their lower performance in the ASALs, *Chloris gayana* varieties Extozi rhodes and Boma rhodes are still extensively promoted in the ASALs but evidence is scantly on their methanogenic and carbon sequestration potential. This is in spite widespread utilization in the ASALs of the indigenous perennial grass species such as *Eragrostis superba*, *Cenchrus ciliaris* and *Chloris roxburghiana* (Kidake *et al*., 2016) that are more adaptable, tolerant to high grazing intensity, heat and moisture stresses (Mganga *et al*., 2010; Mganga *et al*., 2015). These grass pastures provide ecosystem services in being carbon sinks and sequestrating CO_2 from the atmosphere through photosynthesis and storing it as carbon in soil and plant biomass. The deep-rooted improved pastures like *Brachiaria hybrid* species like *Brachiaria cobra, Brachiaria cayman* and *Brachiaria mulato II* are able to sequester carbon in soil and minimize the global effect of atmospheric CO_2. Management practices that achieve optimal stocking rate are essential to promote sustainable forage production as well as soil carbon sequestration. Overgrazing causes depletion of carbon in soils and reduced organic matter, which interferes with carbon sequestration, subsequently resulting in increased accumulation of CO_2 in the atmosphere, further worsening global warming.

Feed quality, production system and management practices are influential factors in methanogenic potential of pastures (Koech *et al*., 2016). High grazing intensity increases digestibility and nutritive value of herbage through prompting re-growth of pasture. This can also lead to overgrazing and decreased vegetation cover, thus changing soil temperature and availability of soil nutrient and carbon (Ren *et al*., 2016). Pasture improvement in the rangeland ecosystems should therefore prioritize grasses with multiple attributes of low methane emissions and a high carbon sequestration, biomass yield and nutritive value in order to check against associated environmental concerns.

Though ruminant production support livelihoods in the rangelands ecosystems from utilizing both indigenous and introduced grasses, there is evidence of association with overgrazing, resulting in degradation of the grasslands (Bolo *et al*., 2019). Overgrazing induces imbalances in energy flow and material cycles, which has implications on the sustainable use of grassland ecosystems (Cao *et al*., 2019). The potential environmental costs associated with production and utilization of livestock feed could be checked with grass pastures that poses multiple attributes of low methane emissions, high carbon sequestration and high nutritive value to ruminants.

In the rangelands ecosystems, producing and utilizing indigenous and introduced grass pastures for ruminant production should support increased productivity with minimized greenhouse gas emissions and increased carbon sequestration to mitigate climate change. Land use changes that expand pasture lands can lead to deforestation, loss of biodiversity and increased carbon emissions. The environmental concerns can only continue to worsen with the increasingly variable and changing climate, especially in the absence of deliberate interventions towards sustainable production and utilization of pastures for ruminant production.

Methane emissions associated with ruminant enteric fermentation and manure management can be quantified using three inventory approaches. These are a constant emission factor (EF) per animal head so termed IPCC Tier I method, dynamic EF so termed IPCC Tier II approach and more detailed dynamic so termed Tier III approach. The application of Tier I approach ignores production, body weight and succession of breeding and feeding systems, while Tier II approach accounts for these dynamic processes, which has influence on the EF estimates. The Tier III uses actual measurements of dry matter intake for gross energy and methane conversion factor (MCF). Application of Tier II and Tier III improves methane estimation in any livestock production systems which is necessary in reporting Nationally Determined Contributions that each country has to report to the United Nations (UN) periodically.

1.2 Statement of the Problem

Locally adaptable grass species such as *Eragrostis superba*, *Cenchrus ciliaris, Panicum maximum* and *Enteropogon macrostachyus* sustain ruminants production in the rangelands (Ndathi *et al*., 2011), but they are low in biomass yields and nutritive quality. Faced with a growing need to increase ruminant productivity in the rangelands, development agencies have introduced some higher biomass yielding grasses with better quality and low moisture demand like *Brachiaria* hybrids (*Brachiaria cayman, Brachiaria cobra, Brachiaria mulato II*) and *Chloris gayana* variety Boma rhodes and Extozi rhodes*)*. However, this intervention is being implemented without the knowledge of whether higher biomass yield and better quality of introduced grasses is accompanied with a reduction in greenhouse gas emissions and increased carbon sequestration in the rangeland ecosystems to support sustainable ruminant production. This is because sustainable pasture management and livestock production in rangeland ecosystems should not only support increased productivity but also minimised greenhouse gas emissions and increased carbon sequestration to mitigate climate change. This necessitates the search for grass pastures with multiple attributes of high biomass yield, high nutritive value but with low methane emissions and high carbon sequestration potential. Moreover, in the rangeland ecosystems, ruminant animals graze extensively on poor and degraded pastures to support livelihood and cope with drought risk which is likely to contribute substantial volumes of enteric methane emissions and to GWP, yet this has attracted limited research to document methane emission and their associated GWP hence empirical evidence remains not availed to inform threats to sustainable use of grassland ecosystem.

1.3 Objectives

1.3.1 Broad objective

To contribute to sustainable rangeland livestock production through identification of grass species with multiple attributes of high biomass yield and nutritive value accompanied with a low methane emission and a high carbon sequestration under rangeland ecosystems.

1.3.2 Specific Objectives

i. To determine the digestibility and methane emission of indigenous and introduced grass species under the Makueni rangeland ecosystem

ii. To determine carbon sequestration potential of indigenous and introduced grass species under the Makueni rangeland ecosystem

iii. To estimate enteric methane emission of cattle population in Makueni rangeland ecosystem using IPCC Tier I and Tier II approaches.

1.4 Hypotheses

i. Digestibility and methane emission are not significantly different between the indigenous and introduced grass species in Makueni rangeland ecosystems

ii. Carbon sequestration potential is not significantly different between the indigenous and introduced grass species in Makueni rangeland ecosystem

iii. Estimates of the enteric methane emission for ruminant animals in Makueni rangeland ecosystem are not substantially different between IPCC Tier I and Tier II approaches.

1.5 Justification of the study

Ruminants' enteric methane emission contributes greatly to climate change through emitting greenhouse gas to the atmosphere. Influencing this are the feed quality, production system and management practices of livestock. Determination of methane emission potential of rangeland grass pastures and their ability to sequestrate carbon will inform selection of grasses for livestock production. The selected grasses will support high productivity with capacity for high carbon sink and low GHG emissions for sustainable ruminant production thus, a contribute to the agenda of development of low carbon economy that checks against increasing high environmental costs. In addition, Estimation of enteric methane emission of cattle in the rangeland ecosystem will show the contribution of livestock sector to the countries nationally determined contribution (NDC), contribute to improved national greenhouse gas inventory and provide basis for better quantification of mitigation target.

CHAPTER TWO

LITERATURE REVIEW

2.1 Characteristics of rangeland ecosystems

Rangeland refers to type of land in Arid and Semi-Arid Lands (ASALs) region which is managed as natural ecosystem and supports indigenous vegetation mainly grasses, grass-like plants, forbs or shrubs (Godde *et al*., 2018). It also supports production of domestic grazing and browsing livestock (Allen *et al.,* 2011). It occupies about half of the world's land area and 80% of Kenya's land (Mwang'ombe *et al*., 2011). Globally, it contributes to the livelihoods for millions of people (Godde *et a*l., 2020) through provision of food, social, economic and resilience to climate shock. It is characterized by low and/or erratic rainfall of (300-500 mm/year for semi-arid and less than 300 mm/year for arid region), poor drainage, rough topography, and often-low soil fertility. Rangelands also provide essential ecosystem services such as climate regulation, carbon sequestration that help in mitigation of greenhouse gases like carbon dioxide. Rangelands includes natural grasslands, wood lands, wetlands, shrub lands and deserts that are grazed by wild herbivores or domestic livestock and managed by controlled livestock grazing and prescribed fire. Rangelands contains more than 33% of above and below ground carbon reserves (Silveira *et al*., 2012) and store 20-25% of global terrestrial carbon in soil and vegetation (Contant *et al.,* 2012) and it is altered by invasive species, climate change, soil degradation and vegetation change.

2.2 Rangeland pastures

Rangeland pastures are native vegetation in the rangeland areas maintained by grazing and fire. They include grasses and grass like plants amongst them are indigenous perennial grass species, such as *Cenchrus ciliaris, Eragrostis superba* and *Enteropogon macrostachyus* (Mganga *et al.,* 2015). The rangeland pastures are highly adapted to grazing pressure and have a high potential for reseeding degraded ASALs areas (Mganga *et al.,* 2010). Most of the rangeland grasses are perennial in nature and are characterized by rapid establishment and deep rooting systems hence potential carbon sinks in the rangeland ecosystem (Tessema *et al*., 2021). In addition, their high adaptation nature enhances their capacity for the rehabilitation of degraded lands. Kidake *et al.* (2016) in their study reported that *Enteropogon macrostachyus, Eragrostis superba, Chloris roxyburghiana* and *Cenchrus ciliaris* as the most common Kenyan rangeland grasses pastures. They also reported the same grasses suitable for reseeding and pasture improvement. They further reported that *Sorghum drummondii,* Columbus grass, *Panicum maximum, Digitaria macroblephara, Themeda* *triandra*, *Chloris gayana* variety Extozi rhodes and *Cenchrus ciliaris* as the most common promoted native grasses in drylands of Kenya.

2.3 Methane emission potential of grasses

Ruminants are major contributors to global warming through enteric methane emission (Banik *et al*., 2013) with 39 % of the methane emission from livestock agriculture coming from enteric fermentation of feed by bacteria archaea in the rumen (Gerber *et al*., 2013). Methane emission from ruminants is influenced by the type of diet, level of feed intake and digestibility of the diet (Haque *et al*., 2018) and varies with agro ecological zones and seasons (Ndung'u *et al*., 2019). Improving the availability and digestibility of pastures increases ruminant stocking density leading to increased enteric methane emission. Sustainable stocking density in improved pasture should help mitigating greenhouse gas emissions as well as increasing livelihood. Poor quality feed is associated with low digestibility, high lignification and low nitrogen content, which leads to high enteric methane emission and decreased animal production performance (Santos *et al*., 2017). Fermentation of carbohydrates in the rumen produces hydrogen, carbon dioxide and volatile fatty acids (VFA). High fibre constituents (NDF, ADF) in ruminant feed shifts short chain fatty acids to production of more acetate and less propionate hence high methane production.

Pasture methane emission is depended on diet quality /feed chemical composition, presence of secondary metabolites such as condensed tannins and degradation of diet in the rumen (Meale *et al*., 2012). Tannins reduce methane production by reducing fibre digestion, reducing degradation of the plant protein in the rumen by binding with proteins, and direct inhibiting growth of methanogens (Haque *et al*., 2018). Methanogens are specialized group of microbes found in anaerobic rumen, which aid in methanogenesis process by utilizing H_2 and CO_2, which are the end products of rumen degradation as substrates to produce methane. The enteric methane emission from rumen fermentation is associated with a loss of energy for the animal and a reduced feed utilization efficiency (Benaouda *et al*., 2020). The energy lost could be of importance in production of animal source food like milk and meat.

Grazing cattle when fed on pasture legumes and herbs show lower methane emission compared to when fed on grass pastures. This is attributed to the fact that legumes are highly digestible with low fibre content (Banik *et al*., 2013). More mature pastures have high concentration of NDF, low CP that reduces their digestibility potential. The NDF concentration and forage digestibility are the key drivers of methane production in the rumen (Archimede *et al*., 2011; Cornelius *et al*., 2019; Doreau *et al*., 2016) and thus feeding ruminants with high quality pastures reduce methane emission while increasing animal productivity potential.

Screening of rangeland grasses for their nutritive composition and relating those attributes to potential methane production forms a basis for selection of suitable grasses with high potential mitigating climate change. The organic matter degradability (OMD) and energy content of feed determines the amount of short chain fatty acid produced which in turn determines the proportion of methane produced (Gemede *et al.*, 2014). The plant cell walls contents (NDF, ADL, ADF) and digestibility has high influence on methane production (Singh *et al.*, 2012). This is because the Organic matter (OM) digestion, fermentation of feed in the rumen and production of short-chain VFAs of forages are mainly dependent on proportion of cell wall composition in their tissues as well as presence of factors that hinder microbial access to walls (Van Soest,1994).Thus ,Carbohydrate and its fractions give a better estimate of *in- vitro* methane production from perennial grasses since they are better predicators of methane production by effecting rumen pH and its microbial population once fed to livestock (Singh *et al.*, (2012).

Koech *et al.* (2016a) in their study found out that the highly promoted range grass pastures in ASAL areas such as *Eragrostis superba*, and *Pennisetum purpureum* (Mganga *et al.*, 2015), contributed to CH_4 production through enteric fermentation. They further reported that *Brachiaria* hybrid (*Mulato II*) showed lower CH_4 production of 36.2 ml per g of DM digested followed by *Panicum maximum* and recommended breeding to improve the species in order to enhance quality and reduce the methane output.

2.4 Methodological approaches to quantifying enteric methane emission potential from Ruminants

Enteric methane emissions from ruminants arising from the fermentation of feed in the digestive tract form the most important source of anthropogenic CH_4 emissions. It is very challenging to measure enteric CH4 emissions from ruminants as the emissions arise from several point sources in an individual animal (exhalation, hindgut, manure). The point sources vary significantly in time. Methodological approaches commonly used to quantify the methane emission potential of ruminants include the *in-vitro* gas production technique, SF6 Tracer technique and Respiration chamber method.

2.4.1 *In-vitro* gas production technique

The *In-vitro* gas production technique (GPT) is used to simulate the ruminal fermentation of feed and feedstuff (Storm *et al.*, 2012). It employs the principle of fermenting feed under a controlled laboratory environment designed to mimic the rumen environment using natural microbes. It involves incubation of rumen inoculum with feed substrate and buffers under an anaerobic environment at 39^{o}C in gas-tight culture bottles for some time, usually 24, 48, 72, 96 or 120 hours. The total gas produced during incubation is measured and gas composition is analyzed. The output is reported as the amount of methane per gram DM. Using the *in-vitro* technique is easy to control fermentation conditions like pH and avoid variations observed in *in-vivo* since it uses the same ruminal inoculum obtained from several donor animals for all treatments. The *in-vitro* gas production technique is easy, less costly and can study large volumes of samples within a short time (Gemeda *et al*., 2014). Use of the *In-vivo* technique in screening the feeding values of grass pastures is expensive and time-consuming. Thus, methane output from a wide range of grass species can be studied using *in-vitro* gas production.

2.4.2 The SF6 Tracer Technique (sulfurhexafluoride tracer technique)

This is a technique used to quantify concentration of gases eructed and respired from mouth and nose of ruminant animal. It uses known source of inert tracer (SF6) inserted in the rumen; a major source of CH_4 (Berndt *et al*., 2014). It is used in examining energy efficacy of free-grazing and untethered animal by capturing real variability of animal intake and behavior. This makes it fit for determination of enteric methane emissions from large numbers of individual ruminant animals. Methane emission is measured if emission rate of tracer gas from rumen is known. The SF6 tracer gas technique allows direct rumen methane measurement without restricting animal from their feeding behavior and natural environment. It is best for free-grazing animals (Storm *et al*., 2012).

2.4.3 Chamber /respiration chambers technique

The respiration chamber method is the most accurate and precise means of measuring emissions of CH_4 and other gases like carbon dioxide (CO_2) and hydrogen gas ($H_{2)}$ coming from enteric fermentation of feeds in the digestive tracts of ruminant animal (Patino *et al*., 2012). It uses the principle of collecting and measuring all exhaled breath from animal in an open circuit respiration chambers. It is a standard method for estimating methane emission from ruminants in a controlled environment. It is a reliable method and measures stability of instrument. Creating an artificial environment is a challenge since created environment might affect normal behavior of animal like daily dry matter intake (DMI). This method is not suitable for free-grazing animals as the animal loses much gross energy grazing. The chamber method is more precise and gives precise methane estimates when compared to SF6 tracer technique (Storm *et al*., 2012).

2.5 Carbon sequestration potential of rangeland grasses

Plants including grass pastures are among the natural agents for carbon sequestration. Carbon sequestration is the process through which carbon dioxide (CO_2) from the atmosphere is captured and stored in carbon pools (Cook *et al*., 2013) over a long period of time. Pastures capture CO_2 from the atmosphere through photosynthesis and store it as carbon in plant carbon pools and in soil. Plants also return part of carbon to the atmosphere as carbon dioxide through respiration. Global ecosystem serves as a carbon sink through photosynthesis and storage of carbon dioxide in live and dead organic matter. Implementation of good pasture management practices such as fertilization, irrigation, and grazing management help in offsetting CO_2 emissions and mitigating climate change effects (Silveira *et al*., 2012). Pasture intensification to cater for feed scarcity leads to more biomass meaning more photosynthesis thus, much of CO_2 is converted into biomass, reducing carbon in the atmosphere and sequestering it in plant tissue as above and below ground biomass (Chavan *et al*., 2012). Net carbon sequestration is given by the difference between sequestration of carbon by plants and respiration of carbon by soil microorganism (West & Haake, 2014). Thornton *et al*. (2010) reported that *Brachiaria* hybrids like *Brachiaria mulato II* as being responsible for improved ruminant productivity and sequestering 29.5 tons per ha more carbon than natural rangeland vegetation.

2.6 Methodological approaches to quantifying carbon sequestration potential

Carbon sequestration potential of range grass pastures is commonly quantified using carbon stock difference method. These involves determination of the differences between carbon sequestration by plant (above and below ground biomass) and soil carbon respiration (West *et al.*, 2014).

2.6.1 Above and below ground biomass

Above ground biomass includes all living biomass above the soil (Grewer *et al.*, 2016).It is largely influenced by seasons, grazing intensity and fire. Increased grazing intensity, controlled fire and optimum rainfall increases the above ground biomass. Destructive method is highly recommended for estimation of above ground biomass in arid and semi-arid lands because it gives accurate results and it is cost effective (Kidake, 2014). Above ground biomass keeps on fluctuating but it is resilient and is able to recover even after shock such as drought and grazing intensity (O' Mara *et al*., 2012).

Below ground, biomass consists of all live roots below the soil surface excluding fine roots with less than 2 mm diameter (Chavan *et al.,* 2012). The fine roots are difficult to distinguish them empirically from soil organic matter hence excluded from below ground biomass. Season is a key factor influencing below ground biomass with fine roots decomposing much during dry season. The below ground biomass accounts for more than 40% of the total carbon stocks and biomass (Fidelis *et al*., 2012) with the greatest proportion of root biomass occurring in the top 30 cm of the soil profile.

2.6.2 Heterotrophic soil respiration

Heterotrophic soil carbon respiration refers to production of carbon dioxide when soil organisms /below ground organisms respire. Carbon is released from soil inform of CO_2 which is then converted to organic compound in process of photosynthesis. Soil temperature, soil moisture, nutrient content and level of oxygen in soil are key factors that control respiration (Chang *et al*., 2012).

2.7 Management practices used in boosting soil carbon sequestration

Soil carbon sequestration and carbon input are highly promoted by techniques used to improve forage production with aim of supporting /sustaining livestock stocking rate and high forage demand (Silveira *et al*., 2012). These techniques include improved pasture management practices like fertilization, irrigation, grazing management, the introduction of legumes, and the use of improved grass species. The use of these techniques helps in offsetting global warming effects which are necessary for mitigating climate change.

2.7.1 Pasture fertilization management

Fertilization of pastures to boost productivity and sustain livestock production plays a key role in climate mitigation and food security. Sustainability is achieved through increasing biomass production which in turn acts as a carbon sink by capturing carbon dioxide from the atmosphere and improving carbon-nitrogen ratios of residues returned into the soil (Conant *et al*., 2001). Moreover, the adoption of fertilizer management practices, e.g. chemical fertilization and manure application are the most efficient and effective manner to promote soil organic carbon (SOC) accumulation. Adding fertilizer (manure or chemical fertilizer) in areas deficient in nutrients helps in increasing crop yield and biomass, thus the crop residue and root carbon input to soil. Further, Maillard and Angers. (2014) in their study reported manure application and litter retention as the most predominant management practices that enhance SOC changes because they directly add Carbon to the soil. This is tied to the fact that complete crop residue removal for fodder and fuel, makes soils lack of organic matter input thus predisposing them to Carbon sources.

2.7.2 Introduction of legumes and use of improved grass species

Introduction and cultivation of Legumes in pasture fields play an important role in SOC sequestration due to their impact on the maintenance of promising soil Carbon to nitrogen ratios (Veloso *et al*., 2019). Legumes achieve these through the increased microbial activity and subsequent improvement of soil structure (aggregation) which is prompted by the addition of organic residues with a favorable carbon-to-nitrogen ratio. According to Kumar *et al*., (2018), Legumes, due to their nitrogen-fixing ability can store 30% higher SOC when compared to other species like grass pastures which in turn improves soil health and soil carbon content. The carbon sequestration potential of leguminous crops depends on the legume species, root morphology, and physiology, climatic condition, soil structure, and aggregation, prevailing cropping systems, and agronomic interventions during the crop growing period. Thus, the inclusion of legumes in the farming system significantly increases SOC sequestration potential more than other cropping systems due to the higher decomposition rate of legume residue than cereals as reported by Virk *et al.* (2021) in their study. On the other hand, the introduction of improved grass pastures under good management/irrigation enhances biomass production, soil health, and structure thus aiding in carbon dioxide capture from the atmosphere.

2.7.3 Grazing management

Grazing land have the capacity to sequester 20-30% of global carbon in soil and offset 20% of annual carbon dioxide emissions from land use and deforestation (Arneth *et al*., 2017). Grazing management practices such as stocking rate and rotational grazing management increase carbon sequestration of grazing land. An appropriate stocking rate promotes forage production as well as soil carbon sequestration (Reeder & Schuman, 2002). Well-managed grazing stimulates the growth of herbaceous species and improves nutrient cycling and digestibility of pastures (Schuman *et al.*, 2002) resulting in greater soil carbon sequestration than in non-grazed land. Storage of carbon in grasslands is influenced by grazing intensity, animal type, and grass species (Macsharry *et al.*, 2013) with improved management of extensive grazing lands providing large carbon sequestration potential (Follett *et al*., 2019) and intensive grazing reducing the concentration of carbon in the soil. Higher grazing intensity increases soil organic carbon in warm-season grass pastures since they can adapt to grazing pressure by having many rhizomes, but decreases soil organic carbon in cool-season grass pastures and decreases below-ground carbon and nitrogen pools (Abdalla *et al.*, 2018). According to Viglizzo *et al.* (2019) intensive and frequent grazing increases carbon removal from roots to allow the regrowth of vegetation thus high stocking density leads to increased carbon loss. Raymond. (2013) reported that heavy grazing decreases vegetation cover and above ground biomass, interfering with the sustainability of grassland which, without proper management, leads to the deterioration of the plant-soil system hence decreased carbon sequestration.

2.8 Methane emission estimates

Estimation of livestock GHG methane emission using methodological options provided by IPCC guidelines for national inventory is commonly done. The IPCC standard models commonly used include Tier I, Tier II, and Tier III. Tier I relies on default constant emission factors of developed countries derived from the literature (IPCC, 2006) and assumes that animals of different breeding status and age have the same emission and the emissions do not vary over time. Tier II uses dynamic emission factors, which better, defines animal productivity, management, and feeding. Tier III uses more sophisticated country-specific information than Tier II with actual animal measurement on GE intake and MCF for specific livestock categories. The Tier II estimation approach uses different formulas to estimate enteric methane emissions from ruminants. They include the formula used by Charmley *et al*. (2016) and Goopy *et al.* (2018) which is the formula used in this study that uses dry matter intake, Moraes *et al*. (2014) which incorporates the use of gross energy intake, and Benaunda *et al*. (2020) which uses dry matter intake and neutral detergent fibre.

CHAPTER THREE

INVITRO DIGESTIBILITY AND METHANE GAS EMISSION OF INDIGENOUS AND INTRODUCED GRASSES IN THE RANGELAND ECOSYSTEMS OF SOUTH EASTERN KENYA

Abstract

Various grass species with high biomass yield and low moisture demand have been introduced in the rangelands in order to realize increased ruminant productivity. However, this intervention ignores the methanogenic potential of the indigenous and introduced grasses, a necessary consideration for realizing increased productivity while minimizing methane emissions toward sustainable pasture and ruminant production. This study determined the digestibility and methane emission of three indigenous grasses: *Eragrostis superba (E. superba)*, *Cenchrus ciliaris* (*C. ciliaris), Enteropogon macrostachyus (E. macrostachyus),* and two introduced grasses; *Chloris gayana* variety Boma rhodes and Extozi rhodes. Samples of these five grasses (whole plant above ground) were collected from established pasture plots at a research station in the South Eastern rangelands of Kenya. The grass samples were collected using one-meter square quadrats for proximate, neutral detergent fibre (NDF) and acid detergent fibre (ADF) analysis using AOAC, (1990) method number 6.5.1and 6.5.2, respectively. *In-vitro* digestibility of the samples was conducted by incubation of the sample and rumen fluid for 72hrs at 39^{o}c and collecting gas emitted for quantification of methane concentration using a gas chromatograph fitted with flame ionization detector (FID). On average, relative to the indigenous grasses, the introduced grasses were higher in crude protein (74.05 g/Kg DM vs. 52.11 g/Kg DM), in digestibility (dry matter digestibility 34.13% vs 31.43%; organic matter digestibility 31.70% vs 29.27%) and in NDF (712.7 g/Kg DM vs. 708.0 g/Kg DM) but with higher methane emission (25.61 ml vs 15.93 ml). Methane production positively correlated with crude protein, neutral detergent fibre, acid detergent lignin, and *in-vitro* digestibility. It is concluded that ruminant production utilizing introduced grasses would achieve increased productivity but with a sustainability tradeoff of increased methane emission, which should be a sustainability concern in the rangeland ecosystems.

3.1 Introduction

Rangeland ecosystems support the largest proportion of ruminant production, but the predominant and adaptable indigenous grasses fail to support increased productivity. These grasses are low in biomass yield and poor in quality, which necessitated introduction of some grasses with higher biomass yield, better quality and low moisture demand in efforts to increase ruminant productivity. Though the indigenous grasses are highly adaptable and are the basal diet for grazing ruminants, their high lignification directly depress their quality and digestibility, which is likely to be associated with high methane emission intensities in the grazing cattle (Berndt & Tomkins., 2013). Improving pasture management, whether indigenous or introduced, is therefore a necessary intervention in the rangelands in meeting the rising demand for ruminant feed resource (Mganga *et al., 2015)* and to mitigate the negative effects of climate change on livestock production.

Some indigenous perennial grasses including *C. cilliaris*, *E. superba* and *E. macrostachyus* predominate grazed pastures in the rangelands (Ndathi *et al.,* 2011). However, they are low in protein quality and high in fibre content, and are vulnerable under climate variability and increased land use pressure (Mganga *et al*., 2013). When grazed they are likely to yield higher methane (CH_4) from enteric fermentation relative to temperate grasses, which have a low methane emission value (0.49g CH_4/Kg LW vs. 0.61g CH_4/Kg LW), as observed by some authors (Archimede *et al*., 2018; Berndt and Tomkins., 2013) when comparing ryegrass and rhodes grass. Tropical grasses improved for high biomass yield and quality like *Chloris gayana* has been introduced from high agricultural potential areas into low potential rangelands to supplement feed base (Shrestha *et al*., 2013). However, their response to high temperatures and low rainfall is poor compared to the indigenous grass pastures, because introduced grasses exhibit inability to cope low moisture stress. The introduced grasses are of high-quality with higher amounts of easily fermentable carbohydrates and less NDF, which can lead to increased feed intake, higher digestibility and passage rate and subsequently minimize CH_4 production (Waghorn *et al*., 2002).

Poor quality grass pastures on the other hand when consumed by ruminants emit higher amount of CH_4 as a by-product of anaerobic fermentation in the rumen increasing their global warming effect. The digestibility of pasture depends on its stage of growth with more mature pastures having higher fibre content and increased carbon to nitrogen ratio, which decrease digestibility hence inducing a higher CH_4 yield. It is therefore important to prioritize not only feed quantity but also quality, methanogenic and carbon sequestration potentials of grass pastures in the rangeland ecosystems for sustainable ruminant production.

Ruminant livestock is the largest contributor to CH_4 emission in the agricultural sector (O'Mara *et al*., 2011) through enteric fermentation of feed by the methanogenic archaea in the rumen. Ruminants accounts for 18% of the global CH_4 emission and 3.3 % of GHG (Patra, 2016). This also represents loss of 5 to 10% of animal Gross Energy intake depending on diet composition and intake level (Haque *et al*., 2014; Johnson and Johnson., 1995) which represents a loss of dietary nutrients that would otherwise have been used for production of meat and milk (Eckard *et al.,* 2010). Most of enteric CH_4 emission from livestock comes from large ruminants (Moss *et al*., 2000) due to their large rumen and it is influenced by quality and digestibility of the feed consumed (Archimede *et al*., 2011; Doreau *et al., 2016*). The highly digestible feed will have an increased feed intake and reduced enteric methane emission. Rumen microbes degrade structural plant fibre under anaerobic conditions to volatile fatty acids (VFA), CO_2 and $H_{2.}$ Among the products, H_2 is reduced using CO_2 with the help of methanogenic archaea in the rumen to form $CH_{4.}$ $2CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$ (Moss *et al*., 2000). Dietary manipulation involving for example improving feed resource base to utilize grass pastures with higher nutritive quality, high carbon sequestration and low CH_4 production would mitigate enteric CH_4 emission from extensive ruminant production systems. However, evidence is scanty on the characterization of CH_4 production potential of locally available grasses when fed to ruminant animals (Bezabih *et al*., 2013). Ruminants *in- vivo* studies are expensive, time consuming and require specialized facilities and resources. For this reason, researchers show interest on use of *in - vitro* techniques to simulate the *in- vivo* process (Melesse *et al*., 2013). The *in -vitro* technique can study large numbers of species within a short time and at a low cost. This study proceeded on testing the hypothesis of whether the digestibility and methane emission differs significantly between indigenous grasses (*E. superba, C. ciliaris* and *E. macrostachyus)* and introduced grasses (*Chloris gayana* varieties Boma rhodes and Extozi rhodes) under rangeland ecosystems. The results should inform on the grass species with co-benefits of high digestibility and nutritive value, and low enteric CH_4 emission for sustainable ruminant productivity under rangeland ecosystems.

3.3 Materials and methods

3.3.1 Study site

The study was conducted in Arid and Rangelands Research Institute (ARLRI) of the Kenya Agriculture and Livestock Research Organization (KALRO), where grass samples were collected from established pasture plots. The station is located at Kiboko in Makindu

Sub County of Makueni County (Fig 3.1), which is in the rangelands found in the South Eastern of Kenya. The area is in Agro Ecological Zone V at an elevation of 975 metres above sea level and lies within latitude 2° 10' and 2° South and longitude 37° 40' and 37° 55' East. The precipitation in the area follows bimodal distribution, with long rainy season from March to May and short rainy season from October to December. The area receives mean annual rainfall of 600 mm and mean annual temperature of 23^{o}C.The plots where grass samples were obtained had ferralsol soils ranging from sandy clay to loamy sand and were low in organic matter and highly vulnerable to erosion and biological degradation.

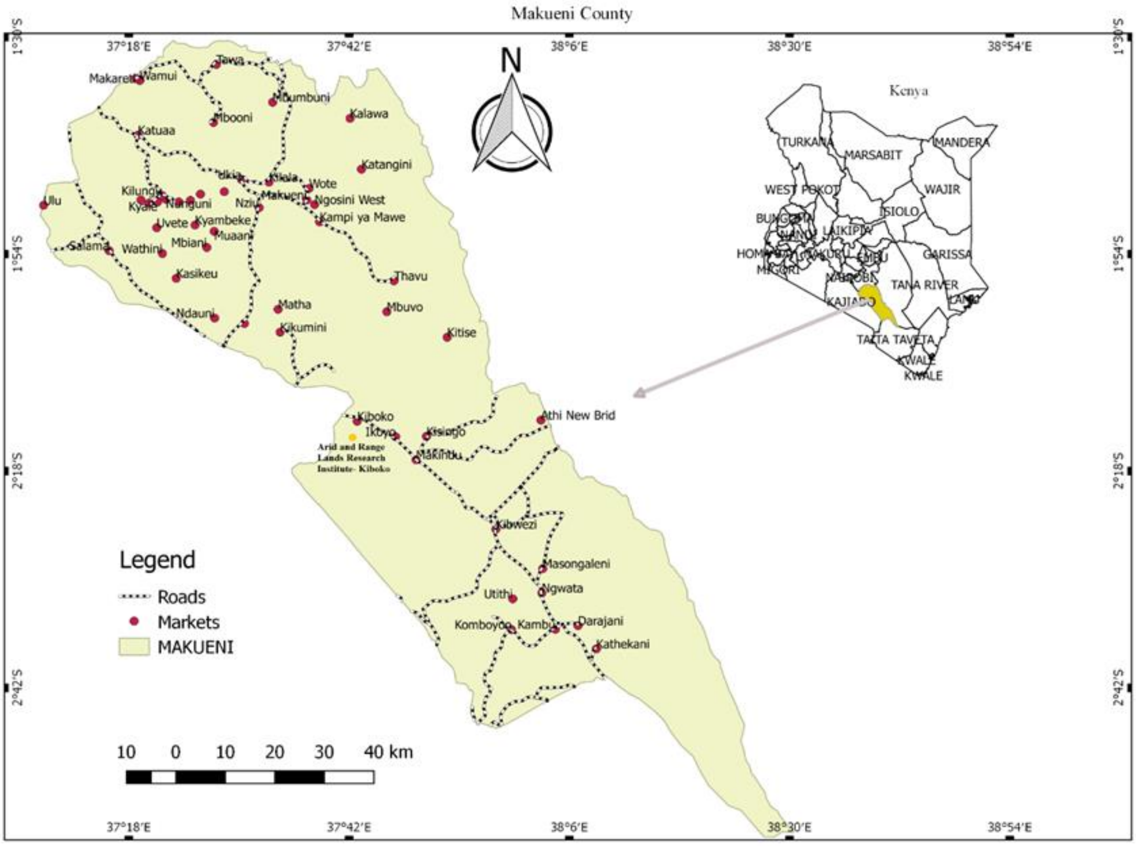


Figure 3.1 : Map showing KALRO Kiboko in Makindu Sub-county

3.3.2 Sampling of the grass species

The studied grass samples were of three indigenous (*E. superba*, *C. ciliaris* and *E. macrostachyus*) and two introduced (*C. gayana* varieties Boma rhodes and Extozi rhodes) species established in five plots (Fig 3.2). In each plot, a line transects of 20.62 metres was set. Three selected sub sites along the transect were taken and using one-meter square quadrats, above ground vegetation was cut at ground level when at bloom stage of pasture growth. The grasses were kept under a shade until transported to the Laboratory in ARLRI, where they were oven-dried at 65^{o}c for 48 hrs. For biomass yield determination, *in vitro* fermentation, methane gas emission determination and chemical composition analyses, the samples were ground to pass through a 1-mm sieve in a mill.

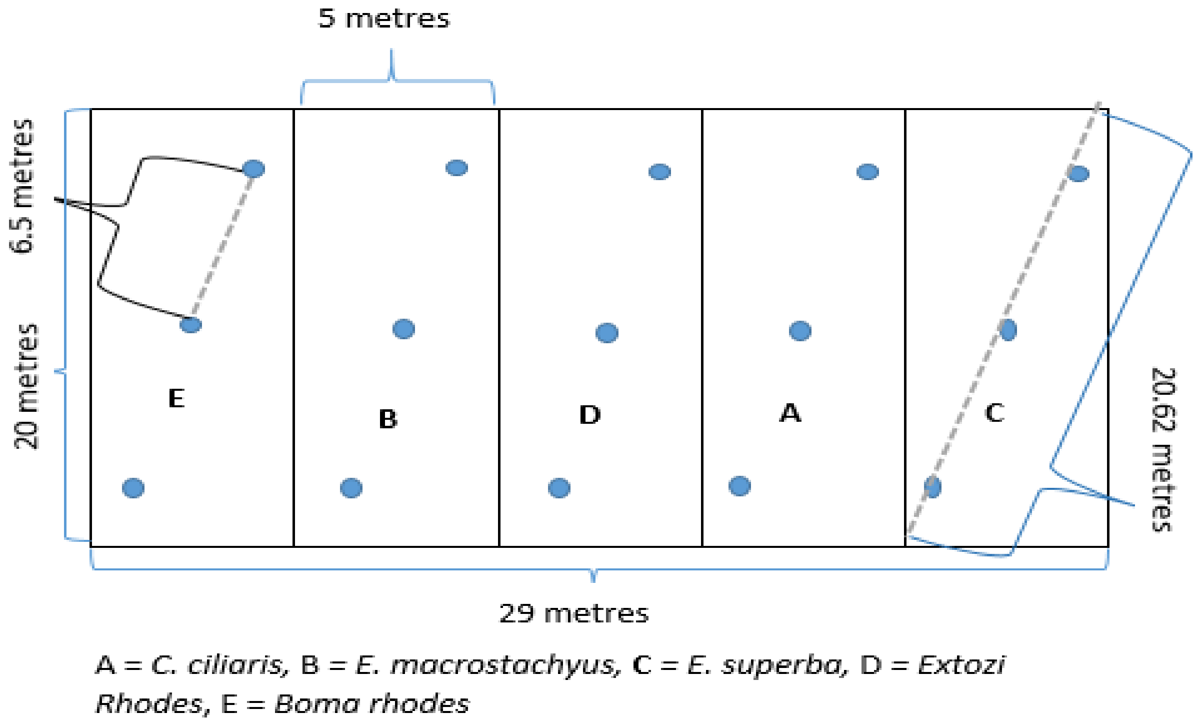


Figure 3.2: Sampling design for the experiment in the five established pasture plots

3.3.3 Determination of chemical composition of grass pastures

The ground samples of each grass species was collected for nutritive content analysis, to determine: True DM (at 105ºC for 24 h) in an air-forced oven (Genlab Oven, Genlab Ltd, UK.); Ash content by combustion in a muffle furnace at 550^{o}C for 4hrs (Heraeus M110 muffle furnace, Heraeus Holding GmbH, Hanau, Germany).This was according to AOAC method (AOAC,1990 method no.924.05).Total nitrogen (N) content was determined following Kjeldahl procedure (AOAC, 1990, method no. 988.05) using selenium catalyst tablets. The crude protein content was estimated by multiplying total N by a factor of 6.25. Further, samples were analyzed for neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) according to AOAC, (1990) method number 6.5.1, 6.5.2 and

973.18 respectively, using an Ankom 200 fibre analyzer (Ankom Technology cooperation, Fairport, USA).

3.3.4 Determination of potential digestibility of grass pastures

For *in-vitro* digestibility determination, samples of each of the five grass species collected was dried at 65°C and ground to 1mm thickness and *in-vitro* digestibility determined according to the method of Menke and Steingass. (1988) described by Abdulrazak and Fujihara. (1999). Rumen fluid was collected from fistulated Zebu steer fed on range grass pasture hay for 7 days and watered *ad libitum*. The rumen fluid was taken before morning feeding through the fistulae of the steer by hand and poured in a warmed thermos flask, then taken to the laboratory where it was strained through a double layer of cheesecloth to remove large particles. Strained rumen fluid was then mixed with buffer prepared at ratio of 3:1 (buffer: rumen fluid) to simulate action of saliva. One gram of each of the five grass samples was inoculated using 50 ml of the mixture in 100 ml gas tight graduated glass syringe barrel in triplicate. The syringe pistons were lubricated with petroleum jelly to ease movement and prevent escape of gas. Syringes were pre warmed at 39°C prior to inoculation of buffer mixture and incubated in water bath maintained at 39°C swirled gently at each reading and gas volume recorded at 3, 6, 9, 12, 24, 48 and 72 hrs. of incubation.

The samples and blank (rumen fluid + buffer) were also run in triplicates to determine gas produced due to endogenous substrates. Net gas produced was computed from the total increase in volume minus the mean blank value from the recorded gas production of all samples. From the computed gas production values, the model of Ørskov and McDonald, (1979) was applied to determine the degradability of the grass samples:

$$Y = a + b(1 - e^{-ct}) \quad \text{.........} \quad (i)$$

where,

Y=the volume of gas produced with time (t)

a=initial gas production,

b=gas produced during incubation,

c= constant gas production rate constant (fraction / hour),

t = time of fermentation

In this case, (a+b) represents the potential extent of the gas production.

The In-*vitro* dry organic matter degradability was calculated using equation of Menke and Steingass. (1988)

$ODM(\%) = 18.53 + 0.9239 * (GP\ at\ 48hrs) + 0.0540 * CP$ .... **(ii)**

where,

CP = Crude Protein,

GP = Gas production

3.3.5 Determination of methane emission of grass pastures

Gas production was determined according to the procedure used by Bhatta *et al.* (2007); Menke & Staingass. (1988). Gas samples were collected after every 3hr of incubation at 3, 6, 9, 12, 24, 48 and 72 hrs. from gas tight ground glass syringe barrel headspace using a 60 ml syringe and transferred to 10 ml glass vials according to Pellikaan *et al.* (2011). The collected gas samples were analyzed for CH_4 gas concentration using gas chromatograph (model 8610C; SRI at the International Livestock Research Institute, Nairobi) fitted with a methanizer on the Flame ionization detector (FID). The gas chromatograph was operated with Hayesep D packed columns (3m, 1/8″) with an oven temperature of 70°C, FID temperature of 350°C, and nitrogen (N_2) was used as carrier gas with a flow rates of 25mL /min. An auto sampler (Model HT200H; Hta) was used to inject 5ml of gas sample into the gas chromatograph system (GC). The detectors output was in the form of peak areas with milli -volts as the units. The peak area and retention time of CH_4 was measured, calculated and reported by digital processor which was then transferred to an excel work sheet for processing. The retention time for CH_4 was then compared to the known standard. The peak areas were then converted into concentration using a calibration curve generated using gases of known concentrations.

3.3.6 Experimental design and statistical analysis

The experimental design was Completely Randomized Design (CRD)

The model;

$Y_{ij} = \mu + T_i + \varepsilon_{ij}$.. (iii)

where,

Y_{ij}=observation on digestibility/methane emission of ith grass species on jth replication

μ= overall mean,

T_i= fixed effect of the grass species i

ε_{ij}=residual error

Data was subjected to general linear model procedure on Statistical Package for Social Sciences (SPSS version 22) to determine significance between the grass species in digestibility and methane emission and the means separated with Tukey HSD at 5% significant level.

3.4 Results

3.4.1 Nutritive value

Table 3.1 shows the nutritive values determined for the sampled three indigenous and two introduced grass species. The differences in nutritive value between the introduced and indigenous grasses are observed in CP and ADF but not in DM, NDF or ADL. For the CP, introduced grasses had higher content (67.13 -80.97 g/Kg DM) than the indigenous grasses (44.23 – 63.13 g/Kg DM), but results also show a higher ADF higher ($p<0.05$) in introduced grasses (440.7 – 449.2 g/Kg DM) than in indigenous grasses (388.6 – 401.0 g/Kg DM).

Table 3.1 : Chemical composition (g/Kg DM) of indigenous and introduced grass species

Grass	Species	DM	CP	NDF	ADF	ADL
Indigenous	*C. ciliaris*	97.64^{b}	48.97^{b}	670.3^{a}	395.8^{ab}	69.93^{a}
	E. superba	96.86^{a}	63.13^{c}	703.7^{b}	401.0^{b}	65.40^{a}
	E. macrostachyus	97.91^{b}	44.23^{a}	749.9^{d}	388.6^{a}	85.27^{b}
	Average	**97.47**	**52.11**	**708.0**	**395.1**	**73.50**
Introduced	*C. gayana* variety Extozi rhodes	97.63^{b}	80.97^{e}	702.5^{b}	440.7^{c}	63.00^{a}
	C. gayana variety Boma rhodes	96.98^{a}	67.13^{d}	722.9^{c}	449.2^{c}	78.00^{b}
	Average	**97.30**	**74.05**	**712.7**	**444.9**	**70.50**
	SEM	**0.101**	**0.761**	**1.60**	**2.31**	**1.52**
Grass effect		NS	**	NS	**	NS

DM= Dry mater, CP= Crude protein, NDF= Neutral detergent fibre, ADF= Acid detergent fibre, ADL= Acid detergent lignin $^{a-d}$Means within a column without a common letter superscript differ at $p<0.05$ Grass effect insignificant (NS) or significant at $p<0.05$ (**)

3.4.2 In -vitro dry matter digestibility and methanogenesis of indigenous and introduced grass species

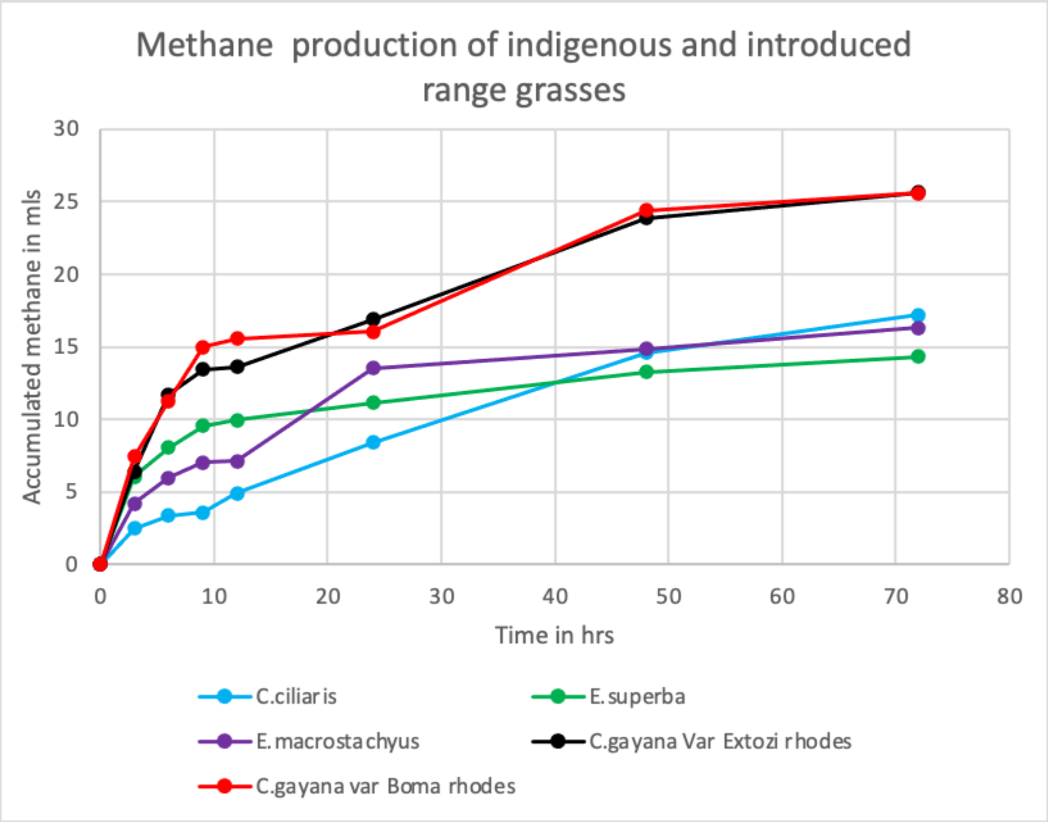
Table 3.2 presents the *in-vitro* digestibility and methanogenesis for the sample of three indigenous and two introduced grass species. The i*n vitro* digestibility of both dry matter and organic matter were higher ($p<0.05$) for the introduced grasses (dry matter 33.67 –

34.59%; organic matter 31.50 -31.89%) than for the indigenous grasses (dry matter 29.26 – 32.58%; organic matter 27.53 – 30.19%). However, methane production estimates at 72hrs was also higher for introduced grasses (25.57 -25.64 ml) than for the indigenous grasses (14.30-17.19 ml). The peak gas production was recorded in the between 36 - 48 hours (Fig 3.3).

Table 3.2: *In- vitro* dry matter ,organic matter digestibility and methane production estimates for three indigenous and two introduced grasses in the South Eastern rangelands of Kenya

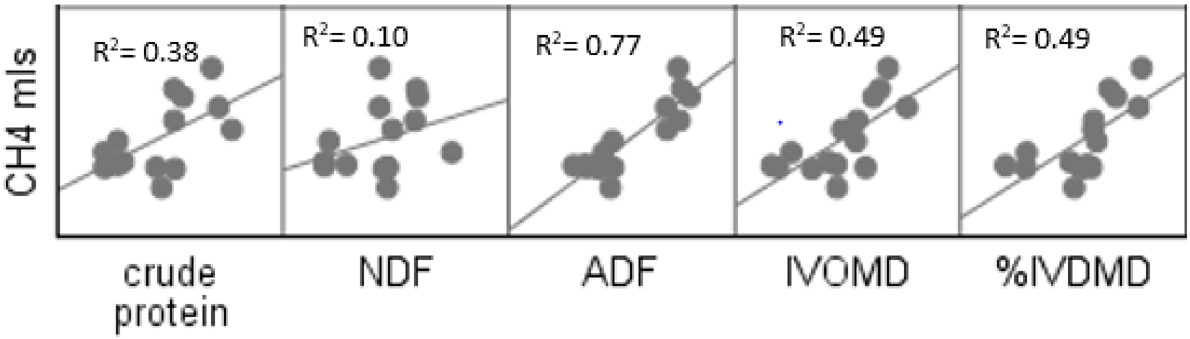
Grass	Species	*IVDMD* (%)	*IVOMD(%)*	CH_4 (ml/g DM)
Indigenous	*C. ciliaris*	32.58^b	30.19^b	17.19^a
	E. superba	32.45^b	30.08^b	14.30^a
	E. macrostachyus	29.26^a	27.53^a	16.29^a
	Average	**31.43**	**29.27**	**15.93**
Introduced	*C. gayana* variety Extozi rhodes	34.59^c	31.89^b	25.64^b
	C. gayana variety Boma rhodes	33.67^{bc}	31.50^b	25.57^b
	Average	**34.13**	**31.70**	**25.61**
	SEM	**0.283**	**0.331**	**0.977**
Grass effect		**	**	**

IVDMD=In-vitro dry matter digestibility, *IVOMD=* I*n-vitro* organic matter digestibility, CH_4 = methane gas produced $^{a\text{-}c}$Means within a column without a common letter superscript differ at p<0.05 .Grass effect insignificant (NS) or significant at p<0.05 (**)



C. ciliaris = *Cenchrus ciliaris*, *E. macrostachyus*= *Enteropogon macrostachyus*, *C. gayana variety* Boma rhodes, *C. gayana* variety Extozi rhodes, *E. superba* = *Eragrostis superba*

Figure 3.3 : In-vitro Methane production trend for the indigenous and introduced grass species incubated for 72hrs.



% IVDMD= *in-vitro* dry matter digestibility, IVOMD= *in-vitro* organic matter digestibility, NDF= Neutral detergent fibre, ADF= Acid detergent fibre

Figure 3.4: Relationship trend between chemical constituents and methane emission

Methane production showed a positive and significant ($p<0.05$) association with the IVOMD, IVDMD, CP and ADF but not NDF (Figure 3.4*)*. A strong significant positive trend was seen between CP, ADF, IVOMD and %IVDMD and CH_4 emission. These means that increase in CP, NDF, IVOMD and %IVDMD resulted to increase in CH_4 yield.

3.5 Discussion

Except for the CP, the nutritive composition of the indigenous and introduced grasses in the present study were comparable with the results of earlier reports in the same South Eastern rangelands of Kenya, from the studies of Koech *et al*. (2016b) and Ndathi *et al*. (2011). The CP content was significantly higher for introduced grass pastures (*C. gayana* variety Extozi rhodes*)* than for indigenous grass pastures (*C. ciliaris*, *E. macrostachyus* and *E. superba).* The CP content of the indigenous grasses was below the 70 g/Kg DM minimum requirement for rumen microbiota (Van Soest, 1994), considered necessary for the optimal breakdown of cell wall content. This means that utilization of these grasses for ruminants would supply sub-optimal nitrogen levels in the rumen, which restricts microbial growth and activity (Hariadi *et al*., 2010; NRC, 2000), consequently reducing feed intake and efficient ruminal fermentation.

The cell-wall contents (NDF, ADF and ADL) observed for both the indigenous and introduced grass species were above the critical value for tropical grasses. For instance, the NDF levels in the range of 670.3 to 749.9 g/Kg DM is above the critical value for tropical grasses of 600 g/kg to 650 g/kg DM (Van Soest *et al*., 1991). In feeds, NDF value beyond the critical value is associated with low digestibility, prolonged digesta retention time in the rumen, which reduces the fermentation rate and increases methane production (Doreau *et al*., 2016). These authors found NDF to have a significant influence on methane production than digestibility, implying a positive relationship between methane production and NDF concentrations. It would follow therefore that producing ruminants on these indigenous grasses presents a nutritional limitation to animal productivity, given that high NDF is associated with increased methane production. NDF is a key driver to hydrogen production from carbohydrate fermentation in the rumen (Cornelius *et al*., 2019; Doreau *et al.,* 2016) through the production of more acetate pathways and less propionate.

Though the introduced grasses were of higher digestibility and crude protein content than the indigenous grasses, the introduced grass species (*Chloris gayana* varieties Boma and Extozi rhodes) produced higher volumes of methane gas when compared to the indigenous grasses (*C. ciliaris, E. macrostachyus* and *E. superba*). A possible explanation could be the high fibre content particularly NDF, being highly influential in hydrogen production from carbohydrate fermentation (Archimede *et al*., 2011; Doreau *et al*., 2016). In addition, other fibre constituents like ADF, cellulose and hemicellulose which are important fibre fractions influencing CH_4 production in the rumen could also have been contributing factors in high methane production in the introduced grass pastures. The high NDF value modifies short fatty chain fraction towards acetate producing more hydrogen which is a major determinant in carbohydrate fermentations as observed by Migwi *et al*. (2013). These authors reported that intake of high fibre forages leads to a significant loss of feed energy as CH_4 gas production in ruminants. The findings of the present study were consistent with those of Melesse *et al*. (2017) who also observed a positive correlation between fibre constituent and CH_4 production. Even though the authors in the latter study observed higher CH_4 production than in the present study (20.9 – 30.80 ml/ g DM), it should be noted that their diets had higher *IVOMD* than the levels obtained in the present study.

The lower *in-vitro* digestibility of the indigenous grass species (*E. macrostachyus)* could be associated with high NDF and low CP levels. The low CP level could have supplied insufficient nitrogen for the proliferation of rumen microorganisms and hence lower fermentation levels compared to the other grasses. Additionally, the high NDF content in the grass could also mean a low supply of readily available energy to nourish the microbes hence further suppressing their activity to result in lower digestibility of the grass (NRC, 2000). The positive correlation between ADF, NDF and CH_4 production were in agreement with the results of Doreau *et al*. (2016), Gemede *et al*. (2014), Moss *et al*. (2000) and Singh *et al*. (2012). These authors reports made findings indicating that carbohydrate fractions /cell wall constituents as better methane predicators compared to feed components.

The positive correlation of CH_4 and CP constituents was in agreement with the report by Kulivand *et al*. (2015). This could be attributed to the fact that crude protein content above a critical threshold of 70 g/kg enhances rumen microbial multiplication in the rumen thus improving fermentation and reducing retention /exposure time of digesta to micro organisms' activity while CP values below this threshold restrict microbial activity (Hariadi *et al*.,2010*)* due to lack of nitrogen to support microbial proliferation. Both the indigenous and introduced grasses were high in fibre constituent (ADL, ADF, NDF), a major limitation to digestibility. The sample indigenous grass species in this study were of poorer nutritional value but lower methane gas production, relative to the introduced grass species. Indigenous grasses produced less CH_4 per gram dry matter of unit feed compared to the introduced grass pastures. Producing ruminants on the indigenous grasses thus would need nitrogen supplementation either inform of protein concentrates or leguminous fodder as recommended by other authors for such feeds (Korir *et al*., 2016; Sampaio *et al*., 2010). Though the introduced grass species would, with their high nutritive values, support increased productivity in ruminant feeding, it is concluded that ruminant production utilizing introduced grasses would achieve increased productivity but with sustainability tradeoff of increased methane emission, which should be a sustainability concern in the rangeland ecosystem. For ruminant production in the rangelands, the use of grasses with lower methane production might have the potential to mitigate methane emission and slow the Global Warming Potential.

3.6 Conclusion

Based on this study, the introduced grasses exhibited significantly higher digestibility and methanogenic potential relative to the indigenous grasses.

CHAPTER FOUR

DRY MATTER PRODUCTION AND CARBON SEQUESTRATION POTENTIAL OF SELECTED INDIGENOUS AND INTRODUCED GRASSES UNDER RANGELAND ECOSYSTEMS OF SOUTH EASTERN KENYA

Abstract

Feed interventions directed towards attaining increased ruminant productivity in the rangelands have prioritized introducing grasses with high biomass yield, better quality and low moisture demand. Yet, with the growing threats of climate change, the choice of grass species to feed ruminants for increased productivity needs to consider as well as enhancing carbon sequestration to mitigate climate change the impacts. This study determined dry matter production and carbon sequestration potential of three indigenous and two introduced grass species under rangeland ecosystems. The indigenous grasses were: Maasai love grass (*Eragrostis superba*), Foxtail (*Cenchrus ciliaris*), Bushrye (*Enteropogon macrostachyus*) and the introduced grasses were: *Chloris gayana* varieties Boma rhodes and Extozi rhodes. The study was in South Eastern rangeland of Kenya and data was collected during peak growing periods of short and long rain seasons from established pasture plots. Plant samples (above ground, below ground and litter) were harvested by randomly placing one-metre ($1m^2$) quadrats in each plot in triplicate. Soil samples were randomly collected from each plot at a depth of 0-20 cm, air-dried and analyzed for carbon content using the Chromic acid digestion method from each plot under selected grasses, bulk density was determined. Harvested plant samples were oven-dried for 48 hours to stable mass at 65^oC, ground (± 2mm size) and combusted in a muffle furnace at 550^oc for 4 hours to determine organic matter concentration. The results revealed that indigenous grasses were 24% higher in dry matter production (17.3 vs 14.0 tons/ha) and 23% higher in carbon stock (11.3 vs 9.2 tons) ($p<0.05$). The results imply that, the indigenous grasses would offer a co-benefit of higher dry matter production for livestock feeding and higher carbon sink capacity contributing to minimizing emission and global warming potential. This is beneficial to mitigating climate change when increasing ruminant production under often degraded rangeland ecosystems. With this evidence, the utilization of indigenous grass species is highly recommended for sustainable rangeland livestock production supporting increased productivity while minimizing carbon emissions.

4.1 Introduction

Extensive grazing of ruminants in the rangelands creates several interactions between livestock production and climate change. Ruminants emit methane, pasture sequester carbon, ruminant animals generate manure which recycles nutrients thus removing the need for inorganic fertilizer, and the production system is vulnerable to the climate change (Contant *et al.*, 2010; Gerber *et al.*, 2013; Rivera-Ferre *et al.*, 2016). Carbon sequestration through the use of grass pastures with high photosynthetic capacity, high biomass and the deep root system is an important climate change mitigation approach in the rangeland ecosystem through carbon dioxide capture. Carbon sequestration is the process of capturing and long-term storage of carbon dioxide as carbon in carbon pools. Grasses that ruminants graze in the rangelands can be an important carbon sink, yet there is scanty empirical evidence on their carbon dynamics and biomass yield (Fidelis *et al.*, 2012; Nijdam *et al.*, 2012).

Feed interventions in the rangelands to attain increased ruminant productivity have prioritized the introduction of grasses with high biomass yield, high nutritive quality value and low moisture demand. Yet, with the growing threats of climate change, the choice of grass species for ruminant production for increased productivity needs to consider as well enhancing carbon sequestration to mitigate climate change impacts. For instance, indigenous grass pastures like *Cenchrus ciliaris* (*C. ciliaris*), *Eragrostis superba (E. superba) and Enteropogon macrostachyus (E. macrostachyus)* can be utilized for ruminant production in the rangelands. They show good adaptation to climate shocks and too low soil moisture, which is manifested in their rapid establishment, faster growth rate and high biomass production (Kidake *et al*., 2016). Added to these are co-benefits of sequestering carbon from the atmosphere by capturing carbon dioxide during photosynthesis and storing it in carbon pools (above-ground biomass, below ground biomass and in the soil as soil organic carbon). These have been articulated by Soussana *et al*. (2010). Their deep rooting system enhances the storage of soil organic carbon (SOC) deep in subsoil. Grass pastures store much of carbon in the below-ground biomass (Fidelis *et al.*, 2012; Liu *et al*., 2010) and the top soil layers within 30 cm (FAO, 2019).

Despite indigenous grasses manifesting co-benefits in sustainable ruminant production in the rangelands, the interventions have instead utilized grass species introduced from high rainfall areas (*Chloris gayana* variety Extozi and Boma rhodes) to increase animal productivity (Mganga *et al*., 2015). This ignores that utilization of these introduced grass species under rangeland could potentially accelerate animal contribution to a large portion of global carbon footprint (Ripple *et al*., 2014) in greenhouse gas emission through transportation, fertilizer application and enteric fermentation. Utilizing grasses with a high capacity for carbon sequestration in ruminant feeding can substantially offset greenhouse gas emissions from ruminant production systems (FAO and IFAD, 2021). This involves stocking carbon while producing livestock products and mitigating climate change (Seo *et al.*, 2017). Conservation of ecosystems is necessary to avoid losing carbon since losing carbon is easy than building carbon stock (Smith, 2014; Soussana *et al.*, 2010).

It is possible to implement the agenda of low carbon livestock development through pasture establishment and utilization by informing livestock producers to utilize grass pastures with a high capacity for carbon sequestration in soils. However, there remains limited research on the role of grass pastures as potential carbon sinks (Odiwe *et al.*,2016). This is linked to their short term carbon storage nature. This study addressed this knowledge gap area by determining dry matter production and carbon sequestration potentials of three indigenous grass species (*E. superba*, *E. macrostachyus* and *C. ciliaris)* and two introduced grass species (*Chloris gayana* Variety Extozi and Boma rhodes*)* in rangeland ecosystems of South Eastern Kenya.

4.3 Materials and methods

4.3.1 Study site

The study was conducted in Arid and Rangelands Research Institute (ARLRI) of the Kenya Agriculture and Livestock Research Organization (KALRO). The station is located at Kiboko in Makindu Sub County of Makueni County, which is in the rangelands found in the South Eastern Kenya. The area is in Agro Ecological Zone V at an elevation of 975 metres above sea level and lies within latitude 2° 10' and 2° South and longitude 37° 40' and 37° 55' East (Fig 3.1). The precipitation in the area follows bimodal distribution, with long rainy season from March to May and short rainy season from October to December. The remaining months in calendar year comprises the dry season. The area receives mean annual rainfall of 600 mm and mean annual temperature of 23^{o}C.

The grass samples were collected from established pasture plots that were seven years old. The plots where grass samples were obtained had Ferralsols soils ranging from sandy clay to loamy sand that were low in organic matter and highly vulnerable to erosion and biological degradation.

4.3.2 Sampling design

Sampling was in a Completely Randomised Design (CRD). *S*amples for the experiment were collected in triplicate from already established seven years old grass pasture plots.

Sampling was done at the peak of the growing period during the short rains, in January 2020, to coincide with the peak growing period for the October – December short rainy season and in May 2020 to coincide with peak growing period for March – May long rain season. In each plot, a line transects of 20.62 metres was set. Three selected sub sites along the transect were identified as illustrated in Fig 3.2.

4.3.3 Determination of dry matter production (biomass) of experimental grass pastures

The above-ground biomass of the grass samples studied was collected in triplicate using randomly positioned 1 m^2 sized quadrants in triplicate. This applied to each of the established plots at the peak of growing period for the two seasons. All the above-ground material within the quadrant were collected through destructive harvesting by clipping to ground level, then packing in a sampling bag, ready for laboratory determination of biomass. The litter material on the above ground was also collected. The samples were then put in oven for oven drying at 65˚C to constant weight for 48 hours, cooled, weighed, recorded and ground through a 2mm mill. The biomass of the sampled grass pastures was determined from the oven dry weight of the sub-samples at 65˚C, which was then converted to total dry biomass weight per unit area of $1m^2$ following the equation (i) used by Pearson *et al.* (2005) and later extrapolated to one hectare area.

$$TDB = \frac{ODWSS}{WWSS} * WWTS \text{..(i)}$$

where

TDB = Total dry biomass in one metre square, ODWSS= Oven dry weight of sub –sample, WWSS= Wet weight of sub sample, WWTS= Wet weight of total sample per hectare

4.3.4 Estimation of carbon stocks in above ground biomass (AGB)

After grinding the AGB and litter, the resulting samples were analyzed for ash concentration by combustion in a muffle furnace at 550^oC for 4 hours (Heraeus M110 muffle furnace, Heraeus Holding GmbH, Hanau, Germany). This was then used to calculate the percentage of organic carbon concentration according to equation (ii) as used by Allen *et al.* (1986):

$$Cconc\% = (100 - Ash\%) * 0.58 \text{ .... (ii)}$$

where

Cconc % = percentage organic carbon concentration, 100 - Ash%= organic matter, 0.58= mass of organic matter.

The percentage organic carbon concentration obtained was then used to compute, carbon stocks using the equation (iii):

$$Carbon\ stock = Cconc\% * dry\ matter\ weight \ldots\ldots\ldots\ldots\ldots\ldots \text{(iii)}$$

where; *Carbon stock* = carbon stored in above ground carbon pool in tons / hectare, *Cconc%* = percentage organic carbon concentration, *Dry matter weight* =Dry biomass of the above ground material in one hectare.

4.3.5 Estimation of carbon stocks in below-ground biomass (BGB)

Soil samples along with roots were collected from the same plots after collecting samples for AGB using soil auger in triplicate during the two peak collection times. The soil samples were then processed by crumbling by hand to extract the roots then packaged for laboratory analysis. Extracted roots were washed with water over a sieve to remove soil. Cleaned roots were oven-dried at 65^{o}C, periodically weighed and removed from the oven when the mass stabilized (48 hours). The extracted root biomass was then ground to achieve 2 mm mill and used for determining ash content by combusting in a muffle furnace at 550^{o}c for 4 hours. Carbon stock stored in the roots biomass was then calculated using equation (ii).

4.3.6 Estimation of soil organic carbon (soil carbon)

Soil samples were randomly collected from each of the plots where samples for above and below-ground biomass were previously collected to a depth of 20 cm using a soil auger in triplicate. Processing involved bagging, labelling, ready for laboratory analysis. In the laboratory, each soil sample was air-dried, passed through a 2-mm sieve for determination of percentage organic carbon content using the Chromic acid digestion method (Walkley-Black method, 1934).

Soil samples for determination of bulk density were collected using core ring at 0-30cm depth down the profile from each plot in triplicate. The collected samples were then oven dried at 105°C to constant weight and weighed to obtain the mass of dry soil. The volume of the cylindrical core ring was also calculated to obtain the volume of the dry soil in the core ring. The soil bulk density was then determined by dividing the oven dry weight by the volume of cores according to Blake and Hartge. (1986) as shown in the equation (iv) below

$$Y = Md/Vd \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(iv)}$$

where ;Y = Bulk density of dry soil (Kg/m^{3}), Md = Mass of dry soil in Kg

Vd = volume of dry soil in M^{3}

The soil bulk density obtained was then used to convert soil carbon concentration to mass carbon per unit area ($1M^2$). Soil organic carbon stock was then calculated using the equation (v) expression.

$$SOC_{stock} = C * BD * D \ldots\ldots (v)$$

Where SOC_{stock}= soil organic carbon stock (tons C per hectare), C=Carbon concentration in the soil, BD =Bulk density (Kg/m^3), D=soil depth in meters.

4.3.7 Total carbon stock ($C_{total\ stock}$)

Total carbon stock (tons /ha) of each grass species was obtained by summation of carbon stock in carbon pools using the equation (vi)

$$C_{total\ stock} = C_{AG} + C_{BG} + C_L + C_{Soil} \ldots\ldots (vi)$$

Where C_{AG} is above ground carbon, C_{BG} is below ground carbon, C_L is litter carbon, and C_{Soil} is soil carbon

4.3.8 Statistical analysis

The experimental design used was Completely Randomized Design (CRD), the model fitted was as expressed in equation (vii) below:

$$Y_{ij} = \mu + \alpha_i + \varepsilon_{ij} \ldots\ldots (vii)$$

where; Y_{ij} = Carbon sequestration potential of i^{th} grass pasture on j^{th} replication , μ =overall mean; α_i= fixed effect of grass pasture i; ε_{ij}=Residual error associated with i^{th} grass pasture and j^{th} replication

The data was subjected to Analysis of variance (ANOVA) using the Statistical Package for Social Sciences (SPSS version 22). The level of significance was set at $p < 0.05$ for detecting grass effects on dry matter production and carbon stock. The separation of the means proceeded with Tukeys HSD procedure for multiple mean comparisons.

4.4 Results

4.4.1 Above and below ground dry matter production

Table 4.1 presents the results of the dry matter production of the above and below-ground biomass for the samples of indigenous and introduced grass species. The dry matter production in the AGB and BGB were both on average lower ($p < 0.05$) for the introduced grass (12.6 ton /ha) species when compared to the indigenous grass species (14.9 tons/ha). The above-ground biomass was lower for the introduced grass species (*C. gayana* variety Extozi rhodes (12.0 tons/ha) and *C. gayana* variety Boma rhodes (13.2 tons/ha) than the estimates for the indigenous grasses (*C. ciliaris* 14.4 tons/ha, *E. superba* 6.2 tons/ha and *E. macrostachyus* 14.0 tons /ha). Similarly, the below-ground biomass was lower for the introduced grasses (*C. gayana* variety Extozi rhodes 1.4 tons/ha and *C. gayana* variety Boma rhodes 1.3 tons/ha than the estimates for the indigenous grasses (*C. ciliaris* 3.4 tons/ha, *E. superba* 2.6 tons/ha and *E. macrostachyus* 1.3 tons/ha).

Grass	Species	Above-ground biomass (tons DM/ha)	Below-ground biomass (tons DM/ha)
Indigenous	*C. ciliaris*	14.4^{bc}	3.4^{c}
	E. superba	6.2^{c}	2.6^{bc}
	E. macrostachyus	14.0^{b}	1.3^{a}
	Average	**14.9**	**2.5**
Introduced	*C. gayana* variety Extozi rhode*s*	12.0^{a}	1.4^{b}
	C. gayana variety Boma rhodes	13.2^{ab}	1.3^{a}
	Average	**12.6**	**1.4**
	SEM	**0.42**	**0.24**
Grass effect		**	**

$^{a\text{-}c}$ Means within a column without a common letter superscript differ at p<0.05

Grass effect insignificant (NS) or significant at p<0.05 (**)

Table 4.1: Dry matter production of the above and below-ground biomass for the sample indigenous and introduced grasses

4.4.2 Carbon stocks in biomass and soil

The carbon stocks in carbon pools estimated in AGB and BGB of the three indigenous and two introduced grass species samples is presented in Table 4.2. Compared to the indigenous grass species, the introduced grass species were on average lower ($p<0.05$) in above ground carbon (C_{AG}) (6.7 tons /ha vs. 8.0 tons /ha), in below ground carbon (C_{BG}) (0.7 tons /ha vs. 1.3 tons /ha) and in soil carbon ($C_{soil)}$ (1.8 tons /ha vs. 2.0 tons /ha). The C_{AG} from introduced grasses (*C. gayana* variety Extozi rhodes 6.4 tons /ha and *C. gayana* variety Boma rhodes 7.1 tons /ha) were lower than those of indigenous grasses (*C. ciliaris* 7.7 tons /ha, *E. superba* 8.7 tons /ha and *E. macrostachyus* 7.5 tons /ha). For the C_{BG}, the introduced grasses (*C. gayana* variety Extozi rhodes 0.8 tons /ha and *C. gayana* variety Boma rhodes 0.7 tons /ha) were also lower than the indigenous grasses (*C. ciliaris* 1.8 tons /ha, *E. superba* 1.4 tons /ha and *E. macrostachyus* 0.7 tons /ha). Even the C_{soil} from plots planted with introduced grasses (*C. gayana* variety Extozi rhodes 1.8 tons /ha and *C. gayana* variety Boma rhodes 1.8 tons /ha) were lower than the estimates from indigenous grasses (*C. ciliaris* 2.3 tons /ha, *E. superba* 2.0 tons /ha and *E. macrostachyus* 1.9 tons /ha).

Table 4.2: Carbon stocks (tons /ha) estimates in the carbon pools above-ground biomass, below-ground biomass and soil of sample indigenous and introduced grasses

Grass	Species	Above-ground Carbon & litter carbon *(***tons /ha***)*	Below-ground Carbon (**tons /ha***)*	Soil carbon (**tons /ha**)
Indigenous	*C. ciliaris*	7.7^{bc}	1.8^{c}	2.3^{b}
	E. superba	8.7^{c}	1.4^{bc}	2.0^{a}
	E. macrostachyus	7.5^{b}	0.7^{a}	1.9^{a}
	Average	**8.0**	**1.3**	**2.0**
Introduced	*C. gayana* variety Extozi rhodes	6.4^{a}	0.8^{b}	1.8^{a}
	C. gayana variety Boma rhodes	7.1^{ab}	0.7^{a}	1.8^{a}
	Average	**6.7**	**0.7**	**1.8**

SEM	**0.23**	**0.13**	**0.04**
Grass effect	**	**	**

$^{a-c}$ Means within a column without a common letter superscript differ at $p<0.05$

Grass effect insignificant (NS) or significant at $p<0.05$ (**)

4.4.3 Total carbon stocks

In table 4.3 are the total dry matter production and total carbon stocks of different carbon pools for the three indigenous and two introduced grass species samples extrapolated to tons/ha. The total carbon stocks are pooled estimates of carbon in the above-ground, below ground and in the soil.

Table 4.3: Total dry matter production and total carbon stocks of different carbon pools for sample indigenous and introduced grasses

Grass	Species	Total carbon stocks (**tons /ha**)	Total dry matter (**tons /ha**)
Indigenous	*C. ciliaris*	11.8^{c}	17.8^{b}
	E. superba	12.1^{c}	18.8^{b}
	E. macrostachyus	10.1^{b}	15.3^{a}
	Average	**11.3**	**17.3**
Introduced	*C. gayana* variety Extozi rhodes	8.9^{a}	13.4^{a}
	C. gayana variety Boma rhodes	9.5^{ab}	14.5^{a}
	Average	**9.2**	**14.0**
	SEM	**0.21**	**0.40**
Grass effect		**	**

$^{a-c}$ Means within a column without a common letter superscript differ at $p<0.05$

Grass effect insignificant (NS) or significant at $p<0.05$ (**)

Relative to the indigenous grass species, the introduced grass species had on average 23% lower ($p<0.05$) total carbon stocks (9.2 tons /ha vs. 11.3 tons /ha) and 24% lower total dry matter production (14.0 tons /ha vs. 17.3 tons /ha). The total carbon stock estimates of the introduced grasses (*C. gayana* variety Extozi rhodes 8.9 tons /ha and *C. gayana* variety Boma rhodes 9.5 tons /ha) were lower than the estimates of the indigenous grasses (*C. ciliaris* 11.8 tons /ha, *E. superba* 12.1 tons /ha and *E. macrostachyus* 10.1 tons /ha). The same pattern was observed for the total dry matter production estimates, with the introduced grasses (*C. gayana* variety Extozi rhodes 13.4 tons /ha and *C. gayana* variety Boma rhodes 14.5 tons /ha) being lower than the estimates from indigenous grasses (*C. ciliaris* 17.8 tons /ha, *E. superba* 18.8 tons /ha and *E. macrostachyus* 15.3 tons /ha).

4.5 Discussion

The high dry matter production observed with the indigenous grasses relative to the introduced grasses can be attributed to several attributes of adaptability and resilience. These attributes include adaptability to high temperatures, low soil moisture and the ability to recover rapidly after climatic shock (Kipchirchir *et al*., 2015). Further, they are deep-rooted with high vegetative nature, which could explain their high biomass production. Supporting this is the observation that *E. superba* produced the highest above-ground dry matter while *C. ciliaris* produced the highest below-ground dry matter; which is attainable with deep stabilizing rootstock as deep as 2 m (Marshall *et al*., 2012). For the introduced grass species, low above-ground dry matter production can be attributed to their shallow root system not reaching deep in the subsoil for scaring soil moisture to support growth.

High total carbon stocks observed with the indigenous grass species can be related to their high above and below-ground biomass deep rooting system, which support the accumulation of high carbon from the photosynthesis process. The highest soil carbon stocks were observed in plots planted with indigenous grass pastures. This is linked to a high rate of root decomposition which might have contributed to the enhanced addition of carbon from the plant's root to the soil during the decomposition process (Odiwe *et al.,* 2016). The findings of Anderson *et al*. (2010) corroborates the observation in this study. The authors explained that the deep root system of indigenous grasses stores a higher amount of carbon in their roots. Further, Tessema *et al*. (2021) made the supportive observation that the deep root system facilitates long term carbon storage in soil by reducing the chances of carbon loss from root decomposition.

The indigenous grass pastures showed the potential to store high carbon in different carbon pools while at the same time producing the highest biomass. This is an important attribute in climate change mitigation because of its high capacity to capture much carbon dioxide concentration from the atmosphere during photosynthesis. Aiding this attribute is their rapid establishment /growth rate, high biomass production and deep root system that store soil organic carbon deep in subsoil. Therefore, utilization of indigenous grasses in ruminant feeding would achieve some co-benefits of higher dry matter biomass production and total carbon sequestration capacity, which is beneficial to mitigating climate change when producing ruminants under the rangeland ecosystem. For nutritive value improvement of the indigenous grasses to support increased ruminant productivity levels, carbon sequestration capacity shouldn't be lost, especially when breeding for nutritive value improvement.

4.6 Conclusion

The indigenous grasses showed higher potential for dry matter production and carbon sequestration relative to introduced grasses.

CHAPTER FIVE

ENTERIC METHANE EMISSION OF CATTLE GRAZING RANGELAND ECOSYSTEMS OF SOUTH EASTERN KENYA

Abstract

Cattle in the rangelands are produced under extensive grazing, characterized by large herds grazing degraded poor pastures. This supports livelihoods and coping with drought risk, but can be associated with enteric methane emissions that contribute to global warming potential (GWP). However, these are hardly quantified to inform emerging threats to sustainable use of grassland ecosystems. This study estimated enteric methane emission and the GWP associated with cattle grazing the rangelands of South Eastern Kenya, specifically Makueni County. Data on cattle population and their classes, performance and activities for the year 2019 was obtained from the County livestock inventory reports while feed quality data was sourced from recently published literature. Estimation applied the IPCC Tier I and Tier II approaches with Tier II incorporating seasonal differences in feed quality, dry matter intake and animal performance as described by Goopy *et al*. (2018). The resultant emission factors were 47.1 kg for females>2yrs; 27.2 kg for heifer 1-2 yrs; 46.5 kg for males>2yrs; 32.9 kg for young males 1-2yrs; and 17.2 kg for calves <1yr.Total estimated enteric methane emission for cattle population grazing the County using Tier I approach was 8,889,997kg /year with GWP of 248,919,916 Kg CO_2eq, which was 4.4% lower than the estimates Tier II approach for total enteric methane emission of 9,279,526.80 Kg/year and GWP of 259,826,750.4Kg CO_2 eq. The results show that the use of IPCC Tier II marginally improved the enteric methane emission and GWP estimates for zebu cattle population grazing the Makueni County rangeland ecosystem.

5.1 Introduction

Globally, enteric methane represents 35% of total emissions from livestock activities (Azizi *et al.*, 2017). Ruminant livestock in the developing world is the main source of methane emission, contributing significantly to human-related emissions. Methane has a GWP of 28 times per molecule greater over 100 years than carbon dioxide (IPCC ,2013) and a life time of 9-15 years in the atmosphere. The high level of ruminants' methane emission comes from enteric fermentation of feeds in the rumen and from hindgut to a small extend (Haque *et al.*, 2018; Yan *et al.*, 2010). This is aided by microbes in the rumen (carbohydrate fermenters) that help in the breakdown of fibrous feeds through anaerobic fermentation into microbial cells, volatile fatty acids (VFA), free hydrogen and carbon dioxide molecules. Of these products, the free hydrogen molecule is reduced using CO_2 with the help of methanogenic archaea to CH_4.

$2CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$ (Moss *et al.*, 2000). The VFA constitutes the major source of energy for the animal. However, the enteric CH_4production represents a loss of 5-10% of animal gross energy (GE) intake (Johnson & Johnson ,1995; Madsen *et al.*, 2010), a loss of dietary nutrients which could have been used for meat and milk production (Liu *et al.*, 2017).

Emissions from ruminants vary from one region to another (Goopy *et al.*, 2018; Ndung'u *et al.*, 2019). These emissions from livestock are mainly dependent on animal class, animal live body weight, dry matter intake, quality and quantity of feed consumed, type of volatile fatty acid produced in the rumen and animal energy expenditure (Hergarty *et al.*, 2010, Johnson & Johnson, 1995; Shrestha *et al.*, 2013; Seinfeld *et al.,* 2006). The IPCC guidelines provide three-level approaches for estimating enteric CH_4 emissions from cattle with varying levels of complexity. These approaches include Tier I, which uses default values provided in the literature and is least precise; Tier II considers animal class, diet and productivity differences while Tier III uses country-specific methodology and parameter estimates. Developed countries like Germany, the EU, Australia, Japan and the Netherlands use a country-specific methodology (Tier III approach). The developing countries still use Tier I because of a lack of technical and financial capacity to upgrade their method (NIR) (UNFCCC 2014).

Kenya is committed to developing and implementing strategies that improve livestock productivity while reducing greenhouse emissions. The largest proportion of greenhouse gas emissions that is of agricultural origin is by ruminant animals from both fibre digestion and from the manure they excrete to the environment, particularly cattle grazing the rangeland pastures (Moss *et al.*, 2000). Kenya is currently using Tier I in the estimation of GHG from livestock and this approach is known to yield high uncertainty levels. A move to Tier II is therefore desirable but its adoption is limited by the availability of farm-level animal and feed data on productivity and activity.

For the rangelands like the South Eastern region of the country, Makueni County, in particular, has some data on the animal production that has been collected over time. This data could be used to estimate enteric CH_4 for the county's expansive cattle population grazing the degraded pastures. Cattle in Makueni rangelands are extensively grazed on degraded poor pastures to support livelihoods and to cope with drought risk. However, this is likely to contribute substantial volumes of enteric methane emissions and to GWP, yet empirical evidence remains not availed to inform threats to sustainable use of grassland ecosystems. Literature search for estimated enteric CH_4 emission from cattle did not find any study conducted using the Tier-II approach in the rangelands Counties of Kenya. In response, this study was designed to contribute knowledge in this area, using Tier I and Tier II approaches to estimate enteric CH_4 emission and GWP associated with zebu cattle grazing the rangelands of Makueni County.

5.3 Materials and methods

5.3.1 Study site

Makueni County, a rangeland in the South Eastern part of Kenya, was the study site. The county lies between Latitude 1^{o} 35$^{\prime}$ and 32 00$^{\prime}$ South and Longitude 37^{o}10$^{\prime}$ and 38^{o} 30$^{\prime}$ east. The average temperature is in the range from 15^{o}C to 26^{o}C and annual rainfall from 250 mm to 400 mm per annum on the lower regions of the county while the higher region receives rainfall ranging from 800 mm to 900 mm. The dominant vegetation are indigenous grasses and shrubs, proving the basal diet for the ruminant livestock, consisting of indigenous cattle - zebu, Boran and their crosses, sheep and goats.

5.3.2 Estimation of enteric methane using Tier I approach

The study used secondary data obtained from Makueni County livestock inventory reports for the year 2019 and published information from Arid and Rangelands Research Institute (ARLRI) located in the County. Data pertained to cattle population, animal classes and their performance and animal activity. Additional data on feed quality was sourced from recently published literature.

Estimation of enteric methane applying IPCC Tier I approach was in several steps. Firstly, the population of cattle was obtained from the County livestock inventory records. Of the 253,175 heads of cattle (Table 5.1), a larger proportion (34%) were mature female>2yrs followed by calves < 1 year (24.3%) and males > 2years (23.8%), used for traction, pulling carts and their beef market value to earn a livelihood.

Secondly, the livestock numbers were multiplied by the default emission factors (Table 6) of the IPCC 2006 guidelines to derive the net enteric CH_4 emissions, according to the description of Gibbs *et al*. (2000):

$$\text{CH4 Emissions} = MEFt * Nt \text{ .... (i)}$$

where,

CH_4 Emissions = Total methane emission from enteric fermentation per animal class

$MEFt$ = Methane emission factor per class of livestock defined in IPCC 2006 guidelines

Nt = Number of head of livestock species per category/class

The CH_4 emission levels obtained were then multiplied by CH_4 GWP of 28 (IPCC, 2013) to estimate the contribution to the greenhouse effect in CO_2 equivalent.

Table 5.1: The Makueni County cattle population by animal classes and IPCC 2006 emission factors (EF) used for Tier I approach

Animal classes	EF (IPCC,2006)	Cattle Population
Females >2yrs	41	87,803
Males >2yrs	49	60,304
Heifers (1-2yrs)	31	26,617
Males (1-2yrs)	31	16,989
Calves <1yr	16	61,462
Total		253,175

5.3.3 Estimation of enteric methane emission using Tier II approach

Application of Tier II approach involved use of detailed data on animal classes, animal performance, feed quality, dry matter intake and animal energy expenditure. The animals were grouped into five classes based on age and sex: females (>2yrs), males (> 2years), heifers (1-2yrs), young males (1-2yrs) and calves (<1 year). Animal data on live weight and live weight gain, milk production, lactation status and estimated distance travelled by the animals from grazing fields to watering points and back to holding bomas were obtained from the County livestock inventory. The computational approach of Goopy *et al*. (2018) was followed for determining feed and animal variables needed to estimate the EF.

5.3.4 Determination of feed quality

Wet season feed quality (total N and ADF) were determined by wet chemistry, as described in AOAC methods (AOAC method no.988.05 and 6.5.1 respectively). A factor of 6.25 was used to convert N to CP.

The nutritive value of average feed available for the animals in the county varied between the seasons with animals having access to better feed during the wet than the dry season (Table 5.2). Weight gain by the animals in the other classes was season-dependent with animals gaining higher weight gains during the wet season than in the dry season.

Table 5.2 : Feed nutritive composition and dry matter digestibility of diets grazed by animals in Makueni County for both the dry and wet seasons.

Season	Feed stuff	DM	OM	%DMD	ADF	NDF	CP
Dry	Mixed range grass hay[1]	93.7	-	49.07	44.7	58.3	5.54
Wet	Mixed range grasses	97.40	91.85	53.36	40.57	70.98	6.08

[1] Korir *et al.* (2020).

The dry season feed nutritional quality was obtained from published sources (Korir *et al.*, 2020) while dry matter digestibility (DMD) was estimated using the equation of Oddy *et al*. (1983):

$$DMD(g/100gDM) = 83.58 - 0.824 * ADF(g/100gDM) + (2.626 * N(g/100gDM)$$

………………………………………………………………………………….. (ii)

where,

ADF = Acid Detergent fibre, N = Nitrogen

5.3.5 Estimation of cattle energy expenditure

Total energy expenditure for each class was calculated based on maintenance energy requirements, distance walked and lactation status using equations previously used by CSIRO (2007); Goopy *et al*. (2018) and Ndung'u *et al*. (2019).

The energy required for maintenance (MER) was estimated from the expression below:

$$MER_M\left(MJ/day = K * S * M(0.26 * MLW^{0.75}) * exp(-0.03 * A)\right)/\left((0.02 * M/D) + 0.5\right)$$

……………………………………………………………………………………(iii)

where:

K = 1.3 (the intermediate value for *Bos taurus* and *Bos indicus*), S = 1 for females and 1.15 for males, M = 1, MLW = mean live weight, a = age in years and M/D = Metabolizable-energy content (ME MJ/DM kg) which was calculated as:

$M/D = 0.172DMD - 1.707$………………………………………………………… (iv)

where:

DMD = % DM digestibility of feed.

Energy requirement for growth

All animal classes except for calves were found to gain an average of 200 g per day during the wet season and an averagely of 50 g per day in the dry season. For the lactating animals, an average milk yield of 2.5- 3.0 litres per day was used inclusive of what the calf suckled (1 litre). Calves on milk were assumed to gain an averagely of 50 g per day across all the seasons.

The energy required for growth as energy consumed for weight gain /loss (MERG/L) was calculated as:

$MER_G\ \ (MJ/day = (ADWG(kg) * 0.92 * EC\ (MJ/Kg))/\ (0.043 * M/D)$………….. (v)

$MER_L(MJ/day) = \left(ADWL(Kg) * 0.92 * EC(MJ/Kg)\right)/0.8$…………………………(vi)

where:

ADWG or ADWL (kg) = average daily weight gains or loss; EC (MJ/kg) = energy content of the tissue taken as 18 MJ/kg

Energy requirement for lactation

The energy required for lactation, was derived from daily milk consumption by pre-ruminant calves (calves between 0-3.5 months) in litres using calves live weight and average calves' growth rates according to Radostits and Bell. (1970) equation assuming the calves' growth rate per day (LWG) to be 50 g/day:

$Daily\ milk\ consumption(L/d) = (LWcalf(kg) * 0.107) + (0.143)$……………… (vii)

where:

LW calf = live weight of calve in kg, 0.107 = Energy required by calves for maintenance.

Daily Milk Yield (DMY) was calculated as:

$DMY(L/d) = (Mean\ daily\ milk\ production(L) * N\ of\ days\ in\ milk) +$

$daily\ milk\ consumption\ of calves$

……………………………………………………………………………………... (viii)

The computation assumed 70% of mature female herd to be lactating. Energy requirements for lactation were calculated using the equation given in NRODR (CSIRO, 2007) as:

$MERL = DMY * ECM/(0.02 * M/D) + 0.04$... (ix)

where:

DMY (kg) = daily milk yield, ECM (MJ/kg) = energy content of milk (taken as 3.054 MJ/kg (CSIRO, 2007) due to a lack of data regarding milk constituents), M/D = Metabolizable energy content.

Energy requirement for locomotion

The energy requirement for locomotion assumed energy expended for locomotion as an estimate of:

$MERT(MJ/day) = DIST(km) + MLW(kg) + 0.0026(MJ)$.............................(x)

Where:

DIST = average distance travelled (km) - average estimated distance from grazing field to watering point; MLW = mean LW and 0.0026 is the energy expended (MJ/ (kg LW/km).

The daily total energy expenditure (MER_{Total}) for each animal class in each season was then calculated using the formulas below.

$MER_{TOTAL}\ (MJ/day) = MERM + MERG/L + MERL + MERT$(Females)..............(xi)

$MER_{TOTAL}(MJ/day) = MERM + MERG/L + MERT$ (Males, heifers and young males)

.... (xii)

$MER_{TOTAL}(MJ/day) = MERM + MERG/L$(Calves)...................................... (xiii)

5.3.6 Calculation of emission factors (EF)

In estimating the emission factors, dry matter intake (DMI) was calculated as a function of MER_{TOTAL} and seasonal DMD of feed using the formulae:

$DMI(Kg) = MER_{TOTAL}\,(Mj/day)/GE\,(Mj/day) * DMD/100))0.81$................. (xiv)

where:

GE = gross energy of the diet assumed to be 18.1MJ/kg DM and 0.81 as the factor to convert ME to digestible energy.

The estimated DMI was used to calculate daily methane production (DMP) using the equation developed by Charmley *et al.* (2016), as follows:

$DMP(g) = 20.7 * DMI(Kg/day)$ .... (xv)

Mean annual methane production per animal (emission factor: EF) for each class of animal in the County was calculated as:

$$EF(kgCH4\ per\ head\ per\ year) = ((DMP(dry\ season * 91.25\ days\ ) +$$

$$(DMP\ (Wet\ sason * 273.75\ days))/(1000)$$

…………………………………………. (xvi)

5.3.7 Statistical analysis

Data on EF were analyzed using R 3.5.3 (R development core team, USA) with the ANOVA to assess the within animal class estimates. A linear model was then fitted with animal class as fixed factor to estimate least square means. The differences between the means were determined with Tukey's method at $p<0.05$.

5.4 Results

5.4.1 Animal energy expenditure

Maintenance energy requirements which was mainly a function of live weight accounted for the highest amount of energy expenditure for all animal classes and in both seasons (Table 5.3).

Table 5.3: Maintenance energy (MER_M), lactation energy (MER_L), growth (loss or gain) energy ($MER_{L/G}$), movements' energy (MER_T) and total energy requirements (MER_{TOTAL}) for different classes of animal during the wet and dry season in Makueni County

Animal class	MER_M	MER_L	$MER_{L/G}$	MER_T	MER_{TOTAL}
	--Wet season------------------------				
Females>2yrs	29.30±0.994	12.42±1.000	10.31	1.29±0.319	53.32±1.774
Males >2yrs	39.46±0.994	-	10.31	1.59±0.319	51.36±1.774
Heifers (1-2 yrs)	21.81±0.994	-	10.31	0.84±0.319	32.96±1.774
Young males (1-2yrs)	27.29±0.994	-	10.31	0.94±0.319	38.54±1.774
Calves<1yr	14.83±0.994	-	2.58	-	17.4±1.774
	-----------------------------Dry season-----------------------------------				
Females>2yrs	28.70±0.994	11.99±1.000	2.86	1.22±0.319	44.76±1.774
Males >2yrs	38.98±0.994	-	2.86	1.52±0.319	43.36±1.774
Heifers (1-2 yrs)	20.84±0.994	-	2.86	0.77±0.319	24.47±1.774
Young males (1-2yrs)	26.28±0.994	-	2.86	0.86±0.319	30.00±1.774

Calves<1yr	13.64±0.994	-	2.86	-	16.5±1.774

The lowest expenditure was on locomotion. Total energy expenditure was higher during the wet season compared to the dry season for all animal classes except for calves, corresponding to higher weight gains during the wet season when the quality of the diet was better.

5.4.2 Enteric methane emission estimates

Table 5.4 presents the enteric methane emission factors estimated with Tier I and Tier II for cattle population grazing the Makueni County rangelands. The two approaches do not reveal substantial differences in the estimates between the animal classes. The EFs were closely associated with the animal body weights and the cattle in Makueni were on average heavier than the reference typical unspecified African cattle defined in the IPCC Tier I 2006.

Table 5.4: Enteric methane emission factors (Kg CH_4/head/year) and mean live weight (Kg) for different classes of cattle estimated with IPCC Tier I (IPCC 2006) and Tier II (present study) for cattle grazing Makueni County rangelands

Cattle class	Tier I EF estimates		Tier II EF estimates	
	Live weight (Kg)	Emission Factor	Live weight (Kg)	Emission Factor
Females >2yrs	200	41	231.8	47.1
Males >2yrs	275	49	287.8	46.5
Heifers (1-2yrs)	-	31	148.2	27.2
Young males (1-2yrs)	-	31	166.2	32.9
Calves <1yr	75	16	75.3	17.2

The enteric CH_4 production and GWP estimates with Tier II, which accounted for differences in performance and feeding practices, were relatively higher compared to Tier I approach estimates (Table 5.5). However, they were only 4.4% higher than the estimates with the Tier I approach, which were referenced to the typical unspecified African cattle defined in IPCC Tier I.

Table 5.5: Total enteric methane emissions and GWP estimates with Tier I and Tier II approaches for cattle grazing Makueni County rangelands

Cattle class	Tier I total emissions (Kg CH_4/year)	Tier II total emission(Kg CH_4/year)
Females >2yrs	3,599,923	4,135,521.30
Males >2yrs	2,954,896	2,804,136.00
Heifers (1-2yrs)	825,127	723,982.40
Young males (1-2yrs)	526,659	558,741
Calves <1yr	983,392	1,057,146.40
Total (Kg CH_4/year)	8,889,997	9,279,527
GWP (Kg CO_2eq/year)	248,919,916	259,826,750.4

EF for Tier 1 IPCC 2006, EF using Tier II Current study, GWP used was 28 (IPCC 2013).

5.5 Discussion

All the animal classes had higher energy expenditure and dry matter intake during the wet season compared to the dry season. This is because of the higher productivity (weight gain and milk yield) during the wet season when diets were of better quality. Maintenance energy requirements accounted for the highest energy expenditure in both wet and dry seasons. The dry matter digestibility of the diets (49.07±0.91% in dry season and 53.36% in wet season), which is indicative of diet quality, was within the range of default estimate values of (50-55%) for mixed African forages reported by Dong *et al.* (2006) and slightly lower than 55% provided in IPCC, (2006) for Tier I estimation. Ndung'u *et al.* (2019) also reported a higher range of dry matter digestibility (53.1-67.9%) from a variety of diets in the feed basket of cattle in Nandi County, which is highlands with a high potential agriculturally. This is an important point to note in the results because feeds harvested in a highland county differ nutritionally from the feeds in lowland rangeland with low potential agriculturally. Feeds in the rangelands deposit more structural tissue that is less digestible (Wilson *et al*., 1991).

The average live weights for the different animal classes were comparable to those of the reference typical African cattle defined in IPCC (IPCC 2006) but slightly lower than what Ndung'u *et al.* (2019) reported in a study from Nandi County in the Kenyan highlands with dairy cattle breeds supported with high biomass production sustained with high bimodal distributed rainfall pattern. In contrast, the cattle population dominant in the Makueni County rangelands are the *Bos indicus* that have a smaller body frame compared to dairy cattle breeds with larger body frames, which dominate in the highlands (Ndung'u *et al*., 2019). The live weights in the current study however were higher than what Goopy *et al.* (2018) reported from a study in the lowland lake basin of Nyando basin where the small East African Zebu cattle dominated.

The total enteric CH_4 emissions from cattle in Makueni County rangelands was only 4.4% higher when estimated using IPCC Tier II compared to using Tier I approach. The Kenyan inventory reporting has used the IPCC Tier I approach estimates. Tier II approach uses dry matter in the computation of EF, and this has a positive correlation with the amount of methane emitted, from animal performance and activity data. These feed values and animal performance variables accounted for in Tier II can explain the 4.4% higher enteric methane and GWP estimates made, when compared to Tier I estimates. This observation concurs with the findings of Kurihara *et al.* (1999) who concluded that the use of IPCC default EF in tropical context is likely to under estimate emissions. They explained this as due to the differences in animal breeds and diets between the tropics and temperate environments where estimation factors were developed.

The total enteric CH_4 emission of cattle in Makueni County using Tier I (8,916,225Kg/year) was 64% lower than the emissions estimate in Kajiado County (24,983,220 Kg/year) as reported by Kimongo *et al*. (2017). This can be explained by larger herds kept by the dominant pastoral community of Kajiado County. In Makueni County rangelands, animals trekked for shorter distances in search of feed and water relative to what Kimongo *et al*. (2018) observed in the Kajiado County study. This is a further explanation of the lower energy expenditure and hence estimated enteric CH_4 production.

Considering the current study used EF developed in a tropical environment (northern Australia), the Tier II figures could have been higher than when Tier I approach was used because tropical diets are more methanogenic than temperate grasses (Archimede *et al.,* 2018*).* These were what was used in the development of the Tier 1 EFs. There is therefore the need to develop locally generated EF using local breeds of animals and locally available feed resources to improve certainties of the enteric methane emissions, which is a requirement in reporting the Nationally Determined Contributions (Cottle & Eckard, 2018).

5.6 Conclusion

Use of IPCC Tier II marginally improved the enteric methane emission and GWP estimates for zebu cattle population grazing the Makueni County rangeland ecosystem.

CHAPTER SIX

GENERAL DISCUSSION,CONCLUSIONS AND RECOMMENDATIONS

6.1. Rationale of the study

This study makes a contribution to sustainable pasture management and livestock production in the rangeland ecosystems. These ecosystems produce larger proportion of the ruminants but under challenge of inadequate feed resource base, characterized by seasonality, scarcity in quantity and poor quality. The situation is linked to these ecosystems being hotspots of changing and variable climate change, which expose livestock to high impact of climate change. when designing intervention, preference has been for introducing grass pastures from high agricultural potential areas to meet the rising feed demand for livestock. Grasses from the high agricultural potential areas are introduced in the rangeland ecosystems because of their higher biomass yields and high nutritive values. This has ignored possibilities that high biomass yields and better nutritive value may not necessarily be accompanied with low methane emissions and high carbon sequestrations, which are attributes important in reducing greenhouse gas emissions associated with global warming. It is therefore important that utilization of the indigenous and introduced grass pastures is evidence informed about their nutritive value, digestibility, and their potential to mitigate GHG emission through limited CH_4 emission potential and carbon sequestration. For sustainable pasture management and livestock production, limiting GHG emissions is important when increasing productivity. Thus, screening and identifying grass pastures with multiple attributes of high biomass yield, high nutritive value, low methane emission and high carbon sequestration should inform selection of suitable grass pastures for sustainable ruminant production in ASALs to contribute to mitigation of climate change.

6.2. Significance of the main findings

The present study shows differences between indigenous and introduced grass pastures based on digestibility and nutritive value composition and in CH_4 emission potential (Chapter 3). The indigenous grasses depicted low methane emission from methanogenic which is evidence of a high potential to mitigate climate change. For realizing low carbon foot print from livestock production, these grasses should thus continue being promoted and disseminated in the ASALs ecosystems. In formulating a ration for ruminant animals, the use of grasses with lower methane production would contribute to mitigating methane emission from the production system (Gemeda *et al*., 2014). The low nutritive value and digestibility of the indigenous grass pastures can be addressed with supplemental feeding, utilizing low-opportunity cost feeds (LCF) such as by-products, waste- products. Nitrogen supplementation using either leguminous fodder or concentrates while feeding livestock with the indigenous range grass pastures is thus recommended to boost low CP contents for optimal microbial activity, building on the observations of other authors for such feeds (Korir *et al.*,2016; Sampaio *et al.*,2010).

The indigenous grass pastures also showed potential to yield high dry matter production despite the harsh climatic conditions in the ASALs. This is attributed to their high adaptability to high temperatures as reported by Mganga *et al.* (2015) and contributed a higher potential for carbon sequestration by storing higher carbon stocks in carbon pools compared to the introduced grass pastures (Chapter 4). The indigenous grass pastures can thus serve as potential carbon sinks in offsetting CO_2 concentration from the atmosphere in the ASALs as well as supplying high dry matter yield for sustainable livestock feed. This is associated with their deep rooting system, adaptation to low moisture, which results in a high biomass yield /vegetative nature as Tessema *et al.* (2021) observed in their works. The perennial nature of these grasses also plays a key role in capturing and long term storage of carbon in the soil and root biomass. Cattle producers need to better improve sustainable use of indigenous grass pastures through application of good management practice that enhance biomass productivity. This would need strengthening the extension services to help in disseminating the information to pastoral herd owners.

Estimation of enteric methane emission of cattle in Makueni county was found to differ with the estimation approach used (Chapter 5). The Tier I approach was found to under estimate enteric CH_4 emission by at least 4.4 % compared to the Tier II approach. This is because Tier I approach used default EF values developed from temperate regions. In this study, animal live weights and activity and seasonal variation in feed quality were accounted for in Tier II approach. The 4.4% difference in the estimates between Tier I and Tier II could be pointing towards the hypothesis that other than feed quality parameters, other factors such as breed, climatic condition or geographical differences do also have influence on the emission factors as well. This was earlier pointed out by Ndung'u *et al.* (2019) who reported emission factors to differ across agro ecological regions. Further, under estimation of the emission factors based on default factors of Tier I has been observed in other studies as well (Goopy *et al.*, 2018; Kouazounde *et al.*, 2015; Ndung'u *et al.*, 2019). This then informs the need to develop locally generated estimation emission factors using local breeds and local feed resources not forgetting to factor in ecological conditions to improve inevitabilities of the enteric methane emissions. This approach would meet the requirements in reporting NDC (Nationally Determined Contribution) that each country has to report to the UN periodically.

6.3 Conclusions

i. The indigenous grasses produced significantly lower CH_4 per gram unit feed incubated compared to the introduced grasses, which is of importance in mitigating greenhouse gas emissions from livestock.
ii. The indigenous grass pastures demonstrated high potential for carbon capture and biomass yield than the introduced grass pastures, thus proved more suitable for increased sustainable livestock productivity while mitigating climate change impacts, which is of importance as potential carbon sinks in mitigating climate change.
iii. Enteric methane emission estimates using IPCC Tier II marginally improved estimation of actual emissions compared to Tier I, which is an indication that it is important to develop estimation factors under local production circumstances.

6.4 Recommendations

i. Nitrogen supplementation while feeding a ruminant animal with indigenous grass pastures is recommended to boost nitrogen supply indicated by low crude protein and digestibility for efficient ruminal activity.
ii. Good management for indigenous grass pastures during establishment through fertilizer application is recommended to boost their biomass yield and high carbon sequestration. Moreover, utilization of indigenous grass species is also highly recommended for sustainable rangeland livestock production supporting increased productivity while minimizing carbon emissions.
iii. Generating estimation factors from local livestock and feeds is important to improve co efficient for estimation of enteric methane emission using Tier II and to validate the results for this study.

6.5 Areas for further studies

i. Animal level experimental studies are recommended to inform better on tradeoffs between improved animal productivity and enteric CH_4 emissions in using the indigenous and the introduced grasses in the rangelands.
ii. Assessment of the carbon emission potentials of both indigenous and introduced types of grass in the rangeland ecosystems and their contribution to greenhouse gas emissions would inform the selection of grass pastures with a low contribution to climate change.
iii. Analysis of input parameters in estimating enteric methane emission factors with the Tier II approach is necessary to improve the accuracy of the national greenhouse gas inventory in the Nationally Determined Contributions for GHG reporting.

iv. There is the need to invest in building technical and infrastructural capacity in Kenya for the application of Tier III measurements to improve accuracy in reporting the Nationally Determined Contributions.

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APPENDICES

Appendix A: Enteric methane emission factors

Enteric methane emission factor (kg/head per year)

Livestock category	IPCC 2006
Mature female grazing cattle	41
Bulls grazing	49
Young cattle	16
Other cattle from Africa	31

Appendix B: Analysis output

2.1 Regression and Pearson correlation between chemical constituents and methane production

Correlations

		CH4 mls	crude protein	NDF	ADF	IVOMD	%IVDMD
Pearson Correlation	CH4 mls	1.000	.624	.017	.880	.705	.705
	crude protein	.624	1.000	-.154	.801	.715	.777
	NDF	.017	-.154	1.000	-.004	-.467	-.540
	ADF	.880	.801	-.004	1.000	.782	.764
	IVOMD	.705	.715	-.467	.782	1.000	.960
	%IVDMD	.705	.777	-.540	.764	.960	1.000
Sig. (1-tailed)	CH4 mls	.	.006	.476	.000	.002	.002
	crude protein	.006	.	.292	.000	.001	.000
	NDF	.476	.292	.	.495	.040	.019
	ADF	.000	.000	.495	.	.000	.000
	IVOMD	.002	.001	.040	.000	.	.000
	%IVDMD	.002	.000	.019	.000	.000	.
N	CH4 mls	15	15	15	15	15	15
	crude protein	15	15	15	15	15	15

	NDF	15	15	15	15	15	15
	ADF	15	15	15	15	15	15
	IVOMD	15	15	15	15	15	15
	%IVDMD	15	15	15	15	15	15

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	%IVDMD, NDF, crude protein, ADF, IVOMD[b]	.	Enter

a. Dependent Variable: CH4 mls

b. All requested variables entered.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.921[a]	.848	.763	2.68974	.848	10.028	5	9	.002

a. Predictors: (Constant), %IVDMD, NDF, crude protein, ADF, IVOMD

b. Dependent Variable: CH4 mls

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	362.746	5	72.549	10.028	.002[b]
	Residual	65.112	9	7.235		
	Total	427.858	14			

a. Dependent Variable: CH4 mls

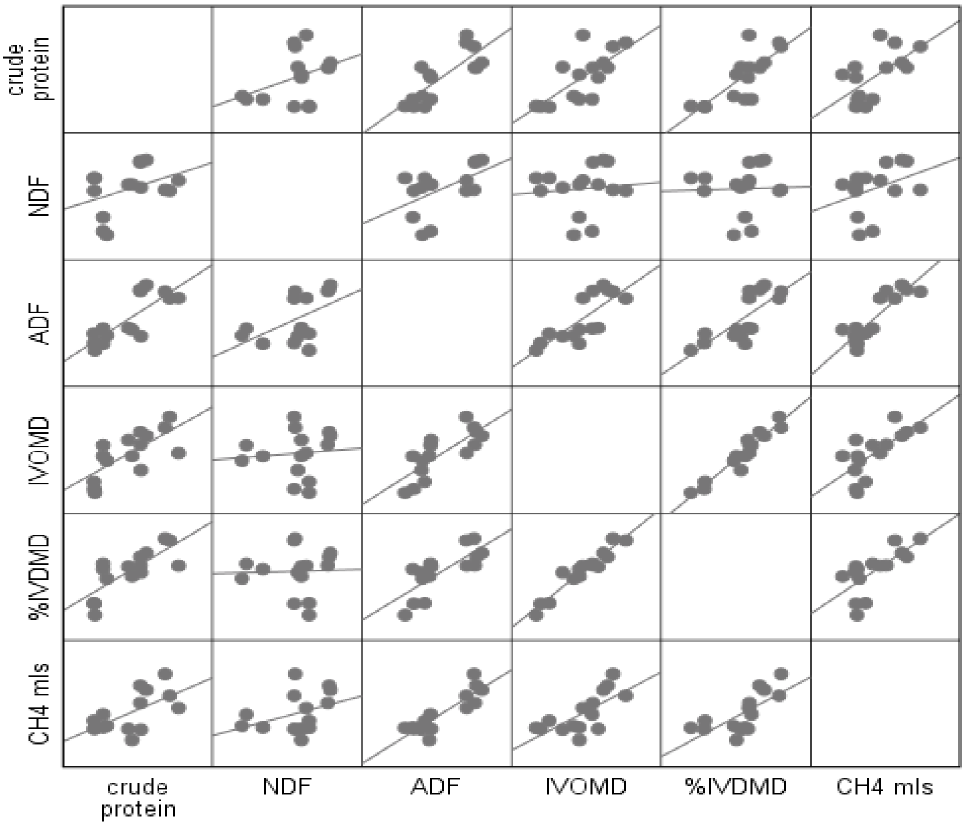
b. Predictors: (Constant), %IVDMD, NDF, crude protein, ADF, IVOMD

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		

1	(Constant)	-135.308	48.638		-2.782	.021
	crude protein	-.194	.107	-.483	-1.816	.103
	NDF	.611	.486	.302	1.257	.240
	ADF	1.739	.684	.828	2.543	.032
	IVOMD	-1.671	1.636	-.536	-1.021	.334
	%IVDMD	3.135	1.848	1.125	1.696	.124

a. Dependent Variable: CH4 mls



2.2 Emission factors (Kg CH4/animal/annum) for the five classes of cattle in the six sub counties of Makueni County in Kenya

modelEF<-lm (EF ~Subcounty + Class, data = makueni2)

ANOVA (modelEF)

Analysis of Variance Table

Response: EF

```
Df Sum Sq Mean Sq.  F value Pr(>F)

Subcounty 6   44.6    7.43   3.3013 0.02008 *

Class      4 3955.2 988.80 439.5089 < 2e-16 ***

Residuals 20   45.0    2.25
```

```
---

Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

cld (lsmeans (modelEF, ~Subcounty*Class), adjust="tukey")
```

```
Subcounty           Class          lsmean     SE       df   lower.CL    upper.CL.       group

Kibwezi East    Calves<1y        15.6       0.866     20    12.5         18.8             1

Kibwezi West   Calves<1y        16.4       0.866     20    13.3         19.6             1

Kilome             Calves<1y       16.7       0.866     20    13.6         19.9             1

Makueni          Calves<1y       16.8       0.866     20    13.6         19.9             1

County       Ave.calves<1y     17.2       0.866     20    11.4          23.0             1

Mbooni           Calves<1y       18.5      0.866     20    15.4         21.6             1

Kaiti                Calves<1y       19.1       0.866     20    16.0          22.3             1

Kibwezi East   Females1-2y   25.6       0.866     20    22.5         28.8             2

Kibwezi West Females1-2y    26.5       0.866     20    23.3          29.6             23

Kilome            Females1-2y   26.8       0.866     20    23.6         29.9             234

Makueni        Females1-2y   26.8       0.866     20    23.7         29.9             234

County     Ave.Females1-2y    27.2      0.866    20    21.4         33.0             234

Mbooni          Females1-2y   28.5       0.866     20    25.4          31.7             2345

Kaiti               Females1-2y    29.2      0.866    20    26.0         32.3            23456

Kibwezi East Males1-2y          31.4       0.866    20    28.2         34.5             34567

Kibwezi West Males1-2y        32.2       0.866    20    29.0         35.3            4567
```

Kilome	Males1-2y	32.5	0.866	20	29.3	35.6	567
Makueni	Males1-2y	32.5	0.866	20	29.4	35.6	567
Mbooni	Males1-2y	34.2	0.866	20	31.1	37.4	67
Kaiti	Males1-2y	34.9	0.866	20	31.7	38.0	7
County	Ave.Males1-2y	32.9	0.866	20	27.1	38.7	567
Kibwezi East	Males>2y	45.0	0.866	20	41.8	48.1	8
Kibwezi East	Females>2y	45.6	0.866	20	42.4	48.7	8
Kibwezi West	Males>2y	45.8	0.866	20	42.6	48.9	8
Kilome	Males>2y	46.1	0.866	20	42.9	49.2	8
Makueni	Males>2y	46.1	0.866	20	43.0	49.3	8
Kibwezi West	Females>2y	46.4	0.866	20	43.2	49.5	8
County	Males>2y	46.5	0.866	20	44.2	48.9	8
Kilome	Females>2y	46.7	0.866	20	43.5	49.8	8
Makueni	Females>2y	46.7	0.866	20	43.6	49.8	8
County Ave.	Females>2y	47.1	0.866	20	41.3	52.9	8
Mbooni	Males>2y	47.9	0.866	20	44.7	51.0	8
Mbooni	Females>2y	48.4	0.866	20	45.3	51.6	8
Kaiti	Males>2y	48.5	0.866	20	45.3	51.6	8
Kaiti	Females>2y	49.1	0.866	20	45.9	52.2	8

Confidence level used: 0.95

Conf-level adjustment: sidak method for 30 estimates

P value adjustment: tukey method for comparing a family of 30 estimates

significance level used: alpha

Appendix C: Research License

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR
SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **402455**

Date of Issue: **08/March/2021**

RESEARCH LICENSE

This is to Certify that Ms.. Annastacia Nduku Maweu of Egerton University, has been licensed to conduct research in Makueni on the topic: Assessing methanogenic and carbon sequestration potential of indigenous and introduced grasses in Rangeland Ecosystems of Eastern Kenya for the period ending : 08/March/2022.

License No: **NACOSTI/P/21/9308**

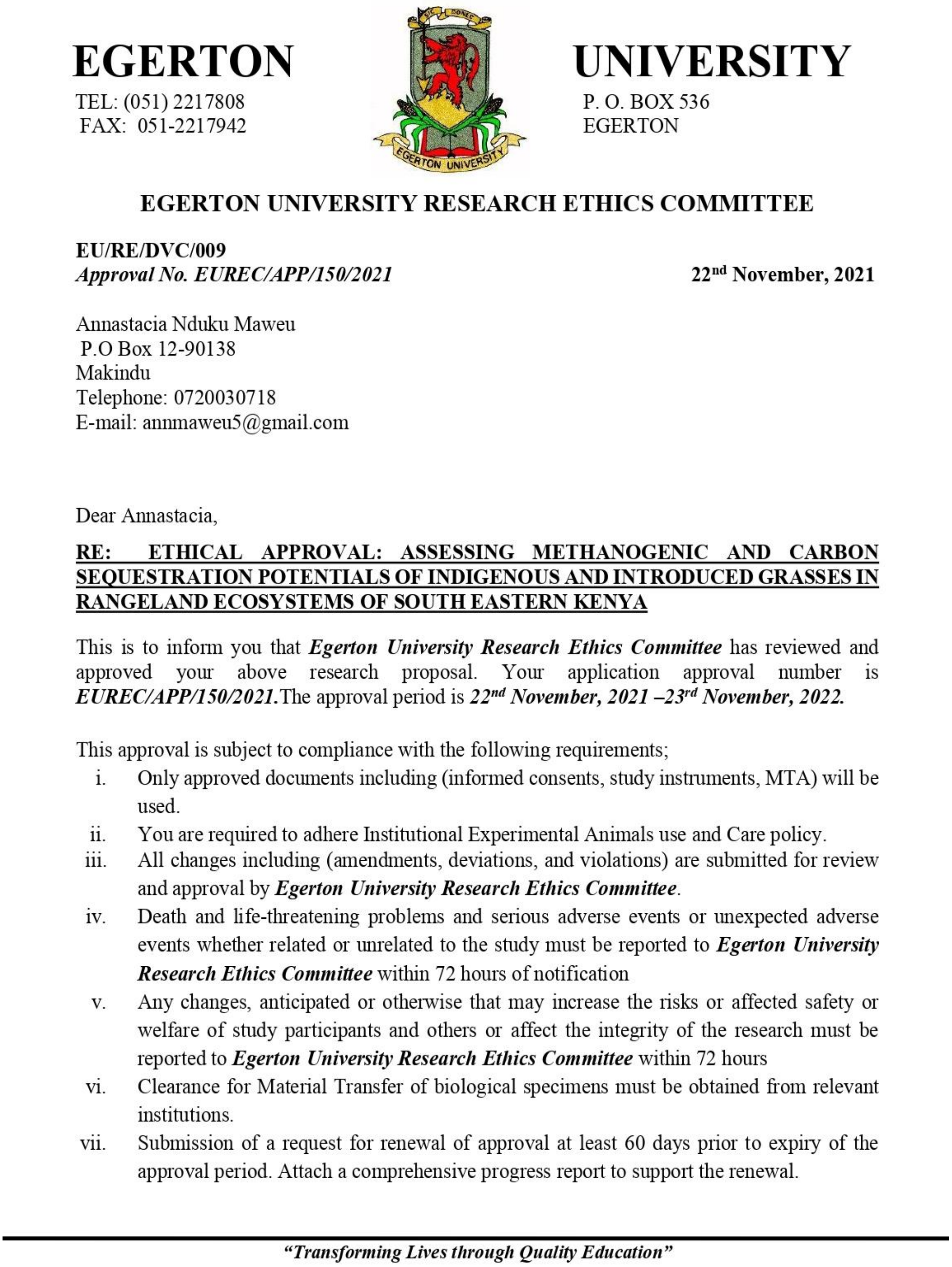
402455
Applicant Identification Number

Director General
NATIONAL COMMISSION FOR
SCIENCE,TECHNOLOGY &
INNOVATION

Verification QR Code

NOTE: This is a computer generated License. To verify the authenticity of this document,
Scan the QR Code using QR scanner application.

Appendix D: Ethical approval



EGERTON **UNIVERSITY**
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EGERTON

EGERTON UNIVERSITY RESEARCH ETHICS COMMITTEE

EU/RE/DVC/009
Approval No. EUREC/APP/150/2021 **22nd November, 2021**

Annastacia Nduku Maweu
P.O Box 12-90138
Makindu
Telephone: 0720030718
E-mail: annmaweu5@gmail.com

Dear Annastacia,

RE: ETHICAL APPROVAL: ASSESSING METHANOGENIC AND CARBON SEQUESTRATION POTENTIALS OF INDIGENOUS AND INTRODUCED GRASSES IN RANGELAND ECOSYSTEMS OF SOUTH EASTERN KENYA

This is to inform you that ***Egerton University Research Ethics Committee*** has reviewed and approved your above research proposal. Your application approval number is ***EUREC/APP/150/2021.***The approval period is ***22nd November, 2021 –23rd November, 2022.***

This approval is subject to compliance with the following requirements;

i. Only approved documents including (informed consents, study instruments, MTA) will be used.
ii. You are required to adhere Institutional Experimental Animals use and Care policy.
iii. All changes including (amendments, deviations, and violations) are submitted for review and approval by ***Egerton University Research Ethics Committee***.
iv. Death and life-threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to ***Egerton University Research Ethics Committee*** within 72 hours of notification
v. Any changes, anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to ***Egerton University Research Ethics Committee*** within 72 hours
vi. Clearance for Material Transfer of biological specimens must be obtained from relevant institutions.
vii. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.

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viii. Submission of an executive summary report within 90 days upon completion of the study to ***Egerton University Research Ethics Committee***.

Prior to commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology and Innovation (NACOSTI) https://oris.nacosti.go.ke and also obtain other clearances needed.

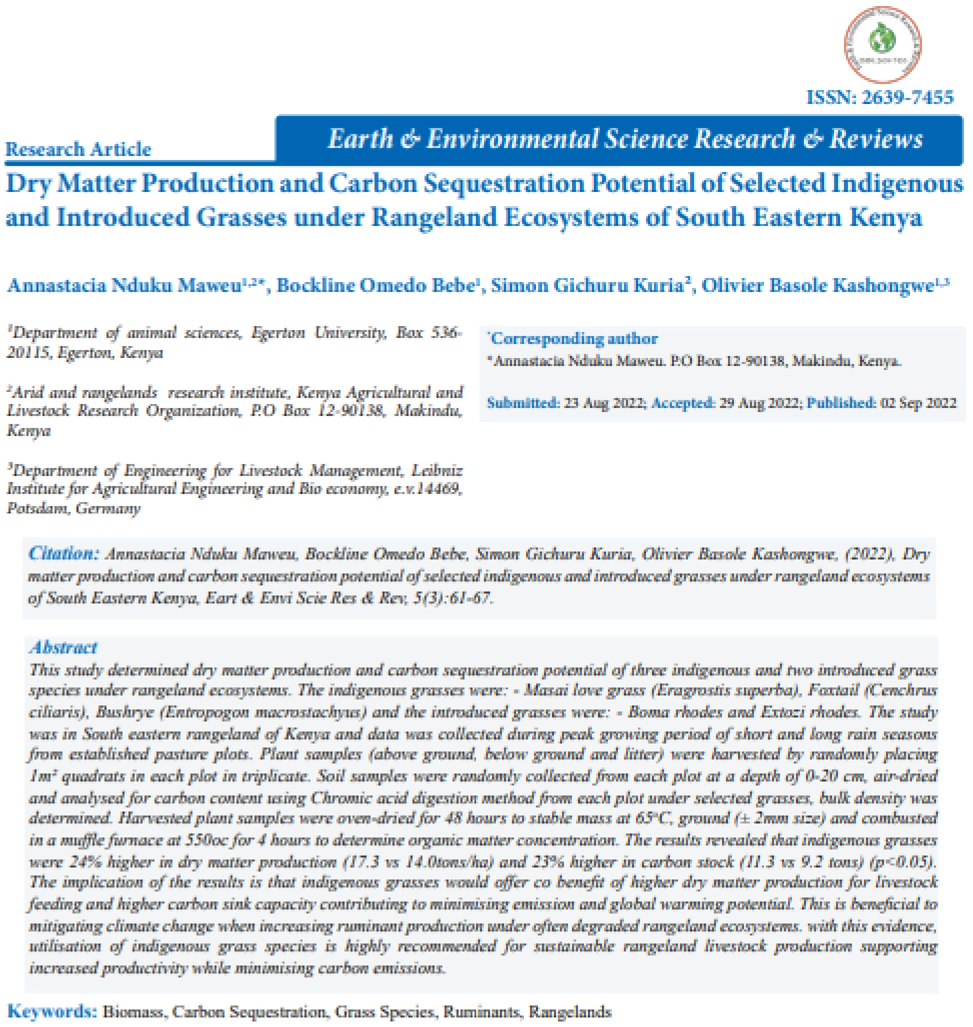
Yours sincerely.

Date. 22/11/2021

Prof. R. Ngure
CHAIRMAN, EGERTON UNIVERSITY RESEARCH ETHICS CTTEE
RMN/BK/

"Transforming Lives through Quality Education"

Appendix E : Publication



ISSN: 2639-7455

Research Article

Earth & Environmental Science Research & Reviews

Dry Matter Production and Carbon Sequestration Potential of Selected Indigenous and Introduced Grasses under Rangeland Ecosystems of South Eastern Kenya

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Submitted: 23 Aug 2022; **Accepted:** 29 Aug 2022; **Published:** 02 Sep 2022

Citation: *Annastacia Nduku Maweu, Bockline Omedo Bebe, Simon Gichuru Kuria, Olivier Basole Kashongwe, (2022), Dry matter production and carbon sequestration potential of selected indigenous and introduced grasses under rangeland ecosystems of South Eastern Kenya, Eart & Envi Scie Res & Rev, 5(3):61-67.*

Abstract

This study determined dry matter production and carbon sequestration potential of three indigenous and two introduced grass species under rangeland ecosystems. The indigenous grasses were: - Masai love grass (Eragrostis superba), Foxtail (Cenchrus ciliaris), Bushrye (Entropogon macrostachyus) and the introduced grasses were: - Boma rhodes and Extozi rhodes. The study was in South eastern rangeland of Kenya and data was collected during peak growing period of short and long rain seasons from established pasture plots. Plant samples (above ground, below ground and litter) were harvested by randomly placing 1m² quadrats in each plot in triplicate. Soil samples were randomly collected from each plot at a depth of 0-20 cm, air-dried and analysed for carbon content using Chromic acid digestion method from each plot under selected grasses, bulk density was determined. Harvested plant samples were oven-dried for 48 hours to stable mass at 65°C, ground (± 2mm size) and combusted in a muffle furnace at 550oc for 4 hours to determine organic matter concentration. The results revealed that indigenous grasses were 24% higher in dry matter production (17.3 vs 14.0tons/ha) and 23% higher in carbon stock (11.3 vs 9.2 tons) ($p<0.05$). The implication of the results is that indigenous grasses would offer co benefit of higher dry matter production for livestock feeding and higher carbon sink capacity contributing to minimising emission and global warming potential. This is beneficial to mitigating climate change when increasing ruminant production under often degraded rangeland ecosystems. with this evidence, utilisation of indigenous grass species is highly recommended for sustainable rangeland livestock production supporting increased productivity while minimising carbon emissions.

Keywords: Biomass, Carbon Sequestration, Grass Species, Ruminants, Rangelands