COMPARATIVE EVALUATION OF SIX INDIGENOUS RANGELAND GRASSES FOR PASTURE PRODUCTION UNDER VARYING SOIL MOISTURE CONTENTS IN TANA RIVER COUNTY, SOUTHEASTERN KENYA

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DECLARATION AND APPROVAL

This thesis titled *“**Comparative evaluation of six indigenous rangeland grasses for pasture production under varying soil moisture contents in Tana River county, southeastern Kenya**”* is my original work and has never been presented for a degree in any other university.

________________________________   ________________________________

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APPROVAL

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DEDICATION

To my parents ***Meshack Koech*** *and* ***Rebecca Koech*** *who made great sacrifices to make me who I am today, for their advice and guidance throughout my studies. To all my family members for financial and moral support all through my studies. To my dear wife* ***Gladys*** *and lovely son* ***Brandon*** *for their support and self denial as I struggled to see this happy moment come to pass. God bless you all.*

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TABLE OF CONTENTS

ACRONYMS

ADF	Acid Detergent Fibre
ADL	Acid Detergent Lignin
AGDM	Above Ground Dry Matter
ANOVA	Analysis of Variance
AOAC	Association of Analytical Communities
ASAL	Arid and Semi-arid Lands
CEC	Cation Exchange Capacity
CF	Crude Fibre
CP	Crude Protein
CSDES	Centre for Sustainable Drylands Ecosystems and Societies
DAAD	German Academic Exchange Service
DM	Dry Matter
DOH	Date of harvest
DOP	Date of Planting
ECe	Electric Conductance
EE	Ether Extract
ET	Evaptranspiration
FAO	Food and Agricultural Organization
FC	Field Capacity
GB	Gypsum Blocks
GI	Germination Index
GOK	Government of Kenya
GP	Germination Percent
ISDMD	*Insacco* Dry Matter Degradability
ISTA	International Seed Testing Association
KARI	Kenya Agricultural Research Institute
LSD	Least Significant Difference
NDF	Neutral Detergent Fibre
NIB	National Irrigation Board
OM	Organic Matter
PAC	Photo Assimilated Carbon
RAE	Reclamation of Arid Environments
UNDP	United Nations Development Programme
USDA	United States Department of Agriculture
WP	Water Productivity
WUE	Water Use Efficiency

SUMMARY

In response to the increasing livestock feed shortages in Kenya's arid and semi-arid rangelands, production and storage of hay and/or other forages for utilization during the dry seasons has been identified as a possible strategy. However, because of the low and highly variable rainfall received in these areas, implementation of this programme would require support of an elaborate irrigation system. In addition, indigenous grass species which are capable of surviving in these rather hash conditions better than most of the introduced species such as Rhodes grass and alfalfa must be incorporated. The initiative should address such questions as which grass species should be cultivated in which areas, and what crop husbandry practices, especially watering will give the best results. The aim of this study was to evaluate the productivity of six range grasses under varying soil moisture contents (80, 50 and 30% Field Capacity; and rainfed conditions), in pure and mixed stands. The study evaluated water use efficiency (WUE) plus the quantity and quality of seeds of each species and how they were affected by the method of storage and length of storage. Finally, the study evaluated the effects of stage of maturity, curing methods and storage on its quality. The grasses evaluated were *Chloris roxburghiana*- (CR), *Eragrostis superba* -(ES), *Enteropogon macrostachyus*-(EM), *Cenchrus ciliaris*- (CC), *Chloris gayana* -(CG), and *Sorghum sudanense* -(SB).

As expected, watering treatments had a positive and significant ($p \leq 0.05$) effect on above ground dry matter (AGDM) yields in all the grasses in pure and mixed stands. *SB* had the highest yields (13.7t ha^{-1}) at 80% FC although not significantly different from the 50 and 30 % FC (11.6t ha^{-1}and 7.7t ha^{-1}, respectively.. Pure grass stands performed better than mixed stands in terms of biomass yields. However, the highest (5-species) mixtures had higher yields than mixtures with fewer species (2, 3 and 4 species) which was attributed to functional diversity effects. Watering also boosted tiller heights and densities in all the species. SB was the tallest followed by *CG* and *EM*. In addition, SB and CG performed better under lower watering profiles making them more likely species for pasture production under irrigation under arid and semi-arid conditions.

Augmenting soil moisture, increased seed yields on all the grasses with SB having the highest yields at 80% FC (1250 kg ha^{-1}), compared to 700.5, 533.9 and 150.7 kg ha^{-1}, at 50 and 30% FC, and control, respectively. CG yielded more seeds at 30% FC (1066.8 kg ha^{-1}) than at 80 and 50% FC and rain fed (766.9, 866.8 and 123.7 kg ha^{-1}, respectively). *CR*, on the other hand had higher seed yields at 50 and 30 % FC (516.1 and 633.4 kg ha^{-1}, respectively), than at 80% FC and rain fed treatment (103 and 54.3 kg ha^{-1}) respectively. ES and CC exhibited no difference in seed yields across the three soil moisture levels. .

Although there were clear differences between the species, duration of seed storage between harvesting and planting had high impact on subsequent germination rates and indices (GI). Two weeks storage had the poorest germination rates for the six species, while more than 24 weeks storage had the highest germination rates. For instance, SB had the highest germination rate (> 50%) when stored for 2 weeks and >75% when stored for 36 weeks. *EM* seeds stored for 2 weeks achieved <10% germination rate even after on the 14th day after sowing. With at least 12 weeks storage, all the grass species started germinating 3 days after sowing.

In terms of forage quality, all the species exhibited a significant ($p \leq 0.05$) decline in crude protein (CP) content as the plants aged. SB hand the lowest CP content of the six species. Curing period did not substantially affect the CP content, while indoor storage had significantly ($p \leq 0.05$) higher CP than outdoor storage. Crude fibre (CF), neutral detergent fibre (NDF) and acid detergent fibre (ADF) forage components increased with increase in maturity in all the species, and in the two storage methods. On the other hand, storage method had no effect on the *in sacco* dry matter digestibility (ISDMD).

As expected, the hay quality was affected by the age of the grass at harvesting and storage methods. Indoor storage is always more beneficial than outdoor method, since it shields the forage from the vagaries of weather. The result of this study demonstrated that harvesting the forage between 8 and 10 weeks old, curing the material for 1-3 days before baling and storing it indoors had better quality hay than the other handling methods.

The six grasses demonstrated distinct differences in water use efficiencies (WUE). Generally, there was a decline in WUE with maturity in all the species. SB had the highest WUE (> 20) WUE between the 8th and 12th week of maturity at 30% FC soil moisture content.

DEFINITIONS OF KEY TERMS USED IN THIS THESIS

- **Rangelands:** *"land on which the native vegetation, predominantly grasses, grass-like plants, forbs, or shrubs are suitable for grazing or browsing use."* They include natural grasslands, savannah, shrublands, most deserts, tundra, alpine communities, coastal marshes and meadows (SRM, 2006).
- **Dry lands:** tropical and temperate areas with an aridity index of less than 0.65 [2]. Drylands can be further classified into four sub-types: dry sub-humid lands, semi-arid lands, arid lands, and hyper-arid lands. Some authorities consider Hyper-arid lands as deserts (UNCCD) although a number of the world's deserts include both hyper arid and arid climate zones.
- **Soil moisture content:** the quantity of water contained in soil (called **soil moisture.** Water content is used in a wide range of scientific and technical areas, and is expressed as a ratio, which can range from 0 (completely dry) to the value of the soil porosity at saturation. It can be given on a volumetric or mass (gravimetric) basis (Dingman, 2002).
- **Water use efficiency (WUE):** the ratio of water used in plant metabolism to water lost by the plant through transpiration (evapotranspiration). This takes into account the amount of biomass produced per unit of evapotranspiration (Tambussi, *et al.,* 2007).
- **Field capacity (FC):** the amount of soil moisture or water content held in the soil after excess water has drained away and the rate of downward movement has decreased (Veihmeyer & Hendrickson, 1949)
- **Pastoralism:** nomads who raise livestock on natural pastures
- **Pastoral farming:** settled farmers who grow crops to feed their livestock
- **Drought:** the absence of rainfall or irrigation for a period of time sufficient to deplete soil moisture and injure plants.
- **Water or Drought stress:** when water loss from the plant exceeds the ability of the plant's roots to absorb water and when the plant's water content is reduced enough to interfere with normal plant processes (Gómez-Luciano *et al.,* 2012).

CHAPTER ONE

General introduction

1. Introduction

Low and erratic rainfall, punctuated by frequent and protracted droughts is today a common feature in the world's rangelands. Consequently, these lands, whose primary economic activity is livestock production, are characterized by low and highly variable supply of poor quality fodder for livestock. The areas 'swing' between periods of excess forage of fairly high quality during the wet season, to situations of very little and poor quality forage during the dry seasons. This has further been worsened by reduced mobility as a result of land fragmentation and land use changes. For many years, pastoralists employed mobility to meet their livestock feed requirements; especially access to forage during dry seasons. According to FAO (2005), these scenarios are major constraint to livestock production particularly in the tropics, due to lack of adequate protein and energy during the dry season.

Livestock industry in Kenya contributes up to 10% of National Gross Domestic Product (GDP) and 40% of agricultural GDP (USAID, 2011; Alila & Otieno, 2006). In arid and semi-arid lands (ASALs), for example, about 90% of employment opportunities and 95% of family incomes are derived from the livestock (FAO, 2005). However, about $2 billion worth of livestock is lost annually through mortality arising from starvation, diseases and missed trade opportunities, leading to increased food insecurity in the ASALs (USAID, 2011). The acute shortage of forage to sustain livestock populations through the dry seasons has threatened the livelihood security of pastoral communities (Ndathi *et al.,* 2011; Opiyo *et al.,* 2011). Death of livestock at the peak of the prolonged droughts has been a common phenomenon in the horn of Africa in the last few decades. For example, in the 2005/2006 drought, livestock worth more than KSh70 billion was lost in North Eastern Kenya (UNDP, 2010). Going forward, climate change coupled with the closely related land use changes associated with the increasing human and livestock populations may further exacerbate this situation. Consequently, there is an urgent need to increase the availability of forage in the drylands in order to maintain and improve the mainstream livelihood systems (Ndathi *et al.,* 2011).

Livestock production especially under agro-pastoral and pure pastoralism is the main economic activity in the drylands of eastern Africa. The communities living in these areas have over the years developed coping mechanisms which enable them to survive through the dry seasons. However, the effectiveness of such mechanisms has been negatively impacted by the rapid increase in human and livestock populations. This situation has been exacerbated by land use changes and climate variability and change (Ndathi *et al.,* 2011). Pastoral areas that were previously used for dry season grazing have been encroached by other land uses such as farming, mining, wildlife conservation, and human settlements leaving the pastoralists with limited options which trigger resource conflicts between them and farmers. Communal grazing areas have been sub-divided into uneconomical and unviable units that can no longer support the nomadic lifestyles of livestock owners (Pratt & Gwynne, 1977; Orindi *et al.,* 2007) while increasing frequency of droughts has led to deaths of large numbers of livestock (Morton 2006; IPCC 2007). This is particularly so because of reduced livestock feed supply especially during the dry seasons.

Production of livestock forage through irrigation in the ASALs has recently been identified as one of the potential intervention measures of dealing with the highly variable livestock feed supply in the ASALs (Mnene, 2006, Mganga *et al.,* 2010a). This will entail growing, harvesting and storing of the forage in form of hay, or preserving it *in situ* as standing hay and utilizing it during the dry season when the open pastures have been completely utilized. While integration of crops, pastures and livestock production has shown some benefits in some of the pastoral areas, especially under irrigation conditions, it has its own challenges (Allen *et al.,* 2007). Anderson & Schatz, (2003) argues that dry land ecosystems are more resilient than has previously been accepted, as long as livestock, crops and pastures are integrated in such a way that they complement each other.

To deal with this challenge, range scientists, pasture experts and animal production specialists have considered several options of ‘bridging’ the feed supply/demand gap. One of them is large-scale cultivation of fodder through irrigation within the ASALs where water for irrigation is available from sources such as rivers, dams, or harvested rain water stored for use during the dry seasons.

Large irrigation schemes exist in some parts of Kenya’s ASALs such as Perkerra in Baringo County, Bura in Tana River County, Katilu and Lokubai in Turkana County among others. However, emphasis has always been on food crop production despite the fact that in most of these areas, the neighbouring communities are pastoralists or agro-pastoralists. This has often resulted in very low level of ownership and support of the development programmes initiated by government. It has also been reported that pastoralists who go into farming during droughts, buy livestock from crop earnings during the wet season when conditions are favourable for growth of natural forages (Kirbride & Grahn, 2008). At times, they also quit farming when situations improve posing even more challenge to livestock feed supply due to rapid increase in livestock numbers thereafter.

A number of studies have evaluated the performance of range grasses under irrigation and some species have shown great potential for higher yields under rainfed cultivation (Opiyo, 2007; Mganga *et al.,* 2010b; Ogillo *et al.,* 2010; Opiyo *et al.,* 2011). However, most of these studies focused on productivity and other morphometric characteristics of the grass species, but hardly any evaluated the practical feasibility of cultivating these species under irrigation in varying soil water profiles. If this option will be pursued, issues of water use efficiency (WUE), seed productivity and quality, watering or irrigation regimes would have to be addressed. Since these grasses in the natural pastures grow in mixed stands, one would want find out which one is more productive: pure (monoculture) or mixed stands? If mixed stands are more productive, which species are more compatible and/or how many species give the optimum forage yield? If this information is availed to farmers and pastoralist then there would be high chances of increasing fodder production in ASALs through irrigation which would close the forage supply gap between the wet and dry season.

2. Scope of the study

This study sought to determine the performance of six dominant rangeland grass species under different soil moisture contents in the southeastern rangelands of Kenya. The study further evaluated the water use efficiency (WUE) of the six grass species as well as the effects of stage of maturity, curing and storage methods on forage quality. The grasses evaluated were: *Chloris roxburghiana* (Horsetail grass), *Eragrostis superba* (Maasai love grass), *Enteropogon macrostachyus (*Bush rye), *Sorghum sudanense* (Sudan grass), *Chloris gayana* (Rhodes grass) and *Cenchrus ciliaris (*African fox tail grass). The six species were selected after a reconnaisence survey which confirmed that they were the most dominant species in the area. A few pastoralists and/or agropastoralists are already cultivating them for commercial production of fodder and seeds.

3. Objectives

The main objective of this study was to evaluate the performance of six local grass species under different soil moisture contents in the southeastern rangelands Kenya.

The specific objectives were:

1. To determine the growth responses (biomass yield and morphometric characteristics) of six range grasses to different soil moisture contents
2. To determine the effects of varying soil moisture content on seed yield of the six range grasses
3. To determine the effects of varying soil moisture content on seed quality of the six range grasses
4. To determine the effects of curing and storage methods on the quality of forage from six range grass species
5. To determine the relative Water Use Efficiencies (WUE) of the six grass species.

4. Research questions

This study attempted to answer the following questions:

1. How does variation in soil water content affect above ground biomass productivity, water use efficiency and forage quality of the various grasses, when grown singly and/or in various mixed stands?
2. How does variation in soil moisture content affect species interaction and responses among grasses, and how does it affect the quality and quantity of forage produced?
3. How do different curing and storage conditions affect the quality of the forage (hay)?
4. How do the species perform in terms of water utilization at different irrigation levels?

References

Alila, P. O., & Atieno, R. (2006). Agricultural policy in Kenya: Issues and processes. In A paper for the Future Agricultures Consortium Workshop, Institute of Development Studies (pp. 20-22). http://tinyurl.com/qx47ryb (Accessed on 17 August, 2011).

Allen, V. G., Baker, M. T., Segarra, E., & Brown, C. P. (2007). Integrated irrigated crop livestock systems in dry climates. *Agronomy Journal*, *99* (2), 346-360.

Anderson, V., & Schatz, B. (2003). Biological and economic synergies, and methods of integrating beef cow and field crops enterprises. 2002. http://www.ag.ndsu.edu/pubs/ansci/beef/2002beef.pdf#page=3

Dingman, S.L. (2002). "Chapter 6, Water in soils: infiltration and redistribution". *Physical Hydrology* (Second ed.). Upper Saddle River, New Jersey: Prentice-Hall, Inc. p. 646. ISBN 0-13-099695-5.

FAO (2005). FAOSTAT data. Food and agriculture organization, Rome. http//:faostat.external.fao.org/default,jsp. (Accessed on 3rd August, 2011

GOK, (2005). Tana River District Strategic Plan 2005-2010 for Implementation of the National Population Policy for Sustainable Development. Available online. http://ncpd ke.org/strategicplans/TanaRiver.pdf. (Accessed 25 June 2012).

Gómez-Luciano, L.B.; Su, S.H. & Hsieh, C.H. (2012). "Establishment of a Rapid Screening Method for Drought Tolerance of Rice Genotypes at Seedling Stage". *Journal of International Cooperation* **7** (2): 107–122. ISSN 1992-1497.

http://earthtrends.wri.org/country_profiles/index.php?theme=4

Intergovernmental Panel on Climate Change (IPCC). (2007) Summary for policy markers. In climate change 2007. Working Group III of the Intergovernmental Panel on Climate Change.

ISTA. (1976). International rules for seed testing. *Seed Science and Technology* 4:23-28

Kirkbride, M., & Grahn, R. (2008). Survival of the fittest: pastoralism and climate change in East Africa. *Oxfam Policy and Practice: Agriculture, Food and Land, 8*(3), 174-220.

Mganga, K. Z., Musimba, N. K., Nyangito, M. M., Nyariki, D. M., Mwangombe, A. W., Ekaya, W. N., & Verhagen, J. (2010a). The role of moisture in the successful rehabilitation of denuded patches of a semi-arid environment in Kenya. *Journal of Environmental Science and Technology, 3*:195-207.

Mganga, K. Z., Musimba, N. K., Nyariki, D. M., Nyangito, M. M., Mwang'ombe, A. W., Ekaya, W. N., & Muiru, W. M. (2010b). Dry matter yields and hydrological properties of three perennial grasses of a semi-arid environment in east Africa. *African. Journal of Plant Science, 4*(5), 138-144.

Middleton N. J. & Thomas D. 1997. World Atlas of Desertification. UNEP, Arnold, London. UK.

Mnene, W.N. (2006). Strategies to increase success rates in natural pasture development through reseeding degraded rangelands of Kenya. *PhD Thesis, University of Nairobi, Nairobi, Kenya.*

Morton, J. (2006). Policy options paper: community based drought management for the pastoral livestock sector in Sub-Saharan Africa. *An Alive Policy Note*. http://www.pnas.org/content/104/50/19680.short

Ndathi, A. J. N., Nyangito, M. M., Musimba, N. K. R., & Mitaru, B. N. 2011. Enhancing output oriented livestock improvement strategies in drylands of Kenya. *Livestock Research for Rural Development*, *23*.

Ogillo, B. P., Nyangito, M. M., Nyariki, D. M., & Kubasu, D. O. (2010): A comparison of two micro-catchment technologies on above ground biomass production and financial returns of three range grasses in southern Kenya, pp 849 – 854. http://tinyurl.com/orrvglq. (Accessed on 15th May 2012).

Opiyo, F. E., Ekaya, W. N., Nyariki, D. M., & Mureithi, S. (2011). Seedbed preparation influence on morphometric characteristics of perennial grasses of a semi-arid rangeland in Kenya. *African Journal of Plant Science, 5*(8), 460-468.

Opiyo, F.O. (2007). Land treatment effects on morphometric characteristics of three grass species and economic returns from reseeding in Kitui district, Kenya. *MSc Thesis, University of Nairobi, Nairobi, Kenya.*

Orindi, V. A., Nyong, A., & Herero M. (2007) Pastoral livelihood adaptation to drought and institutional interventions in Kenya. Human Development Report Office. Occasional paper 54

Pratt D.J. & Gwynne, M.D., (1977). Rangeland Management and Ecology in East Africa. Robert E Krieger Publishing Co., Humington, New York, USA.

SRM, Society for Range Management. 2006. http://www.rangelands.org/srm.shtml. Accessed 28/05/2014.

Tambussi, E. A., Bort, J., & Araus, J. L. (2007). "Water use efficiency in C3 cereals under Mediterranean conditions: a review of physiological aspects", *Annals of Applied Biology*, 150(3), 307–321. doi:10.1111/j.1744-7348.2007.00143.x

UNDP/UNSO, 1997. Aridity zones and dryland populations: an assessment of population levels in the World's drylands. UNSO/UNDP, New York.

United Nations Development Program (UNDP), (2010). Office of the United Nations Humanitarian Coordinator in Kenya. *Kenya Humanitarian update Vol. 66* http://reliefweb.int/sites/reliefweb.int/files/resources/577DE464AA925C5E85257840007433E6-Full_Report.pdf (Accessed on 12th June 2012).

USAID, (2011). Drylands Livestock Development Program. http://kenya.usaid.gov/programs/economic-growth/412 (Accessed 26th September, 2011)

Veihmeyer, F.J. & Hendrickson, A.H. (1949). "The application of some basic concepts of soil moisture to orchard irrigation". Proc. Wash. State Hort. Assoc. 45: 25–41.

World Resource Institute (WRI). (2006). Earthtrend Environmental Information. Population, health and human well-being, Kenya.

CHAPTER TWO

General materials and methods

1. Description of the study site

The study was conducted in Bura Irrigation Scheme located in Tana River County (1°30′S, 40°0′E, 1.5°S 40°E; Figure 1) of Kenya. The irrigation scheme is managed by the National Irrigation Board (NIB) of Kenya, but the farms are owned by the community members. The climate of Tana River County is generally hot and dry with daily temperatures ranging between 20^{o}C and 38^{o}C. Rainfall is bimodal in distribution with long rains falling between April and June and the short ones between November and December. Long-term average rainfall ranges between 220mm and 500mm and are erratic in frequency and distribution. Temperatures are highest February to April and September to October. About 72% of the population of Tana River lives below the absolute poverty line and in the last 10 years, these people have been permanently on food relief (GoK, 2005). Tana River County is divided into three livelihood zones, namely, pastoral, agro-pastoral (mixed farming) and subsistence farming.

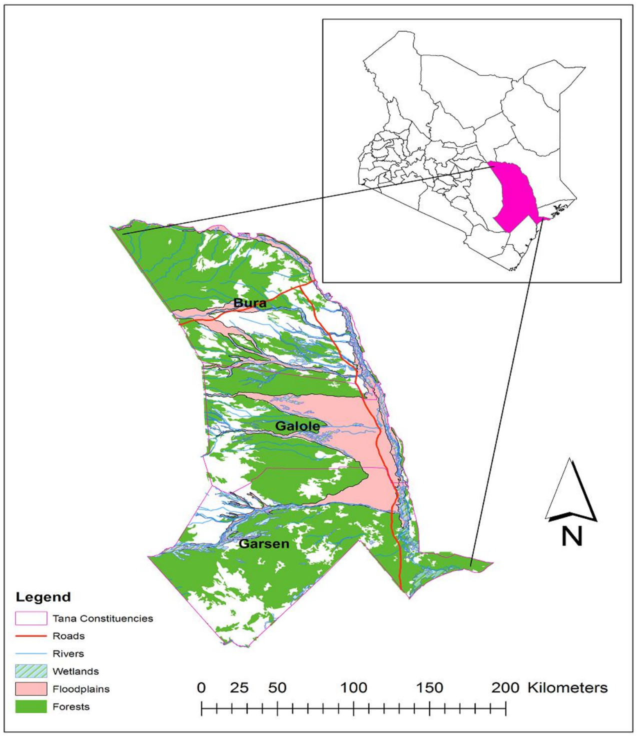

Figure 1 Study area map (Tana River County) in relation to Kenya

2. Soil types

The soil types of Tana River County are mainly vertisols and vertic fluvisols. They are associated with swelling and forming of ponds during wet seasons with low infiltration rates from the sealing by high clay content. During dry seasons, the soils dry out and form cracks. The soils are deep along the river valleys, but highly susceptible to water and wind erosion. Within the same County, the soils in the hinterlands are shallow and have undergone seasons of trampling by livestock, and thus easily eroded during rainy seasons.

3. Vegetation of the study area

Vegetation in the county ranges from thorny thickets of acacia trees to shrubs along the riverine ecosystems. Shrubs and grasses dominate most parts of the grazing areas in the county, with trees and perennial range grasses dominating the wetter parts along the delta. The county is also affected by invasive species such as *Prosopis juliflora*, commonly known as '*Mathenge*' (Mwangi & Swallow, 2008). This species was introduced in Baringo County in 1983 but has spread rapidly into many parts of the country smothering indigenous grasses, trees and shrubs (Andersson, 2005). The species has posed the threat of eliminating natural vegetation, blocking water points, canals and colonizing riparian areas.

4. Water Resources

The major permanent water source in the county is Tana River. However, seasonal rivers ('*laggas*') are present. Tana River is the only permanent river flowing through the County providing water for livestock and domestic use, especially during the dry seasons when all other sources have dried up. The river is also a source of water for irrigation along its course. The *laggas* which cover extensive areas during the wet seasons provide water to most households. They maintain sub-surface flow in the loose sand beds used during dry seasons by pastoralists. There are also numerous natural depressions and water holes across the county, especially areas between the *laggas* which can store water up to three months after the wet seasons hence are important water points for livestock.

5. Economic activities

Pastoral livestock production is the main economic activity in Tana River County. This covers most of the mainland areas of the county except the narrow strip along the river. Crop production is practised along the river banks and in the *lagga* banks during wet seasons. Crops commonly grown are sorghum and millets (Allison & Badjeck, 2004). There are also to large-scale irrigation schemes--Bura and Hola--where maize, beans, cotton are produced.

6. Experimental design, treatments and layout

One-acre parcel of land was identified within the NIB research site in the scheme, cleared off any bushes, ploughed and harrowed to a fine tilth. The ploughed area was then divided into four plots of 39 x 11m with five metre intervals to minimize interference from lateral seepage of water. The blocks were then randomly assigned to the water treatments as follows: treatment one (T1) =80% FC, treatment two (T2) = 50% FC, treatment three (T3) = 30% FC and treatment four (T4) = control (rain fed). Each main plot was then sub-divided into 30 sub-plots measuring 3 m x 3 m with 1 m boundary. Ten grass species treatment levels were then randomly assigned to the 30 sub-plots in three replicates. The treatment levels were: *Chloris roxburghiana* (CR)- (T$_1$), *Eragrostis superba* (ES)- (T$_2$), *Enteropogon macrostachyus* (EM)- (T$_3$), *Cenchrus ciliaris (CC)*- (T$_4$), *Chloris gayana* (CG) (T$_5$), *Sorghum sudanense* (SB)- (T$_5$), *E. superba* + *E. Macrostachyus* (T$_7$), *E. superba* + *E. macrostachyus* + *C. Ciliaris* - (T$_8$), *E. superba* + *E. macrostachyus* + *C. ciliaris* + *C. Gayana*- (T$_9$) and *E. superba* + *E. macrostachyus* + *C. ciliaris* + *C. gayana*; *E. Superba* - (T$_{10}$). For the mixed species treatments, proportional quantities of seeds of each species were mixed manually with aim of attaining >75% germination percentage. The seeds were sowed by broadcast method.

The moisture levels were selected to give high water conditions (80% FC), medium water (50%) and low soil moisture condition (30%). The latter soil moisture condition was above the wilting point of the grasses. The irrigation method was a modified overhead system that involved water being pumped into a storage tank. A hose-pipe was then connected from the tank to the experimental plots sprinkler. The amount of water applied to each plot was determined by a water meter fitted to the hose pipe before the sprinkler. The study layout of this study is illustrated in Table 1.

Table 1 Experimental layout

T 1 - 80% FC									
(T$_1$)	(T$_9$)	(T$_7$)	(T$_5$)	(T$_3$)	(T$_6$)	(T$_1$)	(T$_4$)	(T$_{10}$)	(T$_2$)
(T$_4$)	(T$_8$)	(T$_8$)	(T$_{10}$)	(T$_2$)	(T$_9$)	(T$_3$)	(T$_{10}$)	(T$_3$)	(T$_9$)
(T$_8$)	(T$_5$)	(T$_2$)	(T$_6$)	(T$_1$)	(T$_8$)	(T$_7$)	(T$_6$)	(T$_5$)	(T$_4$)

T 2- 50% FC									
(T$_3$)	(T$_5$)	(T$_7$)	(T$_1$)	(T$_4$)	(T$_5$)	(T$_2$)	(T$_9$)	(T$_6$)	(T$_2$)
(T$_9$)	(T$_7$)	(T$_8$)	(T$_1$)	(T$_2$)	(T$_3$)	(T$_3$)	(T$_{10}$)	(T$_1$)	(T$_9$)
(T$_6$)	(T$_8$)	(T$_1$)	(T$_{10}$)	(T$_5$)	(T$_8$)	(T$_7$)	(T$_6$)	(T$_4$)	(T$_{10}$)

T 3- 30% FC									
(T$_7$)	(T$_5$)	(T$_7$)	(T$_5$)	(T$_1$)	(T$_6$)	(T$_7$)	(T$_9$)	(T$_4$)	(T$_3$)
(T$_2$)	(T$_8$)	(T$_8$)	(T$_4$)	(T$_2$)	(T$_3$)	(T$_3$)	(T$_{10}$)	(T$_6$)	(T$_9$)
(T$_8$)	(T$_1$)	(T$_{10}$)	(T$_1$)	(T$_4$)	(T$_9$)	(T$_6$)	(T$_2$)	(T$_{10}$)	(T$_5$)

T 4 - Control/ Rainfed									
(T_{10})	(T_5)	(T_7)	(T_5)	(T_4)	(T_6)	(T_1)	(T_9)	(T_{10})	(T_2)
(T_7)	(T_8)	(T_8)	(T_4)	(T_2)	(T_3)	(T_3)	(T_1)	(T_3)	(T_9)
(T_4)	(T_5)	(T_2)	(T_{10})	(T_1)	(T_8)	(T_7)	(T_6)	(T_9)	(T_6)

For each treatment, soil moisture was maintained at the prescribed level through irrigation. In order to know when to recharge the plots, soil moisture content was monitored by means of the Delmhorst Soil Moisture Meter Gypsum Blocks (GBs) installed within each sub-plot. The GBs comprised Gypsum cast around two concentric, stainless steel electrodes. Two GBs were installed in each sub-plot. This was done at the centre of each sub plot, at two depths--15 cm and 30cm-- in separate holes dug using a 50 mm soil auger. The GBs were soaked in water overnight prior to installation as recommended. After the installation, the wire ends originating from the installed blocks were carefully supported by vertical sticks placed on the ground for easy access and to avoid burying them in the ground. The moisture readings were thereafter taken by means of GBs moisture metres. The amount of water applied to each treatment was recorded throughout the study period for the three soil water content.

The grass seeds were sourced from Kenya Agricultural Research Institute (KALRO), Kiboko Station. Before planting, the grass seeds were tested for germination rates using the method described by ISTA (1976). The germination rates obtained were used to determine the mixing and sowing rates for each species such that >75% germination rates were obtained. Sowing was done manually by broadcast. DAP fertilizer was applied to all the experimental plots at the rate of 200kg ha^{-1}. All other routine pasture husbandry practices such as weeding were conducted at the same time for all the treatments. Data collections methods pertinent to each of the objective are presented in the chapters.

80% FC

50% FC

30% FC

Plate 1 Photographs showing the grass species grown at 80, 50 and 30% FC soil moisture content

References

Allison, E. H., & Badjeck, M. C. (2004). Livelihoods, local knowledge and the integration of economic development and conservation concerns in the Lower Tana River Basin. Hydrobiologia, 527(1), 19-23.

Andersson, S. (2005). Spread of the introduced tree species Prosopis juliflora (Sw.) DC in the Lake Baringo area, Kenya. Institutionen for Skoglig vegetationsekologi. ISSN, 1652-4918.

Andrew, C. S., & Robins, M. F. (1971). The effect of phosphorus on the growth, chemical composition, and critical phosphorus percentages of some tropical pasture grasses. Crop and Pasture Science, 22(5), 693-706.

GOK, (2005). Tana River District Strategic Plan 2005-2010 for Implementation of the National Population Policy for Sustainable Development. Available online. http://ncpd ke.org/strategicplans/TanaRiver.pdf. (Accessed 25 June 2012).

Leauthaud, C., Duvail, S., Hamerlynck, O., Paul, J. L., Cochet, H., Nyunja, J. & Grünberger, O. (2013). Floods and livelihoods: The impact of changing water resources on wetland agro-ecological production systems in the Tana River Delta, Kenya. Global Environmental Change, 23(1), 252-263.

Mwangi, E., & Swallow, B. (2008). Prosopis juliflora invasion and rural livelihoods in the Lake Baringo area of Kenya. Conservation and Society, 6(2), 130.

CHAPTER THREE

Effect of varying soil moisture content on aboveground biomass yields and morphometric characteristics of six dryland grasses of Kenya

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Abstract

Aboveground biomass yields by six indigenous rangeland grasses in pure and mixed stands at 80%, 50% and 30% field capacity (FC) and rainfed soil moisture conditions were determined. The soil moisture was allocated to four main plots. Each main plot was subdivided into 30 subplots which were randomly allocated to ten grass species treatments replicated three times. All the three water treatment levels yielded significantly ($p \leq 0.05$) higher above ground dry matter (AGDM) than the rainfed in pure and mixed stands. *S. sudanense* had the highest yields at 80% FC (13.7t ha^{-1}), though not significantly different from the 50 and 30 % FC (11.6t ha^{-1}and 7.7t ha^{-1}), respectively. *C. gayana* and *C. roxbhurghiana yields* were not significantly affected by changes in soil moisture content with yields ranging between 10.1 and 10.8t ha^{-1} but were lower than those of *CR* (<3.3t ha^{-1}). *C. ciliaris* performed better at 50% FC (9.1 t ha^{-1}) The 5 species mixed plots had greater than 9t ha^{-1} at 80% FC which is attributed to functional diversity effects under mixture. Differences in tiller numbers across the watering treatments and grass species were not significant, but very low under rainfed conditions. The tiller heights in all the species were lower under rainfed than irrigated treatments. *S. sudanense* had the highest tiller height followed by *C. gayana* and *E. Macrostachyus,* respectively. The three species also had higher AGDM yields than *E. superba, C. ciliaris* and *C. roxburghiana.* Irrigation increased the productivity of the six range grass species. *S. sudanense and C. gayana* performed better in AGDM production under lower irrigation levels and are therefore suited for production under irrigation in the semi-arid rangelands.

Keywords: Soil moisture content; Range grasses; Pasture irrigation; Semi-arid rangelands; Herbage; Biomass yields

1. Introduction

Rangelands are characterized by variable supply of fodder for livestock (Smith *et al.*, 2010) which is largely attributed to low and erratic precipitation. During normal wet seasons, most of these lands support large volumes of forage which is also of relatively high quality (Mbatha & Ward, 2010). The dry seasons, on the other hand, are characterized by scanty amounts forage which is also poor in quality (Ontitism *et al.* (2000). Until recently, pastoralists employed livestock mobility as the main mechanism of adapting to the feed deficits during the dry season (Orindi *et al*, 2007). This strategy is increasingly becoming untenable today due to a wide array of socio-economic, political and anthropogenic factors such as extension of crop farming and human settlements (cities and towns) into the dry lands. These factors are accompanied by rapid land fragmentations. Consequently, in most parts, the vast opentracks of drylands which facilitated the free movements of livestock in search of water and forage are virtually gone. This paradigmatic shift is being compounded by the climate change phenomenon. Under these circumstances, livestock feed supply remains a major challenge and is most likely going to get worse (Kirkbride & Grahn, 2008). Therefore, unless appropriate steps are urgently taken, the livelihoods of the many pastoral and agro-pastoral communities residing in these areas will continue being disrupted.

Large-scale cultivation, harvesting and storing of forage (hay, browse, pods, etc) to be utilized later during the dry season, when the conventional pastures have been depleted, has been marked as a potential strategy for bridging livestock feed deficits and adapting to climate change in the dry lands (USAID, 2011). For this to be pursued formally there is urgent need for research to identify the grass species with fast growth rates, drought tolerance and superior yields. In addition, there is need for information on appropriate agronomic and crop husbandry practices, including water use efficiency (WUE); forage quality and quantity; seed quantity and quality as well as major post-harvest losses of forage and seeds. Since these grasses under natural conditions grow in mixed stands, research to determine whether pure stands are more productive than mixed stands, is required. And if the later are more productive, then which species are most compatible? A comprehensive compendium of this kind of information covering the most dominant forage plants in the rangelands is missing. Very few studies have evaluated the practical feasibility of cultivating a given grass species for hay production in a given agro-ecological zone (Rao *et al.*1996; Muhammad, 1989; Mganga, 2009; Mganga *et al.* 2010b). This study was therefore carried out to evaluate the aboveground biomass yields and morphometric characteristics responses (shoot length, tiller number, tiller length, number of leaves per tiller and plant density) of six dryland grasses of Kenya. The grasses tested were *Chloris roxburghiana* (CR), *Eragrostis superb* (ES), *Enteropogon macrostachyus* (EM), *Cenchrus ciliaris* (CC), *Chloris gayana* (CG), *Sorghum sudanense* (SB).

2. Materials and methods

Experimental design and layout

This information is provided in chapter two.

2.1 Data Collection

2.1.1. Above ground biomass production

Above ground biomass yields were estimated at three phonological stages--12, 14, 16 weeks-- using the total harvesting method where a 0.25m² quadrat was systematically placed in each sub-plot three times and all the aboveground biomass clipped to 2.5cm stubble height each time (Tarawali *et al.*, 1995). The harvested materials from each quadrat were stored in separate labeled paper bags; oven dried at 80ºC for 96 hrs and weighed on a digital scale (AOAC, 1990). The average weights were then extrapolated to production per hectare (kg^{-1} ha^{-1}).

2.1.2 Tiller heights, numbers and number of leaves per tiller

Tiller heights and numbers were determined on the 8th, 10th and 12th week from sowing. The number of tillers around three randomly selected 'mother' shoots were counted, the heights of each tiller measured and the number of leaves per tiller counted. Tiller heights were measured from the base to the tip of the longest leaf. These were tagged for ease of identification during subsequent assessments.

2.1.3 Species density

Plant species density was estimated by frequency grid method (Vogel & Masters). Four grid sampling points were marked by systematically placing the grid in each of the sub-plots and the number of each grass species inside the grid identified and counted. The frequency of each species was then calculated by summing up the number of plots each species appeared from the four grid sampling points and dividing by 100 (Eqn. 1). Frequencies were then multiplied by 0.4 to get an estimate of density (plants m^{-2}) as described by Vogel & Masters (2001) (Eqn 2). Plant density (plant m^{-2}) estimates were done at 12th week from sowing.

$$Frequency = \frac{\text{Number of quadrats in which species occur}}{\text{total number of quadrats sampled (100)}} \text{ x } 100 \qquad (1)$$

$$Species\ density = \text{Frequency (in Eqn 1) x } 0.4 \qquad (2)$$

2.1.4 Statistical analysis

Statistical analyses included Analysis of Variance (ANOVA) at 95% confidence level. Where significant differences were detected, the means were separated by the Least Significant Difference (LSD) method at 5% probability level.

3. Results

3.1 Biomass production

Table 1 contains the average above ground biomass yields (kg ha^{-1}) of the six grass species in pure and mixed stands under 80%, 50% and 30% FC soil moisture regimes and 12, 14 and 16 weeks old. Changes in the soil moisture profiles had a significant ($p<0.05$) effect on the performance of all the grasses, whether in pure or mixed stands (ANOVA - Appendix 2). In pure stands, 12 weeks old and within 80% FC moisture range, SB and CG species performed significantly ($p<0.05$) better (>9.5 and 7.9 t ha^{-1}, respectively) than all the other four species. Under 50% FC moisture content SB and CG, EM, yielded significantly ($p<0.05$) more forage (7.0--9.0 t ha^{-1}) than the other three species, e.g., CR and ES with 2.5 t ha^{-1}). Within the 30% FC moisture profile, CG was the most prolific (>9.0 t ha^{-1}) followed by SB (7.2 t ha^{-1}). At the 14 weeks and 80% FC, CG and SB were still the most prolific (> 9.0 and 12.0 t ha^{-1}) compared to CC and CR which yielded slightly about 2.0 t ha^{-1}. Around 50% FC moisture, EM's performance dropped significantly to 6.7 t ha^{-1} compared to CC and CG (>8.0 and 9.0 t ha^{-1}). Within 30% FC moisture regime, CG and SB species were the most prolific (9.4 and 7.1 t ha^{-1})). At about 16 weeks old (maturity) and 80% FC, SB and CG exhibited higher performance (>10.0 and 13.0 t ha^{-1}, respectively) than the rest. CC was the poorest yielding about 2.5 t ha^{-1}. Within 50% FC moisture level, EM, CC, CG and SB out-performed the other two (9.0—12.0 Vs 1.5—2.5 t ha^{-1}). Under 30% FC moisture treatment, CG performed much better than all the other species (>10.0 Vs < 7.0 t ha^{-1}). Under the rainfed conditions CR, CG and SB were consistently the most productive species although they produced less than 10% what any of the irrigation treatments produced. For the mixed species treatments, the 5-species treatment combination performed consistently higher ($p\leq0.05$) than the 2-, 3- or 4-species combinations.

Table 1 Mean above ground biomass yields (kg ha-1) of the six grass species in pure and mixed stands at 80%, 50% and 30% FC at 12, 14 and 16 weeks old

	CR	***ES***	***EM***	***CC***	***CG***	***SB***	***CR/ES***	***CR/ES/EM***	***CR/ES/EM/CC***	***CR/ES/EM/CC/CG***
WEEK 12										
80% FC	3600.4^{b} ± 76.9	3468.3^{b} ± 34.0	6600.6^{b} ± 37.7	4064.6^{b} ± 18.9	7932.2^{e} ± 93.1	9464.4^{e} ± 23.1	4000.8^{b} ±84.1	3932.5^{b} ± 14.4	5532.7^{b} ± 11.5	9524.2^{e} ± 163.3
50% FC	2532.3^{a} ± 68.1	1800.5^{a} ± 30.4	7400.7^{e} ± 57.7	6532.9^{b} ± 93.0	9400.6^{e}± 44.4	9200.5^{e} ± 31.2	1464.9^{a} ± 2.9	6732.3^{b} ± 59.7	5932.1^{b} ± 66.6	7664.4^{e} ± 59.7
30% FC	2732.3 ^{a} ± 17.6	3264.1^{b} ± 7.6	5400.1^{b} ±30.4	5932.4^{b} ± 45.1	9000.7^{e}± 50.0	7264.8^{e} ± 35.1	1200.9^{a} ±5.0	4132.1^{b} ± 18.9	4932.3^{b} ± 7.6	6800.6 ^{b} ± 21.8
Rainfed	732.5 ^{c} ± 87.1	364.1^{d} ± 57.6	500.3^{d} ±80.4	532.5^{c} ± 75.1	707.5^{c}± 80.0	764.6^{c} ± 55.2	340.4^{d} ±85.2	432.8^{c} ± 78.1	432.4^{c} ± 57.5	610.5^{c} ± 51.8
WEEK 14										
80% FC	2400.2^{a} ± 13.2	4332.5^{b} ± 18.9	5132.9^{b} ± 12.6	2532.4^{a} ± 17.6	9000.3^{e} ± 47.7	12664.7^{f} ± 25.7	8400.3^{e} ± 26.5	5264.2^{b} ± 16.1	5400.3^{b} ± 13.2	8464.4^{e} ± 44.8
50% FC	1800.5^{a} ± 5.0	1200.6^{a} ± 5.0	9000.8^{e} ± 15.0	8400.2^{e}±20.0	9532.1^{e}± 18.9	6864.2^{b}± 128.5	1600.8^{a} ± 18.0	7864.9^{e} ± 15.3	4332.4^{b} ± 12.6	7932.3^{e} ± 81.3
30% FC	3264.5^{b} ± 7.6	3600.b^{a} ± 5.0	6400.9^{b} ± 5.0	5332.1^{b} ± 10.4	9400.5^{e}± 18.0	7124.3^{e} ± 10.4	1932.1 ^{a} ± 5.8	4064.0^{b} ± 10.4	5000.1^{b} ±15.0	5800.7^{b} ± 26.5
Rainfed	764.2^{c} ± 57.6	381.0^{d} ± 55.1	604.3^{d} ± 45.0	558.2^{c} ± 50.4	767.0^{c}± 48.0	824.9^{c} ± 60.4	532.8^{c} ± 55.5	464.8^{c} ± 60.3	511.0^{c} ±65.1	680.6^{c} ± 56.5
WEEK 16										
80% FC	3320.6^{b} ± 9.8	5600.3^{b} ± 13.2	6464.5^{b}± 20.8	2464.8^{a} ± 24.7	10864.1^{e} ± 41.9	13664.2^{f} ± 17.6	8864.8^{e} ± 34.03	5600.9^{b} ±13.2	5732.5^{b} ± 15.3	9664.2^{e} ± 106.1
50% FC	2,532.3 ^{a} ± 10.4	1532.2 ^{a} ±12.5	10,464.4 ^{e}± 17.6	9132.6 ^{e} ± 34.0	10200.1^{e}±25.0	11600.0^{e} ±17.3	1800.5^{a} ± 5.0	7332.1^{e} ± 59.2	6200.8^{b} ± 37.8	9264.6^{e} ± 20.0
30% FC	2132.6^{a} ± 12.6	3132.7^{b} ± 12.6	6664.8^{b} ± 10.4	6864.8^{b} ± 12.6	10132.1^{e} ± 7.6	7664.5^{e} ± 10.4	2864.3^{a} ± 12.6	4400.2^{b} ± 18.0	5132.1^{b} ±2.9	6800.0b ± 15.0
Rainfed	759.8^{c} ± 62.2	372.3^{d} ± 42.6	664.8^{c} ± 50.4	664.5^{c} ± 42.5	832.7^{c} ±3 7.6	964.8^{c} ± 60.5	764.5^{c} ± 42.5	480.1^{c} ± 48.0	532.4^{c} ±32.2	702.3^{c} ± 45.1

Means within the same columns with different superscripts are significantly different at $p<0.05$.
Key: CR=Chloris roxburghiana, ES= Eragrostis superba, EM= Enteropogon macrostachyus, CC= Cenchrus ciliaris, CG= Chloris gayana, SB= Sorghum sudanense, FC= Field capacity, ± Standard deviation

3. 2 Effect of soil moisture on number of tillers and leaves

Table 2 presents tiller numbers and lengths; number of leaves per tiller and plant density by species and soil moisture content levels (80, 50, 30% FC and rain-fed). Soil moisture content in the irrigated plots did not have a significant influence on either the number of tillers, number of leaves per tiller and/or the tiller lengths in any of the species   However, the effect was significant ($p \leq 0.05$) in the control plots. SB had the highest number of tillers in all the three soil moisture content levels ($p \leq 0.05$). Differences in plant density across the six grass species and soil moisture contents were significant ($p \leq 0.05$), with SB having the highest density followed by CG and EM.

Table 2 Mean tiller number, tiller length (cm), shoot length, plant density and leaves per tiller of six grass species at 80, 50 and 30% FC soil moisture content

	CR	***ES***	***EM***	***CC***	***CG***	***SB***
Tiller numbers						
80% FC	11.1^{b} ±2.3	19.3^{b} ±4.7	16.2^{b} ±2.3	28.0^{b} ±6.4	21.1^{b} ±11.1	31.0^{b} ±16.1
50% FC	10.8^{b}±3.3	14.3^{b} ±5.8	14.1^{ab} ±3.3	22.0^{ab} ±11.4	18.1^{ab} ±9.1	29.0^{b} ±6.1
30% FC	12.3^{ab} ±6.3	18.3^{b} ±7.1	12.1^{ab} ±2.4	20.0^{ab} ±8.4	16.3^{ab} ±9.4	31.2^{b} ±11.1
Rainfed	3.3^{a} ±1.3	3.1^{a} ±1.1	4.1^{a} ±2.3	4.7^{a} ±2.4	4.3^{a} ±1.2	5.2^{a} ±2.1
Tiller length (cm)						
80% FC	98.9^{c}±23.1	111.9^{c} ±54.8	89.7^{c} ±13.8	76.8^{ab} ±12.7	114.8^{b}±21.9	119.6^{b} ±67.9
50% FC	57.9^{b} ±21.4	99.7^{b} ±47.3	74.3^{b}±32.5	96.5^{b} ±44.2	102.8^{b} ±54.3	128.6^{b} ±57.1
30% FC	64.6^{b} ±31.3	97.9^{b} ±41.1	77.7^{b} ±33.3	100.8^{e} ±56.8	109.8^{b}±51.3	143.3^{c} ±54.7
Rainfed	24.6^{a} ±11.2	33.1^{a} ±21.6	41.3^{a} ±11.3	33.2^{a} ±18.1	43.3^{a}±19.5	52.4^{a} ±24.3
Leaves per tiller						
80% FC	4.4^{a} ±2.1	6.9^{a} ±2.1	5.1^{a} ±2.1	7.8^{b} ±2.8	8.1^{a} ±3.1	6.9^{a} ±2.2
50% FC	4.4 ^{a} ±2.1	6.9^{a} ±2.1	5.2^{a} ±2.1	8.6 ^{b} ±2.8	8.5^{a} ±2.1	4.8^{a} ±2.1
30% FC	3.4^{a} ±1.1	7.1^{a} ±4.1	6.2^{a}±3.3	9.2^{b} ±3.8	8.1^{a} ±3.2	6.1^{a} ±2.2
Rainfed	3.5^{a} ±2.1	4.1^{a} ±2.1	4.2^{a}±2.2	4.6^{a} ±2.8	5.2^{a} ±2.2	5.1^{a} ±2.5
Plant Density (plant m-^{2})						
80% FC	21.2^{b}	24.4^{ab}	32.4^{b}	27.6^{a}	27.6^{b}	32.8^{b}
50% FC	20.8^{b}	20.4^{ab}	31.6^{b}	25.2^{a}	28.4^{b}	34.8^{b}
30% FC	22.0^{b}	26.8^{ab}	29.2^{ab}	26.0^{a}	28.8^{b}	30.0^{b}
Rainfed	18.0^{a}	19.0a	17.2^{a}	22.0^{a}	20.9^{a}	23.3^{a}

Means within the same columns with different superscripts are significantly different at $p<0.05$.

Key: CR=Chloris roxburghiana, ES= Eragrostis superba, EM= Enteropogon macrostachyus, CC= Cenchrus ciliaris, CG= Chloris gayana, SB= Sorghum sudanense, FC=Field capacity, ± Standard deviation

4. Discussion

The above results have confirmed that soil moisture is major determinant of biomass yields in grasses. With adequate and regular supply of water, as well as other plant growth requirements, biomass yield will increase to the maximum. The higher biomass yields exhibited by EM and SB in this study were largely attributed to their early and faster germination rates which gave them a competitive advantage over the other four species which were slow in germinating (Kadmon & Schimida, 1990). These findings concur with those of Ferat *et al.* (2009), who obtained higher yields of 11.68 t ha^{-1} in SB (*Chopper* variety) under irrigation.

The differences in biomass yields at the different phenological stages, on the other hand, were attributed to morphological differences among the grasses. For instance, SB is naturally stemmier than the other species and therefore able to maintain higher vegetative productivity which, in turn, can account for a large portion of the higher dry matter yields above the other species. The same species had higher and longer number of tillers than the other species, which further contributes to overall biomass yields. Other studies have shown that *SB* generally has longer roots and higher water use efficiency than most of its contemporary species (Koech *et al.* 2014; Uzun *et al.,* 2009) which give it drought tolerance traits.

The relatively lower yields exhibited by CC at 80% FC soil moisture was attributed to the species' low tolerance to excess soil moisture content conditions (Jacobs *et al.,* 2004). Akram, *et al.* (2008) classified CC as drought tolerant because it showed high tendency to accumulate N, P, K^+ and Ca^{+2} during growth which enhances plants' productivity at lower moisture levels. The same species has also been identified as super performer (14.6 t ha^{-1}) under low irrigation and sandy-loam soils in the United Arab Emirates (Osman *et al.,* 2008).

The unusually high yields of *CG* in all the three soil moisture contents compared to *CC* are contrary to the findings of Asadullah & Ahmed, (2010), which were the opposite. However, their study focused on moisture 'extraction' capacities and not the biomass yields.

For this study, the higher performance of CG than *CC* could be largely attributed to higher germination rates of the former than the latter. Ability to germinate faster allows quick and fast penetration of roots through the soil profile which increases the volume of soil from which the plants extract water (Bibi *et al.*, 2010). Similarly higher yield of CG than CC and ES were reported by Bulle *et al.* (2010) in Northern Kenya, but under rainfed conditions. Ontitism *et al.* (2000) also earmarked CG as a potential livestock feed game-changer in the drylands. These characteristics give the species a competitive edge over many other range grasses in selecting species for pasture establishment and reseeding of denuded rangeland sites.

The extremely low productivity of all the six grass species under rainfed treatment (control) was not a surprise, given the fact that the amount of rainfall received during the study period was not only below normal, but also unevenly distributed (266.1mm with 56% received in 3 days).

The higher biomass yields from the five-species mixed stands than the monoculture stands observed in this study, was surprising as one would have expected the reverse. This phenomenon has been attributed to the diversity (synergistic) factor (Berdahl *et al.*, 2001; Donald-Thompson, 2013). Each species contributes to the total biomass yield on the basis of their individual physiological and morphological traits which play out differently depending on their level of adaptability (Berdahl *et al.*, 2001; Donald-Thompson, 2013). Mganga *et al.* (2010a) working with *CC*, *ES* and *EM* in pure stands and in mixtures also observed the biodiversity factor-- the mixed stands had higher yields than pure stands which was attributed to enhancement of some growth and development traits of the species when cropped in mixtures. Donald Thompson, (2013) working with grass-alfalfa and orchardgrass-fescuegrass mixtures also observed that the mixtures outperformed alfalfa, orchardgrass, and tall fescuegrass monocultures which he associated with the diversity factor. When several plant species grow side-by-side naturally in a mixture, some species grow much faster than others and become more dominant. This is largely attributed to their ability to utilize the available moisture and other nutrients (Bergh, 1968).

The observed differences in tiller numbers and heights could be attributed to the morphological differences which are associated with genetic differences among the grass species. SB and *EM* have vertical growth habits with strong and thicker culms and therefore have advantage over the semi-erect species like *CG* and *ES.* Such growth habits have been shown to impart competitive advantages in resource utilization and species survival. Kanak *et al.* (2013) attributed the higher performance of grass species with vertical growth habit to their ability to shade other plants and reduce competition for resources.

The observed increase in tiller lengths and shoot height in all the six grass species with advance in maturity is normal. Site conditions, soil type and rainfall amounts determine the performance of the species (Opiyo, 2007). Morphometric characteristics such as tiller numbers are important for plant adaptability and survival under grazing pressure since they determine photosynthetic rates and ultimately, the food reserves (Laidlaw, 2005). The number of tillers per plant determines the rate of biomass accumulation and the quality of forage (Skinner & Moore, 2007). Tillers contain leaves which are easily digestible and more preferred since they have less structural carbohydrates, especially the newly developed tillers with young leaves (Wilson *et al.,* 1991). However, a tiller will have both old leaves from previous season and young leaves from current season. The old leaves are lower in quality but enhance total biomass yields (Soininen, 2010), while the young ones improve the quality. Increase in tiller numbers with increase in water supply can be attributed to enhanced tiller recruitment. The findings of Mganga *et al.* (2010b) closely agreed with those of this study in terms of tiller recruitment patterns as the plants advanced in growth.

Surukhan *et al.* (1984), Skerman and Riveros, 1990; and Laidlaw 2005 concluded that grass species with higher number of tillers are more persistent and contribute more resources to the next generation of reproductive tillers in the sward. Differences in tiller density observed in this study could be attributed to their genetic differences coupled with environmental conditions including soil water content.

Leaf dynamics in grasses are a function of new leaf development and death of leaves which are determined by the environment and genetics of the grasses (Harper, 1989; Huibert & Jan, 1998). However, there is a close relationship between tiller numbers and leaf recruitment per tiller (Matthew *et al.*, 2000). Plant leaves determine the quality of forage for livestock with higher young and green leaves contributing more to the increase in crude protein (Michel & Helene, 2000; Arzani *et al.,* 2001). The leaf: stem ratio is a parameter of concern when evaluating pasture quality, and grass species with higher proportion of leaves per tiller and less stems tend to be of higher quality (Ball *et al.,* 2001; Rad *et al.,* 2013). Therefore the higher leaf numbers in *CG* and *CC* suggest better quality forage grasses.

Conclusion

The above findings amplify the importance of water availability in determining the overall biomass yields by the six indigenous grasses. As such, the heavy reliance on rainfall in forage production in all ASALs is the main cause of the rampant feed deficits in these areas. It was evident that SB, CG and EM were the most productive when properly watered. All of them produced more than 10t ha^{-1} equivalent to 700 bales of 14kgs each even under lowest soil moisture content. CC could give maximum yields at medium (50% FC) water supply. Because of the clear differences in WUE in each species, the need to grow the species separately and not in mixtures is apparent and hence the need to supply each of them with the appropriate amount of water throughout the growing period. SB and CG were the best choices for pasture production in moisture deficit environments.

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References

Akram, N A, Shahbaz M, Ashraf M. 2008. Nutrient acquisition in differentially adapted populations of *Cynondon dactylon* (L.) Per. and *Cenchrus ciliaris* L.under drought stress. *Pakistan Journal of Botany*. 40 (4):1433-1440.

AOAC. 1990. Official methods of analysis. 15th ed. Association of Official Analytical Chemists, Arlington, VA.

Arzani H, Torkan J, Jafari, M, et al. 2001. Investigation on effects of phenological stages and environmental factors (soil and climate) on forage quality of some important range species. *Journal of Agricultural Sciences.32: 385-397*

Asadullah A L A, Ahmed A. S. 2010. Soil water uptake efficiency of some irrigated indigenous and exotic forage species under desert climatic conditions. *Asian Journal of Science and Technology. 1 (1), 001-004,*

Ball D M, Collins M, Lacefield G.D, et al.2001. Understanding forage quality. Park Ridge, USA: American Farm Bureau Federation Publication.

Berdahl J D, Karn J F, Hendrickson J R. 2001. Dry matter yields of cool-season grass monocultures and grass–alfalfa binary mixtures. *Agronomy journal*, *93*(2), 463-467.

Bergh J.1968. An analysis of yields of grasses in mixed and pure stands. *Agriculture Research Reproduction, 714*.

Bibi A, Sadaqat H A, Akram H M, et al. 2010. Physiological and agronomic response of *Sorghum sudanense* to water stress. *Journal of Agricultural Research* 48: 3706379.

Bulle H, Mamo M, Geikuku P. 2010. Comparative evaluation of *Chrolis gayana* (Kunth), *Eragrostis superba* (Peyr) and *Cenchrus ciliaris* (L) for pasture production in Marsabit central district, northern Kenya. Proceedings of the 12th KARI biennial scientific conference. 8th – 12th November, Nairobi, Kenya, pp 826 – 830.

Donald Thompson. 2013. Yield and nutritive value of irrigated tall fescue compared with orchardgrass: In monocultures or mixed with alfalfa. *Canadian Journal of Plant Science,* 2013, 93(5): 799-807.

Ferat U, Serdal U, Mehmet S. 2009. Yield, Nutritional and Chemical Properties of Some Sorghum x *Sorghum sudanense* Hybrids (*Sorghum bicolor* (L.) *Moench* x *Sorghum sudanense* Stapf.). *Journal of Animal and Veterinary Advances, 8: 1602-1608.*

Grismer M. 2001. Sudangrass uses water at rates similar to alfalfa, depending on location. *California Agriculture*, *55*(4), 44-48.

Harper J L. 1989.Canopies as populations. In: Russell G, Marshall B, Jarvis DG, eds. Plant canopies: their growth form and function Cambridge: Cambridge University Press

Heuzé V, Tran G, Baumont R. 2013. *Buffel grass (Cenchrus ciliaris)*. Feedipedia.org. A programme by INRA, CIRAD, AFZ and FAO. http://www.feedipedia.org/node/482 *Last updated on August 23, 2013, 10:25. Accessed 12th Dec 2013.*

Huibert J B, Jan H N. 1998. Morphological analysis of leaf and tiller number dynamics of wheat (triticum aestivuml.): responses to temperature and light intensity. *Annals of botany* 81: 131-139. http://aob.oxfordjournals.org/content/81/1/131.full.pdf. (Accessed 9th Apr 2013)

ISTA. 1976. International rules for seed testing. Seed Science and Technology 4:23-28

Jacobs, S. S., van Niekerk, W. A. & Coertze, R. J. (2004). Qualitative evaluation of *Cenchrus ciliaris* cv. Molopo and Gayndah as forage. South African Journal of Animal Science. 34 (5): 65-67

Jeremiah J M, Jacob N B, Guy B K, et al. 2013. Root System Dynamics of *Miscanthus* × *giganteus* and *Panicum virgatum* in Response to Rainfed and Irrigated Conditions in California. *Bio Energy Research*, 6(2), 678-687.

Kadmon R. Schimida A. 1990. Patterns of spatial variation in the reproductive success of a desert annual. *Oecologia 83:139-144.*

Kanak A R, Khan M J, Debi MR. et al. 2013. Comparison on biomass production of three fodder germplasms. *Bangladesh Journal of Animal Science 42 (1), 35-39*

Kirkbride M, Grahn R. 2008. Survival of the fittest: pastoralism and climate change in East Africa. Oxfam Policy and Practice: Agriculture, Food and Land, 8(3), 174-220.

Koech O K, Kinuthia R N, Mureithi S M. et al. 2014. "Effect of Different Soil Water Content and Seed Storage on Quality of Six Range Grasses in the Semi-Arid Ecosystems of Kenya." *Environment and Ecology Research*. Submitted;2(2):261-271.

Laidlaw A S. 2005. The relationship between tiller appearance in spring and contribution of dry matter yield in perennial ryegrass (*Lolium perenne* L.) cultivars differing in heading date. *Grass and Forage Science*, 60:200-209

Matthew C, Assuero S G, Black C K. 2000. Tiller Dynamics of Grazed 7 Swards. *Grassland ecophysiology and grazing ecology*, 127

Mbatha K R, Ward D. 2010. The effects of grazing, fire, nitrogen and water availability on nutritional quality of grass in semi-arid savanna, South Africa. *Journal of Arid Environments*, *74*(10), 1294-1301.

Mero R N, Uden P. 1997. Promising tropical grasses and legumes as feed resources in central Tanzania I. Effect of different cutting patterns on production and nutritive value of six grasses and six legumes. Tropical grasslands, 31, 549-555.

Mganga K Z, Musimba N K, Nyangito M M et al. 2010a. The role of moisture in the successful rehabilitation of denuded patches of a semi-arid environment in Kenya. *Journal of Environmental Science and Technology, 3*: 195-207.

Mganga K Z, Musimba N K, Nyariki D M et al. 2010b. Dry matter yields and hydrological properties of three perennial grasses of a semi-arid environment in east Africa. *African Journal of Plant Science 4*(5), 138-144.

Mganga K Z. 2009. Impact of grass reseeding technology on rehabilitation of the degraded rangelands: a case study of Kibwezi district, Kenya. *MSc Thesis, University of Nairobi, Nairobi, Kenya).*

Michel D, Helene D. 200). Growth and Senescence of the Successive Grass Leaves on a Tiller. Ontogenic Development and Effect of Temperature. *Annals of Botany* 85: 635-643.

Muhammad N. 1989. Rangeland Management in Pakistan. ICIMOD Senior fellowship series No.1. Pan Graphics (Pvt.) Ltd. Islamabad. 193pp.

Ogillo B P, Nyangito M M, Nyariki D M et al. 2010. A comparison of two micro-catchment technologies on above ground biomass production and financial returns of three range grasses in southern Kenya, pp 849 – 854. http://tinyurl.com/orrvglq. (Accessed 15th May 2012).

Ontitism S M, Ondabu N, Ouda J et al. 2000. The Performance and Composition of Ley Grasses and Legumes, Sweet Potatoes and Fodder Trees. In Wamae L, Murithi F, Wasike W (Eds.) Proceeding of 7th KARI biennial scientific conference held on 13th-17th Nov. 2000. Nairobi. pp. 389-392

Opiyo F E O, Ekaya W N, Nyariki D M et al. 2011. Seedbed preparation influence on morphomeric characteristics of perennial grasses of a semi-arid rangeland in Kenya. *African Journal of Plant Science*. 5(8), 460-468.

Opiyo O F E. 2007. Land treatment effects on morphometric characters of Three grass species and economic returns from Reseeding in Kitui district, Kenya *(MSc. Thesis, University of Nairobi).*

Orindi V A, Nyong A, Herrero M. 2007. Pastoral livelihood adaptation to drought and institutional interventions in Kenya. Human Development Report Office, Occasional Paper, 54. http://www.ilri.org/Link/Publications/orindi_nyong_herrero.pdf

Osman A E, Makawi M, Ahmed R. 2008. Potential of the indigenous desert grasses of the Arabian Peninsula for forage production in a water-scarce region. *Grass and Forage Sci*ence. 63 (4): 495–503

Rad M S, Rad J S, da Silva J A T et al. 2013. Forage quality of two halophytic species, *Aeluropus lagopoides* and *Aeluropus littoralis*, in two phenological stages. *International Journal of Agronomy and Plant Production*, *4*(5), 998-1005

Rao A S, Singh K C, White G R. 1996. Productivity of *Cenchrus ciliaris* in relation to rainfall and fertilization. *Journal of Range Management*, 49: 143-146

Sarukhan J, Martinez-Ramos M, Pinero D. 1984. The analysis of demographic variability at the individual level and its population consequences. In: Sarukhan J and Dirzo R (eds) Perspectives on population ecology. Sinauer Associates Inc., Sunderland, Massachusetts, USA, pp. 141-165.

Skerman P J, Riveros F. 1990. Tropical grasses. Food and Agriculture Organization of the United Nations, Rome.

Skinner H R, Moore K J. 2007. Growth and development of forage plant. In: Barnes R.F., Nelson C.J., Moore K.J.,Collins M. (eds): Forages: *The Science of Grassland Agriculture*. 6th Ed. Wiley-Blackwell, Ames, USA, 53–66.

Smith P, Gregory P J, Van Vuuren D et al. 2010. Competition for land. Philosophical Transactions of the Royal Society B: Biological Sciences, 365(1554), 2941-2957.

Snyman L D, Joubert H W. 1996. Effect of maturity stage and method of preservation on the yield and quality of forage sorghum. *Animal feed science and technology*, 57(1), 63-73.

Soininen E M, Hübner C E, Jónsdóttir I S. 2010. Food selection by barnacle geese (*Branta leucopsis*) in an Arctic pre-breeding area. *Polar Research*. 29*:* 404–412.

Tarawali S A, Tarawali G, Larbi A et al. 1995. Methods for the Evaluation of Legumes, Grasses and Fodder Trees for Use as Livestock Feed. ILRI Manual 1. ILRI (International Livestock Research Institute), Nairobi, Kenya. pp. 51.

Teague W R, Dowhower S L. 2002. Irrigation impact on harvest efficiency in grazed Old World Bluestem. *Journal of Range Management*. 55: 260-265

USAID. 2011. Drylands Livestock Development Program. http://kenya.usaid.gov/programs/economic-growth/412 (Accessed 26th September, 2011

Uzun F, Ugur S, Sulak M. 2009. Yield, Nutritional and Chemical Properties of Some Sorghum x Sudan Grass Hybrids (*Sorghum bicolour* (L.) Moench x *Sorghum sudanense* Stapf.). *Journal of Animal and Veterinary Advances*, *8*(8), 1602-1608.

Vogel K P, Masters R A, 2001. Frequency grid—a simple tool for measuring grassland establishment. *Journal of Range Management* 54:653–655

Wilson J R, Deinum B, Engels F M. 1991. Temperature effects on anatomy and digestibility of leaf and stem of tropical and temperate forage species. Netherlands *Journal of Agricultural Science*, 39:31–48

CHAPTER FOUR

Effect of Varied Soil Moisture Content on Seed Yield by Six Range Grasses in southeastern Rangelands of Kenya

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Abstract

Seed yields of six range grass species grown at 80, 50 and 30% field capacity (FC) soil moisture content and rain fed condition were evaluated. Watered treatments had higher seed yields than rain fed for all the grasses. *C. roxburghiana* had higher seed yields at 50 and 30 % FC (516.1 and 633.4 kg ha^{-1}, respectively), than at 80% FC and rain fed treatment (103 and 54.3 kg ha^{-1}, respectively). *E. superba* and *E. macrostachyus* showed no difference in seed yields across watered treatments. *C. ciliaris* had no significant difference among watered and rain fed. *C. gayana* produced more seeds at 30% FC (1066.8 kg ha^{-1}), than 80, 50% FC and rain fed had 766.9, 866.8 and 123.7 kg ha^{-1}, respectively. The highest yield was observed in *S. sudanense* at 80% FC (1250 kg ha^{-1}), compared to 50, 30% FC and rain-fed (700.5, 533.9 and 150.7 kg ha^{-1}, respectively). Even under rain-fed conditions, *S. sudanense* yielded the highest quantity of seeds (150.7 kg ha^{-1}) compared to *C. ciliaris* (21.8 kg ha^{-1}). *C. gayana* and *S. sudanense* were the most promising species under limited water supply.

Keywords: Field Capacity, Irrigated Pasture, Range Grasses, Grass Seeds, Soil moisture content, Kenya

1. Introduction

Kenyan rangelands are increasingly becoming less productive in terms of livestock forage due to range degradation (Nyangito *et al.*, 2008; Kigomo & Muturi 2013). This has become more severe with the increasing climate change phenomenon that has resulted into reduced precipitations leading to reduced livestock productivity due to feed shortage (Musimba *et al.*, 2004). The main drivers of rangeland degradation are overgrazing, inappropriate cultivation in the marginal and fragile areas, deforestation and climate change (Mganga *et al.*, 2010b; Clay *et al.*, 2014) hence accelerated loss of dryland community’s livelihoods in the long term. The effects of land degradation has far much impacts on livestock production (Nyangito, 2005; Simba *et al.,* 2013) with direct effects on reduced feed supply, reduced carrying capacity and the frequently observed livestock mortality due to starvation.

Production of pastures under irrigation for dry season use has been used as one of the interventions for sustaining and improving forage production and consequently improving livestock production in rangelands (Mnene, 2005; Mganga *et al.,* 2010b; Mganga *et al.,* 2013). Integration of crops, pastures and livestock production has shown some benefits in pastoral areas especially under irrigation conditions (Allen *et al.,* 2007; Anderson &Schatz, 2013) and some range scientists have argued that dryland ecosystems are more resilient than has previously been accepted, as long as livestock, crops and pastures are integrated to complement each other. Establishment of irrigated pastures has been touted as one of the ways to enhance adaptation of livestock production to climate change in the drylands through utilization of established pastures for strategic feeding during dry seasons (USAID, 2011). This is especially so because pasture production under natural rainfall has failed to sustain the pastoral production systems.

Past studies on performance of range grasses under irrigation have shown greater potential in rangelands (Opiyo, 2007; Mganga *et al.,* 2010b; Ogillo *et al.,* 2010; Opiyo et al., 2011). However, these studies assessed the range grasses in terms of biomass productivity and ecological restoration capacities and never evaluated the productivity under different soil moisture profiles and water use efficiencies (WUE). The increasing pressure on available water use for both crops and pastures calls for studies that maximize water available with greater benefits in biomass and seed yields.

Recently, there has been a steady increase in demand for grass seeds for rehabilitation of degraded rangelands and establishment of pastures. However, the challenge has all along been availability of adequate quantities of seeds of high quality (Reynolds *et al.,* 2005; Mganga *et al.,* 2010a). Many efforts to reclaim denuded rangelands have shown positive responses. For instance, range land reseeding in Kenya by a charitable organization: "Reclamation of Arid Environments (RAE)", has reclaimed denuded areas of Baringo County using range grasses under rain-fed conditions. Other efforts have been made in the southern rangelands of Kenya with the support of Kenya Agricultural Research Institute (KARI). All the same, the impacts and coverage are far too few for the vast degraded rangelands. This is largely attributed to the low seed yields under rainfed conditions. This calls for more research on grass seed multiplication for rehabilitation and pasture establishment for improved livestock production. A study by Mganga *et al.* (2010a) reported that farmer's efforts to rehabilitate denuded southern rangelands were hampered by lack of adequate and high quality seeds.

This study aimed at evaluating the potential of six local grass species to produce seeds under different soil moisture conditions. Most previous studies have focused on evaluating the impacts of agronomic management on grass seed yields with little attention to WUE and its effects on seed production (Griffiths, 1993; Awad *et al.*, 2013; Guan *et al.*, 2014). The study contributes information on varied soil moisture content effects on range grass seed yields which could be useful in large scale seed multiplication for reseeding, as well as providing farmers with access to grass seeds for pasture production. This is further supported by the current increasing demand for rangeland rehabilitation, increasing livestock forage demand, making grass seed production a priority for Kenyan rangelands (Mnene, 2005; Mganga *et al.*, 2010b; Mganga *et al.*, 2013).

2. Materials and Methods

Experimental design and layout have been described in chapter two.

2.1 Data collection

Data collection covered the period between planting and 16 weeks of age.

2.1.1 Seed Yields Determination

Seed yield determination was conducted in pure stands experimental plots only. Ripe seeds were hand-harvested from three systematically placed $1m^2$ quadrats within each of the pure species sub plots in the main blocks. The seeds were stored in brown paper bags, sun-dried and weighed using a digital balance. The dry weights were then converted to yields per hectare.

2.1.2. Data Analysis

To determine whether treatments had significant effects on seed yields, the data were subjected to Analysis of Variance (ANOVA) using SAS Version 9 [28]. Where a significant difference was detected, the means were separated by Least Significant Difference (LSD) at 5% probability level.

3. Results

Table 1 contains average seed yields (kg ha^{-1}) of the six grasses under 80, 50 and 30 % FC soil moisture profiles and the control (rain fed). Seed yields varied significantly ($p \leq 0.05$) among the grass species and soil moisture content levels (see ANOVA tables in Appendix 3). Generally, all the watered treatments produced higher seed yields than the rain fed treatment. CR realized the highest seed yield at 30% FC moisture content though it was not significantly above that of 50% FC. Yields from ES and EM were not significantly affected by changes in soil moisture content. However, yields were significantly lower ($p < 0.05$) under rain-fed treatment than under the watered conditions for the all the grasses. CG gave the higher seed yields (1066.8 kg ha^{-1}) at 30% FC soil moisture content than at 80 and50% FC and rain fed (766.9, 866.8 and 123.7 kg ha^{-1}, respectively). Among the six grasses, SB gave higher (1250.7 kg ha^{-1}) seed yields than the other species at 80% FC moisture content and under rain-fed conditions (150.7 kg ha $^{-1}$).

Table 1. Mean seed yields (kg ha^{-1}) by the six range grasses under 80, 50, 30 %FC and rain fed soil moisture content conditions

	80 % FC	50 % FC	30 % FC	Rain fed (control)
C R	103.3^{a} ± 5.77	516.1^{c} ± 7.64	633.4^{c} ± 14.43	54.2^{ab}±9.62
E S	350.1^{b} ± 57.66	286.0^{b} ± 41.63	343.2^{b} ± 50.57	39.8 ^{a}±7.91
EM	566.3^{c} ± 2.88	550.4^{c} ± 0.00	516.3^{c} ± 5.77	105.3^{b}±21.11
CC	150.5^{a} ± 13.22	136.6^{a} ± 16.07	156.6^{a} ± 20.21	21.8^{a}±4.43
CG	766.9^{d} ± 15.27	866.8^{d} ± 20.20	1066.8^{e} ± 2.88	123.7^{c}±33.21
SB	1250.7^{e} ± 7.07	700.5^{d} ± 10.00	533.9^{c} ± 2.88	150.7^{c}±31.42

Means within the same columns with different superscripts are significantly different at $p \leq 0.05$.
Key: CR=*Chloris roxburghiana*, ES= *Eragrostis superba*, EM= *Enteropogon macrostachyus*, CC= *Cenchrus ciliaris*, CG= *Chloris gayana*, SB= *Sorghum sudanense*,
±Standard deviation

Table 2 presents the average number of tillers per shoot at 12 weeks after planting. Changes in soil moisture content did not significantly affect the number of tillers in any of the species. As expected, moisture supplementation significantly ($p < 0.05$) increased tiller numbers across all the species.

Table 2. Mean number of tillers per shoot for the six grasses under 80, 50, 30 % FC soil moisture content and rain fed.

	80 % FC	50 % FC	30 % FC	Rain fed (control)
C R	11.1^{a} ±2.3	10.8^{ab}±3.3	12.3^{ab} ±6.3	3.3^{ab} ±1.3
E S	19.3^{a} ±4.7	14.3^{ab} ±5.8	18.3^{b} ±7.1	3.1^{ab} ±1.1
EM	16.2^{a} ±2.3	14.1^{ab} ±3.3	12.1^{ab} ±2.4	4.1^{b} ±2.3
CC	28.0^{b} ±6.4	22.0^{b} ±11.4	20.0^{b} ±8.4	4.7^{b} ±2.4
CG	21.1^{b} ±11.1	18.1^{ab} ±9.1	16.3^{b} ±9.4	4.3^{b} ±1.2
SB	31.0^{b} ±16.1	29.0^{c} ±6.1	31.2^{c} ±11.1	5.2^{b} ±2.1

Means within the same columns with different superscripts are significantly different at $p \leq 0.05$.
Key: CR=*Chloris roxburghiana*, ES= *Eragrostis superba*, EM= *Enteropogon macrostachyus*, CC= *Cenchrus ciliaris*, CG= *Chloris gayana,* SB= *Sorghum sudanense*
± Standard deviation

4. Discussions

Results of this study have demonstrated that genetic and morphological differences were major ’drivers’ of quantity and quality of seeds produced by individual grass species (Masuka *et al.,* 2012; Mganga *et al.,* 2013). The relatively large size of SB seeds compared to those of the other species was highly attributed to its higher biomass and seed yields. Studies by Mganga *et al.* (2010b) showed that ES had higher seed yields than CC which was attributed to high spikelet densities per inflorescence. Other morphometric characteristics with a big impact on seed yields include tiller density. This relationship was also reported by Awad *et al.* (2013) working with SB who demonstrated a positive correlation between grain yields and number of tillers and panicles per plant. Other studies have affirmed that grasses with many reproductive tillers produce more seeds (Adler *et al.,* 2006; Silvertown & Charlesworth, 2009; Guan *et al.,* 2014) than those with fewer or many which are non-reproductive. In our study SB which has higher number of reproductive tillers had higher seed yields than CC and EM. This was also observed by Opiyo *et al.,* (2011) working with EM, ES and CC under rain fed conditions and different land preparation methods--reaped and hand cleared.

These findings also closely concurred with those of Mganga *et al.* (2010b), where tiller densities varied with grass species and influenced biomass productivity. Besides tiller density influencing seed yields, it also influences adaptability to grazing pressure, which is a function of photosynthetic rate and food reserves (Laidlaw, 2005). The number of tillers in a plant determines the biomass production and the quality of forage (Mganga *et al.,* 2013; Skinner & Moore, 2007). Tillers contain leaves which have more easily digestible nutrients and less structural components especially from the newly developed tillers with young leaves (Wilson *et al.,* 1991). Essentially, a tiller will have both old and young leaves. The older leaves are less active in terms of food manufacturing but contribute more biomass (Soininen *et al.,* 2010) while the young ones contribute more new tissues and substances required for growth and development.

Water plays important role in nutrient absorption and translocation by plants as well as modulation of plant temperature through transpiration (Oddo *et al.,* 2014) which is conducive for plant growth and development. Therefore, irrigation will always have beneficial effects on plants. It does not only increase the germination rate of seeds and subsequent establishment of the plant species, but will also boost biomass and seed yields (Horton *et al.,* 1990; Lee *et al.,* 2013; Sulc & franzluebbers, 2013). Therefore, the seed yield patterns observed in this study, were a direct response to the soil moisture differences which were transmitted through the plants' physiological process; and productivity in terms of biomass seed yields. The results of the study by Martiniello *et al.* (2007) where SB yielded 130 kg ha^{-1} and 110 kg ha^{-1} under irrigation and rain fed conditions, respectively, support the findings of this study.

5. Conclusions and recommendations

The findings of this study provide useful information on which recommendations to farmers or individuals in the dry lands who would want to produce seeds from indigenous grass species. These results amplify the importance of adequate water supply to the plants throughout the growing season for high seed yields to be realized. These further, emphasized the fact that different grass species have different water requirements during the growth period, an aspect which if incorporated in the routine husbandry practices of the grasses, can improve seeds and/or other grass products. According to our results, CC would be the best choice for seed production under conditions of limited water supply, while CR was the best pick under medium water supply situations and SB the best in areas where water is not limited at all. On the basis of the results of this study, successful seed production from local grass species in the arid and semi-arid conditions will require either full or supplemental irrigation. And, although the study did not compare the performance of the local and exotic grass species, it is evident that the local species, by virtual of their adaptation to the arid conditions, would be the better choices.

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REFERENCES

Adler, P. R., Sanderson, M. A., Boateng, A. A., Weimer, P. J., & Jung, H. J. G. (2006). Biomass yield and biofuel quality of switchgrass harvested in fall or spring. Agronomy Journal, 98(6), 1518-1525.

Allen, V. G., Baker, M. T., Segarra, E., & Brown, C. P. (2007). Integrated irrigated crop–livestock systems in dry climates. Agronomy Journal, 99(2), 346-360.

Anderson, V., & Schatz, B. (2003). Biological and economic synergies, and methods of integrating beef cow and field crops enterprises. 2002. http://www.ag.ndsu.edu/pubs/ansci/beef/2002beef.pdf#page=3. Accessed 25th Feb 2013

Awad, A., Salah H., Mohammed, S. H., Azza, E., Salah, E. (2013). Grain yield production of Sudan grass (Sorghum sudanense (Piper) Stapf) as influenced by cutting numbers, potassium rates, and intrarow spacing in a semiarid environment. Turkish Journal of Agriculture and Forestry (2013) 37

Clay, D. E., Clay, S. A., Reitsma, K. D., Dunn, B. H., Smart, A. J., Carlson, G. G., & Stone, J. J. (2014). Does the conversion of grasslands to row crop production in semi-arid areas threaten global food supplies? Global Food Security. http://www.sciencedirect.com/science/article/pii/S2211912413000564. Accessed 25th Feb 2013

Griffiths, R. (1993). Sustainable supplies of quality herbage seed for sub-Saharan Africa smallholder’s pp. 662-665. In: MJ Baker (ed). Grasslands for our world. Sir Publishing, Wellington, New Zealand

Guan, D., Al-Kaisi, M. M., Zhang, Y., Duan, L., Tan, W., Zhang, M., & Li, Z. (2014). Tillage practices affect biomass and grain yield through regulating root growth, root-bleeding sap and nutrients uptake in summer maize. Field Crops Research, 157, 89-97.

Horton H., Asay K. H., Glover T. F., Young S. A., Haws B. A., Dewey S. A. & Evans J. O. (1990). Grass Seed Production for Guide for Utah. ttp://tinyurl.com/qbs8pxq. Accessed 27th Feb 2013

Kigomo, J. N. & Muturi G. M. (2013). Impacts of enclosures in rehabilitation of degraded rangelands of Turkana County, Kenya. Journal of Ecology and the Natural Environment. Vol. 5(7), pp. 165 171. http://www.academicjournals.org/jene/PDF/Pdf2013/July/Kigomo%20and%20Muturi.pdf

Laidlaw, A.S. (2005). The relationship between tiller appearance in spring and contribution of dry matter yield in perennial ryegrass (Lolium perenne L.) cultivars differing in heading date. Grass and Forage Science, 60:200-209

Lee, J. M., Clark, A. J., & Roche, J. R. (2013). Climate□change effects and adaptation options for temperate pasture□based dairy farming systems: a review. Grass and Forage Science, 68(4), 485-503

Martiniello, P., Gesualdo, G., Sabia, E., Terzano, M. G, Pacelli, C. & Berardo, N. (2007). Intensive rainfed and irrigated forage crop production for Mediterranean Italian buffalo feeding. Italian Journal of Animal Science 6, 1226-1229.

Masuka, B., Araus, J. L., Das, B., Sonder, K., & Cairns, J. E. (2012). Phenotyping for Abiotic Stress Tolerance in MaizeF. Journal of integrative plant biology, 54(4), 238-249.

Mganga, K. Z., Musimba, N. K. R., Nyangito, M. M., Nyariki, D. M., & Mwang'ombe, A. W. (2010c). Improving Hydrological Responses of Degraded Soils in Semi Arid Kenya. Journal of Environmental Science & Technology, 3(4). 217-225.

Mganga, K. Z., Musimba, N. K. R., Nyariki, D. M., Nyangito, M. M., & Mwang'ombe, A. W. (2013). The choice of grass species to combat desertification in semi□arid Kenyan rangelands is greatly influenced by their forage value for livestock. Grass and Forage Science. http://onlinelibrary.wiley.com/doi/10.1111/gfs.12089/full. Accessed 20th Feb 2014

Mganga, K. Z., Musimba, N. K., Nyangito, M. M., Nyariki, D. M., Mwangombe, A. W., Ekaya, W. N., & Verhagen, J. (2010a). The role of moisture in the successful rehabilitation of denuded patches of a semi-arid environment in Kenya. Journal of Environmental Science and Technology, 3, 195-207.

Mganga, K. Z., Musimba, N. K., Nyariki, D. M., Nyangito, M. M., Mwang’ombe, A. W., Ekaya, W. N., and Muiru, W. M. (2010b). Dry matter yields and hydrological properties of three perennial grasses of a semi-arid environment in east Africa. African Journal of Plant Science, 4(5), 138-144.

Mnene, W.N. (2005). Strategies to increase success rates in natural pasture development through reseeding degraded rangelands of Kenya. PhD Thesis, University of Nairobi, Nairobi, Nairobi, Kenya

Musimba, N.K.R., Nyariki D.M., Ikutwa C.N. & Teka T. (2004). Dryland Husbandry for sustainable development in the southern rangelands of Kenya. OSSREA, Addis Ababa, 2004.

Nyangito, M.M. (2005). Grazing patterns, energy extraction and livestock productivity in agropastoral production systems in Kibwezi, southeastern Kenya. PhD Thesis, University of Nairobi, Nairobi, Kenya.

Nyangito, M.M. Musimba, N.K.R & Nyariki D.M. (2008). Range use and dynamics in the agropastoral system of southeastern Kenya. African Journal of Environmental Science and Technology 2(8): 220-230

Oddo, E., Inzerillo, S., Grisafi, F., Sajeva, M., Salleo, S., & Nardini, A. (2014). Does short-term potassium fertilization improve recovery from drought stress in laurel? Tree Physiology, tpt120

Ogillo, B. P., Nyangito, M. M., Nyariki, D. M., & Kubasu, D. O. (2010): A comparison of two micro-catchment technologies on aboveground biomass production and financial returns of three range grasses in southern Kenya, pp 849 – 854. http://tinyurl.com/orrvglq. (Accessed 15th May 2012)

Opiyo, F. E., Ekaya, W. N., Nyariki, D. M., & Mureithi, S. (2011). Seedbed preparation influence on morphometric characteristics of perennial grasses of a semi-arid rangeland in Kenya. African Journal of Plant Science, 5(8), 460-468.

Opiyo, F.O. (2007). Land treatment effects on morphometric characteristics of three grass species and economic returns from reseeding in Kitui district, Kenya. MSc Thesis, University of Nairobi, Nairobi, Kenya.

Reynolds, S. G., Batello, C., Baas, S., & Mack, S. (2005). Grassland and forage to improve livelihoods and reduce poverty. Grassland: A global resource. Wageningen Academic Publishers, Wageningen, the Netherlands, 323-338.

SAS Institute. (2011). SAS 9. 3 Output Delivery System: User's Guide. SAS institute.

Silvertown, J., & Charlesworth, D. (2009). Introduction to plant population biology. Wiley. com. http://tinyurl.com/o4oyddd. Accessed 12th Jan 2014.

Simba, F. M., Mubvuma, M., Murwendo, T., & Chikodzi, D. (2013). Prediction of yield and biomass productions: A remedy to climate change in semi-arid regions of Zimbabwe. International Journal of Advance Agricultural Research, 1, 14-21.

Skinner H.R., & Moore K.J. (2007). Growth and development of forage plant. In: Barnes R.F., Nelson C.J., Moore K.J.,Collins M. (eds): Forages: The Science of Grassland Agriculture. 6th Ed. Wiley-Blackwell, Ames, USA, 53–66.

Soininen E. M., Hübner C. E. & Jónsdóttir I. S. (2010). Food selection by barnacle geese (Branta leucopsis) in an Arctic pre-breeding area. Polar Research. 29: 404–412

Sulc, R. M., & Franzluebbers, A. J. (2013). Exploring integrated crop–livestock systems in different ecoregions of the United States. European Journal of Agronomy. http://www.sciencedirect.com/science/article/pii/S1161030113001482. Accessed 3rd Jan 2014

USAID, (2011). Drylands Livestock Development Program. http://kenya.usaid.gov/programs/economic-growth/412 (Accessed 26th September, 2013)

Wilson J.R., Deinum B., & Engels F.M. (1991). Temperature effects on anatomy and digestibility of leaf and stem of tropical and temperate forage species. Netherlands Journal of Agricultural Science, 39, 31–48.

CHAPTER FIVE

Effect of Varied Soil Moisture Contents and Storage on Quality of Seeds of Six Range Grasses in the Semi-Arid Ecosystems of Kenya

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Abstract

Effect of three soil moisture levels (80, 50, 30% field capacity; and rainfed) and period of storage (2, 12, 24 and 36) on quality of seeds of six range grasses in the semi-arid ecosystems of Kenya were evaluated. Seeds stored for only two weeks after harvesting had the lowest germination rate (GP). *E. macrostachyus* showed low GP (<10%) after 2 weeks storage, but at the late incubation periods of 11th to 14th day. *S. sudanense* demonstrated higher GP (> 50%) after storage period of 2 weeks from DOH and GP>75% from the three soil water content after storage period of 36 weeks. The results also showed after storage periods of 12 weeks, all the grass species start to germination after day 3 of incubation, unlike in the freshly harvested -2 weeks storage period where germination starts after 7 days of incubation except for *S .sudanense*. Germination index (GI) increased with storage periods for all the grass species with *S. sudanense* having the highest GI of over 20 after 12 weeks of storage. Storage period of 12 weeks increases seed viability of the six grasses and *S. sudanense* has higher seed viability even when freshly harvested compared to the other species.

Keywords Germination Index; Germination Percentage; Field Capacity; Grass reseeding; Range grasses, grass seed quality; Grass seed storage; Kenya

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1. Introduction

Livestock production plays a central role in Kenyan drylands, with 70% of livestock, 30% of human population, and over 80% of wildlife being supported by these ecosystems (GOK, 2005). These areas have been under serious degradation, with increased loss of native grass species that supported livestock population under pastoralism. Rangeland rehabilitation has been identified as one option of restoring these degraded areas (Rietkerk *et al.,* 2000), which can be combined with soil and water conservation activities (Nyangito *et al.,* 2008). Restoration of range lands through reseeding has been widely used in Kenya to assist degraded areas to recover much faster and increase productivity (Visser *et al.,* 2007). This has been achieved through use of native species (Musimba *et al.,* 2004;

Mnene, 2005; Mganga *et al.,* 2010b). However, the major challenge has been availability of quality grass seeds of the indigenous species which are adapted to the local conditions of the vast rangelands to be rehabilitated (Mnene, 2005). The use of perennial native grasses has always been emphasized due to their ability to improve soil moisture retention, increase infiltration rates and protect the top soil from erosion (Seobi *et al.,* 2005; Mganga 2009; Nyangito *et al.,* 2009).

Research efforts are needed on grass seed multiplication for rehabilitation of denuded areas and pasture establishment for improved pastoral livestock production (Boonman, 1993; Mwadalu & Mawangi, 2013; Pizarro *et al.,* 2013). Vegetation and mainly grasses forms an important ecosystem link in terms of energy flow within rangeland ecosystems (Bestelmeyer *et al.,* 2003; Kreuter *et al.,* 2012). The pastoralist main source of livelihood is livestock keeping and heavily relies on range grasses for products and income from their herds (Mlote *et al.,* 2013; Yosef *et al.,* 2013). The scenario of reduced pastures, increased degradation and loss of native species has worsened their adaptive mechanism threatening their sole livelihood option (Samuel, 2013). For the attainment of millennium development goals (MDGS) and Kenya's vision 2030, of ensuring all citizens have access to adequate and quality food for better lives, a collective action in research and dissemination of information regarding grass seeds and reseeding in the ASALs is urgently required. Previous rangeland reseeding study by Mganga *et al.* (2010b) reported that the efforts were seriously constrained by lack of high quality seeds. Lack of correct technical information on pre- and post-harvest handling of grass seeds is a main contributor to this situation (Mganga *et al.,* 2013; Mwadalu & Mwangi, 2013).

The few previous studies on seed production from indigenous species in this region have focused on the impacts of selected agronomic practices on fodder yields, with little emphasis on their effects on seed quantity and quality (Griffiths, 1993; Fynn, 2012; Awad *et al.,* 2013). This study evaluated the quality of range grass seeds produced under three soil moisture content profiles and the effect of period of shortage on the quality of the seeds.

2. Materials and Methods

Experimental design and layout of this study is provided in chapter two.

2.1 Data Collection

Data collection was carried out between sowing and 16 weeks of age.

2.1.1 Seed harvesting

This involved hand-harvesting of mature and ripened seeds within a 1m x 1m systematically placed quadrats replicated three times for each of six species. The seeds were stored in labeled brown paper bags after sun drying before being stored for the stipulated periods.

2.1.2 Seed quality determination

Seed quality was estimated by means germination rate (% germination--GP) and germination index (GI). The seeds harvested from the six grass species subjected to the four soil moisture content levels (including rain-fed) were tested for quality. The seeds were stored in brown papers at room temperature (28^oC). Procedures followed in determining GP and GI are described below.

Germination rates of seeds of each species after 2, 12, 24 and 36 weeks was determined following the petri-dish method described by the International Seed Testing Association (ISTA, 1987; Tarawali *et al.*, 1995; Mganga *et al.*, 2010a). A 100 seeds of each grass species were selected in four replicates. The seeds were then placed on Whitman filter paper in a petridish under room temperature (28^oC). The seeds were incubated for 14 days and monitored for germination. The grass seeds that germinated everyday were counted and removed from the petri-dishes. Seeds were deemed to have germinated when the radical could be clearly identified (Opiyo, 2007). Germination rate (%) was then calculated using the equation 1 below:

$$\%\,\text{Germination} = \frac{\text{Total number of seeds germinated}\ \ \text{X 100}}{\text{Seeds per petri}-\text{dish} \times \text{Replicates}} \text{..........Equation (1)}$$

This procedure was performed for seeds of all the six species at the end of each selected storage period--2, 12, 24 and 36 weeks.

2.1.4 Germination Index (GI)

GI was computed by use of the following formula (Equation 2).

$$GI = n/d \text{..Equation (2)}$$

Where, n =number of seedlings emerging on day'd' and d = day after planting.

For GI as an indicator of seed quality, the high the GI, the higher the quality (viability) of the seeds (ISTA, 1987).

3. Results

3. 1 Germination rate (GP)

Tables 1, 2, 3 and 4 presents the daily mean germination rates for the six grasses, across the four soil moisture levels (80, 50, 30% FC; and rainfed), and the four storage periods (2, 12, 24 and 36 weeks). The ANOVA tables are presented in Appendix 4. There were significant differences ($p \leq 0.05$) in seed germination rate among the species and storage periods. However, the effect of soil moisture on germination rates was not significant. Generally, germination rates increased with increase in storage period with 2 weeks storage period giving the lowest germination rate (<15% all species, except SB) and 36 weeks storage the highest (>50% for all species). CR, ES and CC seeds stored for 2 weeks did not germinate even after 14 days incubation. SB seeds were the most prolific across the storage periods, attaining >60% germination rate on the 14th day after sowing and >75% germination rate on the 13th day after sowing for seeds stored for 24 weeks. For the six grasses, 12 weeks was the minimum storage period for germination to start, but 36 weeks had the best germination rates. Between 24 and 36 weeks storage period, all the six species started germinating after 3 days.

Table 1. Average daily (1—14 days) germination rates (%) of the six grass species seeds grown under 80% FC soil moisture content and stored for 2, 12, 24 and 36 weeks after harvest

Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Week 2														
C R	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E S	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EM	0	0	0	0	0	0	0	0	0	0	6.1	6.4^{a}	8.5^{a}	8.8^{a}
CC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CG	0	0	0	0	0	0	0	8.2^{a}	10.4^{a}	10.5^{a}	10.2^{a}	11.4^{a}	11.8^{a}	14.5^{a}
SB	0	0	5.2^{a}	6.3^{a}	11.4^{a}	12.0^{a}	12.5^{a}	16.1^{a}	17.4^{a}	31.5^{a}	39.8^{b}	45.5^{b}	60.5^{c}	60.3^{c}
Week 12														
C R	0	0	0	8.3^{a}	8.0^{a}	10.2^{a}	11.5^{a}	11.2^{a}	12.4^{a}	12.6^{a}	12.5^{a}	14.2^{a}	16.^{a}	21.2^{b}
E S	0	0	3.1^{a}	6.5^{a}	7.1^{a}	7.0^{a}	8.5^{a}	10.2^{a}	13.1^{a}	13.0^{a}	15.2^{a}	14.9^{a}	16.7^{a}	19.8^{a}
EM	0	0	11.2^{a}	15.4^{a}	15.5^{a}	15.9^{a}	16.7^{a}	18.6^{a}	22.1^{b}	22.0^{a}	25.0^{a}	24.8^{a}	26.5^{b}	26.6^{b}
CC	0	0	4.5^{a}	5.5^{a}	5.3^{a}	7.8^{a}	7.0^{a}	7.2^{a}	9.7^{a}	9.3^{a}	8.7^{a}	8.5^{a}	10.2^{a}	13.1^{a}
CG	0	1.1^{a}	13.0^{a}	15.7^{a}	16.1^{a}	19.3^{a}	20.4^{a}	37.0^{b}	38.5^{b}	44.5^{b}	49.7^{c}	51.9^{a}	54.5^{c}	58.7^{c}
SB	0	0	18.2^{a}	26.3^{b}	27.4^{b}	32.0^{b}	32.5^{b}	46.1^{c}	57.4^{c}	61.5^{c}	69.8^{c}	65.5^{c}	70.5^{d}	70.3^{d}
Week 24														
C R	0	0	10.5^{a}	19.5^{a}	29.1^{b}	29.4^{b}	29.5^{b}	33.5^{b}	37.4^{b}	38.6^{b}	37.5^{b}	51.2^{c}	56.1	54.7^{c}
E S	0	0	26.0^{b}	28.5^{a}	47.1^{c}	47.0^{c}	48.5^{c}	51.2^{c}	53.4^{c}	53.0^{c}	55.2^{c}	54.9^{c}	56.7^{c}	59.8^{c}
EM	0	0	31.4^{b}	35.5^{b}	35.8^{b}	35.9^{b}	36.8^{b}	38.2^{b}	45.1^{b}	52.0^{c}	55.0^{c}	59.4^{c}	61.3^{c}	66.7^{c}
CC	0	0	30.2^{b}	35.5^{b}	35.2^{b}	37.9^{b}	37.9^{b}	42.2^{b}	49.1^{b}	49.7^{c}	49.9^{c}	51.5^{c}	55.8^{c}	57.9^{c}
CG	0	0	18.0^{a}	25.7^{b}	26.7^{b}	39.3^{b}	38.9^{b}	37.0^{b}	42.4^{b}	47.3^{c}	46.8^{c}	52.4^{c}	51.9^{c}	57.4^{c}
SB	0	0	55.8^{c}	59.5^{c}	57.5^{c}	59.0^{c}	65.5^{c}	65.9^{c}	69.1^{c}	69.5^{c}	69.6^{c}	71.5^{d}	75.5^{d}	73.3^{d}
Week 36														
C R	0	0	29.7^{b}	30.4^{b}	32.1^{b}	32.4^{b}	36.8^{b}	37.9^{b}	39.8^{b}	42.5^{b}	46.2^{b}	47.8^{c}	52.8^{c}	57.2^{c}
E S	0	0	27.1^{b}	27.5^{b}	57.1^{c}	57.8^{c}	58.2^{c}	58.5^{c}	59.4^{c}	61.0^{c}	62.3^{c}	64.9^{c}	65.1^{c}	65.3^{c}
EM	0	0	33.5^{b}	35.0^{b}	36.2^{b}	36.9^{c}	43.8^{b}	45.8^{b}	55.3^{c}	62.0^{c}	65.8^{c}	69.6^{c}	66.3^{c}	69.8^{c}
CC	0	0	40.0^{b}	41.8^{b}	42.5^{b}	45.2^{c}	45.2^{b}	45.1^{b}	45.8^{b}	48.8^{c}	50.0^{c}	53.6^{c}	57.5^{c}	61.4^{c}
CG	0	0	21.1^{a}	23.8^{a}	36.7^{b}	39.8^{b}	42.1^{b}	43.0^{b}	45.3^{b}	48.6^{c}	51.3^{c}	58.6^{c}	61.4^{c}	67.9^{c}
SB	0	0	53.8^{c}	58.5^{c}	59.0^{c}	59.2^{c}	66.4^{c}	68.9^{c}	69.1^{c}	69.4^{c}	69.7^{c}	71.5^{c}	74.6^{d}	75.2^{d}

Means within the same columns with different superscripts are significantly different at $p<0.05$.

Key: CR=Chloris roxburghiana, ES= Eragrostis superba, EM= Enteropogon macrostachyus, CC= Cenchrus ciliaris, CG= Chloris gayana, SB= Sorghum sudanense

Table 2. Average daily (1—14 days) germination rates (%) of the six grass species seeds grown under 50% FC soil moisture content and stored for 2, 12, 24 and 36 weeks after harvest

Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Week 2														
C R	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E S	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EM	0	0	0	0	0	0	0	0	2.3^{a}	4.5^{a}	5.2^{a}	6.1^{a}	6.4^{a}	9.2^{a}
CC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CG	0	0	0	0	0	0	0	7.0^{a}	8.0^{a}	9.1^{a}	9.6^{a}	10.2^{a}	10.8^{a}	12.1^{a}
SB	0	0	2.5^{a}	4.1^{a}	8.6^{a}	12.3^{a}	11.5^{a}	15.1^{a}	16.9^{a}	28.5^{b}	29.8^{b}	35.5^{b}	44.5^{b}	59.1^{c}
Week 12														
C R	0	0	0	7.8^{a}	8.1^{a}	9.3^{a}	10.5^{a}	10.8^{a}	11.3^{a}	12.0^{a}	13.4^{a}	14.0^{a}	15.8^{a}	19.5^{a}
E S	0	0	4.0^{a}	5.2^{a}	6.3^{a}	6.6^{a}	9.0^{a}	9.2^{a}	10.4^{a}	12.3^{a}	14.1^{a}	15.9^{a}	17.4^{a}	22.1^{a}
EM	0	0	10.2^{a}	13.4^{a}	14.3^{a}	16.0^{a}	16.6^{a}	19.2^{a}	23.1^{b}	24.5^{a}	25.7^{b}	28.7^{b}	29.5^{b}	29.9^{a}
CC	0	0	3.0^{a}	4.5^{a}	6.0^{a}	7.3^{a}	7.6^{a}	8.0^{a}	9.5^{a}	10.1^{a}	11.0^{a}	12.5^{a}	12.9^{a}	13.6^{a}
CG	0	0	8.0^{a}	8.7^{a}	15.1^{a}	17.5^{a}	21.4^{b}	27.0^{b}	28.6^{b}	34.9^{b}	44.7^{b}	48.6^{b}	53.0^{c}	54.0^{c}
SB	0	0	21.5^{b}	27.8^{b}	29.5^{b}	33.0^{b}	35.6^{b}	44.1^{b}	47.3^{b}	51.5^{c}	59.6^{c}	63.0^{c}	65.2^{c}	68.0^{b}
Week 24														
C R	0	0	8.6^{a}	15.3^{b}	25.2^{b}	29.0^{b}	30.0^{b}	36.2^{b}	38.0^{b}	42.4^{b}	47.0^{b}	50.1^{c}	50.5^{c}	52.0^{c}
E S	0	0	21.0^{b}	22.8^{b}	27.5^{b}	37.0^{b}	42.5^{b}	50.0^{c}	52.3^{c}	53.5^{c}	54.0^{c}	57.0^{c}	59.9^{c}	61.9^{c}
EM	0	0	28.0^{b}	30.7^{b}	36.0^{b}	39.0^{b}	41.5^{b}	42.3^{b}	43.0^{b}	50.2^{c}	53.1^{c}	55.5^{c}	59.8^{c}	68.0^{c}
CC	0	0	28.0^{b}	33.0^{b}	36.1^{b}	38.2^{b}	40.4^{b}	44.0^{b}	45.3^{b}	48.7^{b}	48.3^{b}	53.7^{c}	55.0^{c}	55.3^{c}
CG	0	0	9.0^{a}	24.3^{b}	28.6^{b}	37.0^{b}	41.0^{b}	43.1^{b}	45.0^{b}	45.5^{b}	48.2^{b}	50.0^{c}	55.1^{c}	59.2^{c}
SB	0	0	52.1^{c}	55.1^{c}	58.0^{c}	61.0^{c}	63.1^{c}	65.2^{b}	67.0^{c}	70.5^{c}	71.0^{d}	72.0^{d}	72.9^{d}	76.5^{d}
Week 36														
C R	0	0	25.0^{b}	29.0^{b}	30.1^{b}	32.1^{b}	35.2^{b}	35.6^{b}	40.2^{b}	45.1^{b}	48.0^{b}	50.5^{c}	53.5^{c}	58.0^{c}
E S	0	0	20.0^{b}	25.2^{b}	45.3^{b}	55.1^{c}	57.8^{c}	59.0^{b}	60.2^{c}	63.1^{c}	64.1^{c}	65.0^{c}	67.2^{c}	68.0^{c}
EM	0	0	27.0^{b}	30.2^{b}	35.0^{b}	38.8^{b}	40.2^{b}	44.0^{b}	49.2^{b}	58.6^{c}	63.0^{c}	65.2^{c}	69.1^{c}	70.1^{d}
CC	0	0	25.0^{b}	31.2^{b}	40.5^{b}	43.5^{b}	46.0^{b}	46.9^{b}	50.3^{c}	52.2^{c}	54.0^{b}	61.0^{c}	62.1^{c}	65.1^{c}
CG	0	0	28.1^{b}	33.2^{b}	35.3^{b}	40.8^{b}	43.0^{b}	45.2^{b}	47.1^{b}	50.5^{c}	55.2^{b}	59.0^{c}	64.6^{c}	69.0^{c}
SB	0	0	55.0^{c}	58.2^{c}	60.1^{c}	62.0^{c}	64.2^{c}	66.6^{c}	67.9^{d}	72.1^{d}	74.1^{d}	73.0^{d}	74.2^{d}	75.0^{d}

Means within the same columns with different superscripts are significantly different at $p<0.05$.

Key: CR=Chloris roxburghiana, ES= Eragrostis superba, EM= Enteropogon macrostachyus, CC= Cenchrus ciliaris, CG= Chloris gayana, SB= Sorghum sudanense

Table 3. Average daily (1—14 days) germination rates (%) of the six grass species seeds grown under 30% FC soil moisture content and stored for 2, 12, 24 and 36 weeks after harvest

Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Week 2														
C R	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E S	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EM	0	0	0	0	0	0	0	0	2.0^{a}	3.5^{a}	4.9^{a}	5.8^{a}	6.0^{a}	8.5^{a}
CC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CG	0	0	0	0	0	0	0	4.1^{a}	7.0^{a}	8.0^{a}	9.5^{a}	11.1^{a}	11.8^{b}	12.4^{a}
SB	0	0	3.0^{a}	5.1^{a}	6.5^{a}	11.3^{a}	12.6^{b}	14.3^{a}	15.3^{a}	30.1^{a}	33.8^{b}	34.2^{b}	40.5^{b}	58.0^{c}
Week 12														
C R	0	0	3.0^{a}	5.1^{a}	7.0^{a}	8.0^{a}	10.0^{a}	11.7^{a}	11.9^{a}	12.4^{a}	13.7^{a}	14.2^{a}	14.8^{a}	18.3^{a}
E S	0	0	5.0^{a}	5.7^{a}	6.0^{a}	7.0^{a}	9.5^{a}	10.2^{a}	11.6^{a}	12.0^{a}	13.2^{a}	14.1^{a}	15.0^{a}	19.5^{a}
EM	0	0	12.0^{a}	14.1^{a}	15.5^{a}	17.2^{a}	18.6^{a}	19.4^{a}	22.5^{a}	25.0^{b}	27.1^{c}	31.5^{b}	35.5^{b}	42.8^{b}
CC	0	0	4.0^{a}	6.1^{a}	8.0^{a}	10.2^{a}	11.3^{a}	12.2^{a}	13.4^{a}	14.9^{a}	15.6^{b}	18.0^{a}	22.2^{b}	29.5^{b}
CG	0	0	6.0^{a}	10.3^{a}	16.0^{a}	18.8^{a}	22.1^{b}	26.5^{b}	29.3^{b}	32.4^{b}	41.8^{b}	47.3^{b}	51.2^{c}	53.4^{c}
SB	0	0	24.5^{b}	29.3^{b}	29.0^{b}	32.1^{b}	34.8^{b}	42.0^{b}	45.5^{b}	49.8^{b}	54.3^{c}	58.0^{c}	62.7^{c}	65.4^{c}
Week 24														
C R	0	0	3.0^{a}	9.5^{a}	15.2^{a}	13.5^{a}	25.6^{b}	33.1^{b}	35.0^{b}	41.5^{b}	45.0^{b}	47.2^{b}	51.6^{c}	54.0^{b}
E S	0	0	16.3^{a}	21.9^{b}	26.0^{b}	35.0^{b}	40.1^{b}	45.5^{b}	47.2^{b}	51.0^{c}	53.2^{c}	54.0^{c}	55.4^{c}	59.6^{b}
EM	0	0	24.5^{b}	33.8^{b}	39.2^{b}	42.0^{b}	45.7^{b}	48.0^{b}	47.2^{b}	52.1^{c}	54.0^{c}	57.1^{c}	59.3^{c}	64.2^{c}
CC	0	0	21.0^{b}	26.2^{b}	32.0^{b}	35.1^{b}	39.4^{b}	42.5^{b}	44.1^{b}	46.9^{b}	48.0^{b}	51.3^{c}	53.0^{c}	52.8^{c}
CG	0	0	5.2^{a}	22.4^{b}	33.1^{b}	38.2^{b}	43.0^{b}	45.6^{b}	47.0^{b}	49.5^{c}	52.2^{c}	54.0^{c}	56.1^{c}	58.8^{c}
SB	0	0	49.8^{c}	53.8^{c}	55.0^{c}	58.9^{b}	60.0^{c}	63.1^{b}	64.0^{c}	67.1^{c}	69.4^{c}	73.0^{d}	74.8^{d}	75.5^{d}
Week 36														
C R	0	0	18.3^{a}	25.0^{b}	28.8^{b}	30.5^{b}	33.8^{b}	37.5^{b}	41.1^{b}	44.6^{b}	47.0^{b}	51.2^{c}	54.4^{c}	56.1^{c}
E S	0	0	25.2^{b}	27.0^{b}	35.8^{b}	45.7^{b}	55.1^{c}	54.0^{b}	57.8^{c}	61.2^{c}	62.0^{c}	63.9^{c}	65.1^{c}	65.2^{c}
EM	0	0	30.0^{b}	33.2^{b}	36.1^{b}	39.2^{b}	42.9^{b}	44.9^{b}	47.6^{b}	51.4^{c}	55.5^{c}	58.8^{b}	62.4^{c}	68.8^{c}
CC	0	0	23.8^{b}	27.9^{b}	30.7^{b}	37.7^{b}	41.2^{b}	44.4^{b}	47.3^{b}	51.6^{c}	53.9^{c}	55.6^{b}	58.8^{c}	62.0^{c}
CG	0	0	7.0^{a}	22.1^{b}	31.8^{b}	36.4^{b}	41.0^{c}	44.2^{b}	45.0^{b}	48.6^{b}	52.7^{c}	55.0^{b}	61.1^{c}	63.2^{c}
SB	0	0	52.9^{c}	61.0^{c}	63.1^{c}	64.1^{c}	66.1^{c}	68.2^{c}	68.9^{c}	71.0^{d}	72.4^{d}	74.5^{d}	75.1^{d}	76.1^{d}

Means within the same columns with different superscripts are significantly different at $p<0.05$.

Key: CR=Chloris roxburghiana, ES= Eragrostis superba, EM= Enteropogon macrostachyus, CC= Cenchrus ciliaris, CG= Chloris gayana, SB= Sorghum sudanense

Table 4. Average daily (1—14 days) germination rates (%) of the six grass species seeds grown under rain-fed (control) soil moisture content and stored for 2, 12, 24 and 36 weeks after harvest

Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Week 2														
C R	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E S	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EM	0	0	0	0	0	0	0	0	3.0^{a}	3.0^{a}	4.2^{a}	5.2^{a}	6.3^{a}	7.5^{a}
CC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CG	0	0	0	0	0	0	0	3.0^{a}	6.5^{a}	7.7^{a}	8.5^{a}	11.1^{a}	12.0^{a}	12.0^{a}
SB	0	0	2.1^{a}	3.1^{a}	5.5^{a}	9.8^{a}	14.2^{a}	14.6^{a}	18.2^{a}	25.2^{b}	28.8^{b}	32.0^{b}	36.1^{b}	48.2^{c}
Week 12														
C R	0	0	2.2^{a}	3.0^{a}	6.0^{a}	8.2^{a}	11.0^{a}	12.3^{a}	12.5^{a}	13.4^{a}	14.2^{a}	14.0^{a}	16.0^{a}	17.2^{a}
E S	0	0	4.0^{a}	8.3^{a}	9.0^{a}	9.1^{a}	9.8^{a}	11.4^{a}	12.7^{a}	13.0^{a}	13.1^{a}	13.0^{a}	16.0^{a}	18.5^{a}
EM	0	0	7.0^{a}	11.1^{a}	14.2^{a}	17.3^{a}	18.2^{a}	20.4^{b}	21.0^{a}	24.0^{b}	25.8^{b}	29.5^{b}	34.0^{b}	39.5^{b}
CC	0	0	3.0^{a}	6.5^{a}	7.5^{a}	11.1^{a}	11.8^{a}	13.0^{a}	13.0^{a}	14.0^{a}	14.5^{a}	19.0^{a}	28.1^{b}	30.0^{b}
CG	0	0	5.1^{a}	6.0^{a}	13.0^{a}	16.4^{a}	20.1^{a}	24.2^{b}	24.4^{b}	28.4^{b}	33.1^{b}	37.0^{b}	41.5^{b}	47.0^{c}
SB	0	0	14.5^{a}	27.0^{b}	28.1^{b}	32.4^{b}	33.0^{b}	37.0^{b}	42.3^{b}	45.0^{b}	45.3^{b}	48.0^{c}	50.3^{c}	55.1^{c}
Week 24														
C R	0	0	2.8^{a}	6.3^{a}	9.2^{a}	12.3^{a}	24.0^{b}	30.1^{b}	34.0^{b}	38.0^{b}	42.0^{b}	44.2^{b}	46.7^{b}	49.3^{c}
E S	0	0	10.2^{a}	19.3^{a}	22.0^{b}	28.0^{b}	37.2^{b}	42.0^{b}	45.1^{b}	49.1^{c}	51.2	52.0^{c}	50.4^{c}	52.5^{c}
EM	0	0	14.3^{a}	21.2^{b}	28.1^{b}	37.0^{b}	43.1^{b}	45.0^{b}	45.2^{b}	47.0^{c}	49.3	52.0^{c}	54.1^{c}	54.2^{c}
CC	0	0	18.0^{a}	21.7^{b}	27.0^{b}	34.2^{b}	35.2^{b}	40.5^{b}	43.6^{b}	47.3^{c}	47.0	47.3^{c}	47.5^{c}	49.5^{c}
CG	0	0	5.9^{a}	14.6^{a}	24.5^{b}	29.6^{b}	33.0^{b}	38.6^{b}	41.1^{b}	45.5^{c}	46.2	47.0^{c}	46.1^{b}	52.0^{c}
SB	0	0	33.1^{b}	38.0^{b}	42.0^{b}	48.7^{c}	52.0^{c}	54.0^{c}	54.0^{b}	57.2^{c}	57.0^{c}	59.1^{d}	62.0^{d}	65.3^{d}
Week 36														
C R	0	0	14.8^{a}	18.7^{a}	23.8^{b}	29.0^{b}	31.0^{b}	34.2^{b}	38.1^{b}	42.0^{b}	44.0^{b}	47.2^{c}	48.4^{c}	51.0^{c}
E S	0	0	19.8^{a}	20.4^{b}	27.0^{b}	35.2^{b}	35.3^{b}	41.0^{b}	45.9^{b}	49.7^{c}	51.0^{c}	53.6^{c}	55.0^{c}	55.7^{c}
EM	0	0	24.6^{b}	25.2^{b}	34.2^{b}	38.0^{b}	40.0^{b}	43.9^{b}	47.0^{c}	50.1^{c}	52.6^{c}	55.0^{c}	55.4^{c}	58.8^{c}
CC	0	0	23.4^{b}	23.0^{b}	29.7^{b}	38.4^{b}	44.1^{b}	45.0^{b}	48.2^{c}	53.7^{c}	53.9^{c}	54.0^{c}	55.8^{c}	57.0^{c}
CG	0	0	6.5^{a}	19.3^{a}	29.0^{b}	38.0^{b}	44.0^{b}	44.6^{b}	49.0^{c}	49.6^{c}	48.0^{c}	51.3^{c}	55.6^{c}	61.2^{d}
SB	0	0	45.8^{b}	50.3^{c}	50.8^{c}	52.2^{c}	53.7^{c}	56.0^{c}	57.0^{c}	57.9^{c}	62.4^{d}	64.5^{d}	65.1^{d}	69.5^{d}

Means within the same columns with different superscripts are significantly different at $p<0.05$.

Key: CR=Chloris roxburghiana, ES= Eragrostis superba, EM= Enteropogon macrostachyus, CC= Cenchrus ciliaris, CG= Chloris gayana, SB= Sorghum sudanense

3.2 Germination Index (GI)

Table 5 below presents the GI of the six grass species. Generally, the average GI was significantly different among the species, but increased with increase in storage period, attaining maximum between 24 and 36 weeks. Supplemental watering enhanced the GI in all the species, with SB seeds stored for more than 24 weeks exhibiting the highest (>20) overall GI, across the three soil moisture treatment levels. Under rainfed conditions, SB which was the most prolific, only attained >20 GI after 36 weeks storage period. After 12 weeks of storage, SB had the highest GI, followed by EM and CC.

Table 5. Germination indices of seeds of the six grasses produced under different soil moisture regimes (80, 50, 30% FC and rain-fed) and stored for different periods (2, 12, 24 and 36 weeks)

	80% FC	50% FC	30% FC	Rain-fed (control)
Week 2				
C R	0.0	0.0	0.0	0.0
E S	0.2^{a}	0.0	1.1^{a}	1.0^{a}
EM	3.1^{a}	2.7^{a}	2.0^{a}	1.5^{a}
CC	0.0	0.1^{a}	0.0	0.0
CG	2.4^{a}	1.8^{a}	2.1^{a}	1.7^{a}
SB	25.3^{b}	28.4^{b}	24.3^{a}	13.4^{a}
Week 12				
C R	6.4^{a}	8.1^{a}	8.8^{a}	3.4^{a}
E S	12.4^{a}	16.3^{a}	11.5^{a}	8.8^{a}
EM	21.6^{b}	27.5^{b}	23.2^{b}	12.5^{a}
CC	14.2^{a}	15.1^{a}	18.3^{a}	6.8^{a}
CG	12.5^{a}	15.7^{a}	16.8^{a}	10.2^{a}
SB	27.7^{b}	31.6^{b}	26.5^{b}	18.8^{a}
Week 24				
C R	8.5^{a}	8.6^{a}	9.4^{a}	5.5^{a}
E S	13.1^{a}	15.5^{a}	14.2^{a}	10.3^{a}
EM	20.9^{b}	24.3^{b}	22.8^{b}	12.5^{a}
CC	18.6^{a}	21.2^{b}	24.4^{b}	15.2^{a}
CG	15.2^{a}	13.8^{a}	16.1^{a}	13.4^{a}
SB	25.2^{b}	26.3^{b}	24.8^{b}	18.3^{a}
Week 36				
C R	8.8^{a}	7.3^{a}	9.2^{a}	7.5^{a}
E S	14.1^{a}	13.9^{a}	12.6^{a}	11.3^{a}
EM	22.3^{b}	25.1^{b}	23.7^{b}	17.1^{a}
CC	19.1^{a}	18.6^{a}	24.7^{b}	15.2^{a}
CG	14.8^{a}	15.9^{a}	15.8^{a}	12.9^{a}
SB	25.2^{b}	23.6^{b}	27.2^{b}	21.1^{b}

Means within the same columns with different superscripts are significantly different at $p<0.05$.

Key: CR=Chloris roxburghiana, ES= Eragrostis superba, EM= Enteropogon macrostachyus, CC= Cenchrus ciliaris, CG= Chloris gayana, SB= Sorghum sudanense

4. Discussions

Soil moisture and nutrient status during the entire growing period of any plant, is a key determinant of the quality and quantity of seeds that will ultimately be produced. On the other hand, the storage conditions of the seeds after harvesting, as well the duration the seeds are stored before planting has a major effect on the viability (germination rate) of the seeds. The fact that soil moisture content did not show significant effect on germination rate of the seeds does not diminish its role as it had a high impact on seed yields, which is equally critical in biomass production. This simply means that the moisture content was not high enough to trigger germination. The results show that seeds should be stored for long enough period, during which period they dry further and resulting in improved viability. Seeds from the current season should not be earmarked for planting in the up-coming season. Of the six grasses evaluated in this study, 6-12 months storage period of seeds before planting seemed to be ideal. And in addition, CC and SB seemed to be the best choices, especially under conditions of limited water availability for irrigation. They exhibited relatively higher tolerance to moisture stress.

The high GP exhibited by SB under all the experimental conditions can be mainly attributed to the relatively large seed size compared to the other five species (Guo *et al.,* 2000). Dourado (1989) demonstrated that seed size had direct effect on seed quality and a positive correlation between seed size and germination percent. The higher germination rate observed in EM than CC and ES, on the other hand, can be attributed to differences in seed dormancy which is related to existence of an integument. EM has both a tough integument and protracted dormancy early in the storage period Mganga *et al.,* 2010a).

Grasses whose seeds germinate faster than those of their contemporaries have the advantage of reduced competition from weeds and the benefit of escaping the vagaries of moisture deficits during the dry seasons (Mnene 2005; Verdu &Traveset, 2005; Mganga *et al.,* 2009; 2010a). In this study, SB and EM species exhibited higher germination rates which were largely attributed to seed size and dormancy mechanism, which seemed to working relatively better than in the other four species. In dryland grasses, fast seed germination is desirable as it allows plants to establish themselves very rapidly after enough moisture has been received, thus increasing the chances of survival of that plant species if a dry spell ensues (Mganga 2010b). This perspective accounts for the rapid establishment, survival rate and biomass yields shown by SB and CG--964.8 and 832.7 Kg/ha, under irrigation and rain fed conditions, respectively. Germination rate is a high indicator of seed quality (ISTA, 1976). However, seed vigor is also an important pointer of seed quality which can evaluated through GI tests (Chin & Wong, 1993; Lusembo *et al.,* 1993).

The observed higher GI in CC than CG in this study can be attributed to the difference in number of hairy fascicles which reduce moisture loss from around the caryopsis and, thus enhancing the germination rates. Similar observations were reported by Dewir *et al.* (2011); Mganga (2009) and Zadeh & Murdoch, (2001) where CC had higher germination rate than ES. This observation suggests that individual grass species have different germination rates, which could be attributed to the plants' adaptive capacity to persevere austere climates through either morphological or physiological traits (Qi, 1993; Opiyo 2007).

The observed lower germination rate of CC under rain fed conditions than under watered condition suggests an enhanced dormancy by water stress during seed maturation. This finding concurs with those of Sharif-Zadeh and Murdoch (2000) who worked with CC and observed that seed dormancy increased substantially when water stress was imposed during maturation, especially when the mother plants were exposed to water stress after the caryopses had fully ripened. This could be the case in this study since the heading of the grasses occurred after the rains had ceased and the grasses seeded under dry season.

5. Conclusion and Recommendation

The results of this study have provided evidence-based information upon which recommendations for production and storage of seeds of the six local grasses can be drawn. The results have shown that storage of seeds of any of the species for less than 12 weeks before planting should not be recommended; rather, more than 24 weeks should be recommended for acceptable germination rates. On the other hand, farmers should not use freshly harvested seeds. Of the six species evaluated, SB is the species of choice under all the conditions covered in this study, including rain fed. For instance, if one had no alternative than to plant seeds from the just ended season, SB should be recommended; and where early germination is desired due to possibility of early rainfall cessation, it should still be best choice.

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REFERENCE

Awad, A., Hafiz, S., Hammada, M.S, El-Nouby, A., & El-Hendawy, S. (2013) Grain yield production of Sorghum sudanense (Sudan grass) as influenced by cutting numbers, potassium rates, and intrarow spacing in a semiarid environment. Turkish Journal of Agriculture and Forestry, 37(6), 657-664.

Bestelmeyer, B.T., Miller, J.R. & Wiens, J.A. (2003) Applying species diversity theory to land management. Ecological Applications, 13(6), 1750-1761.

Boonman, G, (1993) (ed) East Africa's grasses and fodders: Their ecology and husbandry (Vol. 29).

Springer.

Chin, H.F. & Wong, C.C. (1993). The importance of tropical pasture seed quality and factors affecting it in smallholder farming systems. In Proc. XVII Int. Grassland Congress.

Dewir, Y.H., El-Mahrouk, M.E., & Naidoo, Y. (2011) Effect of some mechanical and chemical treatments on seed germination of Sabal palmetto and Thrinax morrisii palms. Australian Journal of Crop Science, 5(3), 248-253

Dourado, A.M. (1989) The effect of seed size, method of harvest and accelerated ageing on germination. Proceedings of the International Seed Test Association, 17. http://agris.fao.org/agris-search/search/display.do?f=1989/CH/CH89002.xml;CH8923236

Fynn, R.W. (2012) Functional resource heterogeneity increases livestock and rangeland productivity. Rangeland Ecology & Management, 65(4), 319-329.

GOK, (2005) Tana River District Strategic Plan 2005-2010 for Implementation of the National Population Policy for Sustainable Development. http://ncpdnke.org/strategicplans/TanaRiver.pdf. (Accessed on 25 June 2012).

Griffiths, R., (1993) Sustainable supplies of quality herbage seed for sub-Saharan Africa smallholder’s pp. 662-665. In: MJ Baker (ed). Grasslands for our world. Sir Publishing, Wellington, New Zealand

Guo, Q., Brown, J.H., Valone, T.J. & Kachman, S.D. (2000) Constraints of seed size on plant distribution and abundance. Ecology, 81(8), 2149-2155.

ISTA. (1987) Handbook of Vigour Test Methods." International Seed Testing Association”

ISTA. (1976) International rules for seed testing. Seed Science and Technology 4:23-28

Kreuter, U.P., Fox, W.E., Tanaka, J.A., Maczko, K.A., McCollum, D.W., Mitchell, J.E., & Hidinger, L. (2012) Framework for comparing ecosystem impacts of developing unconventional energy resources on western US rangelands. Rangeland Ecology and Management, 65(5), 433-443.

Lusembo, P., Sabiiti, E.N., Mugerwa, J.S., Ndikumana, J. & Leeuw, P.D. (1993). The effect of staking on seed yield and quality characteristics of *Macroptilium atropurpureum* at Namulonge, Uganda. In Workshop for the African Feed Resources Network (AFRNET), Harare (Zimbabwe) 6-10 December 1993.

Mganga, K. Z., Musimba, N.K., Nyangito, M.M., Nyariki, D.M., Mwangombe, A.W., Ekaya, W.N. & Verhagen, J. (2010a). The role of moisture in the successful rehabilitation of denuded patches of a semi-arid environment in Kenya. Journal of Environmental Science and Technology, 3, 195-207.

Mganga, K.Z., Musimba, N.K., Nyariki, D.M., Nyangito, M.M., Mwang'ombe, A.W., Ekaya, W.N. & Muiru, W.M. (2010b). Dry matter yields and hydrological properties of three perennial grasses of a semi-arid environment in east Africa. African journal of Plant Science, 4(5), 138-144

Mganga, K.Z., Musimba, N.R., Nyariki, D.M., Nyangito, M.M. & Mwang'ombe, A.W. (2013). The choice of grass species to combat desertification in semi-arid Kenyan rangelands is greatly influenced by their forage value for livestock. Grass and Forage Science.

Mganga, K.Z. (2009). Impact of grass reseeding technology on rehabilitation of the degraded rangelands: a case study of Kibwezi District, Kenya. MSc Thesis, University of Nairobi, Nairobi, Kenya

Mlote, S.N., Mdoe, N.S., Isinika, A.C. & Mtenga, L.A. (2013). Factors Affecting Agro-Pastoralist and Pastoralists' Willingness to Adopt Beef Cattle Fattening in the Lake Zone in Tanzania. Journal of Agricultural Science (1916-9752), 5(10).

Mnene, W.N. (2005). Strategies to increase success rates in natural pasture development through reseeding degraded rangelands of Kenya. PhD Thesis, University of Nairobi, Nairobi, Nairobi, Kenya.

Musimba, N.K.R., Nyariki, D.M., Ikutwa, C.N. & Teka, T. (2004) Dryland Husbandry for sustainable development in the southern rangelands of Kenya. OSSREA, Addis Ababa, 2004.

Mwadalu, R. & Mwangi, M. (2013) The potential role of sorghum in enhancing food security in semi-arid eastern Kenya: A review. Journal of Applied Biosciences, 71(1), 5786-5799.

Nyangito, M.M., Musimba, N.K.R. & Nyariki, D.M. (2008). Range use and dynamics in the agropastoral system of southeastern Kenya. African Journal of Environmental Science and Technology 2(8): 220-230

Nyangito, M.M., Musimba, N.K.R. & Nyariki, D.M. (2009) Hydrological properties of grazed perennial swards in semiarid southeastern Kenya. African Journal of Environmental Science and Technology 3(2): 026-033.

Opiyo, F.O. (2007) Land treatment effects on morphometric characteristics of three grass species and economic returns from reseeding in Kitui district, Kenya. MSc Thesis, University of Nairobi, Nairobi, Kenya.

Pizarro, E.A., Hare, M.D., Mutimura, M. & Changjun, B. (2013) Brachiaria hybrids: potential, forage use and seed yield. Tropical Grasslands-Forrajes Tropicales, 1(1), 31-35.

Qi, M.Q. & Redmann, R.E. (1993) Seed germination and seedling survival of C3 and C4 grasses under water stress. Journal of Arid Environments, 24(3), 277-285.

Rietkerk, M., Ketner, P., Burger, J., Hoorens, B. & Olff, H. (2000) Multiscale soil and vegetation patchiness along a gradient of herbivore impact in a semi-arid grazing system in West Africa. Plant Ecology, 148:207-224.

Samuel, T. (2013). From cattle herding to sedentary agriculture: the role of hamer women in the transition. African study monographs. Supplementary issue., 46, 121-133.

Seobi, T., Anderson, S.H., Udawatta, R.P. & Gantzer, C.J. (2005) Influence of grass and agroforestry buffer strips on soil hydraulic properties for an Albaqualf. Soil Science Society of America Journal 69:893-901.

Sharif-Zadeh, F & Murdoch, A. J. (2000) The effects of different maturation conditions on seed dormancy and germination of Cenchrus ciliaris. Seed Science Research, 10(04), 447-457.

Verdú, M. & Traveset, A., (2005) Early emergence enhances plant fitness: a phylogenetically controlled meta-analysis. Ecology, 86(6), 1385-1394.

Visser, N., Morris, C., Hardy, M.B. & Botha, J.C, (2007) Restoring bare patches in the Nama-Karoo of South Africa. African Journal of Range and Forage Science 24(2):87-96.

Yosef, T., Mengistu, U., Solomon, A., Mohammed, Y.K. & Kefelegn, K. (2013) Camel and cattle population dynamics and livelihood diversification as a response to climate change in pastoral areas of Ethiopia. *Livestock Research for Rural Development*, 25(9).

Zadeh, F., & Murdoch, A.J. (2001) The effects of temperature and moisture on after-ripening of *Cenchrus ciliaris* seeds. *Journal of arid environments*, 49(4), 823-831.

CHAPTER SIX

Effect of stage of maturity, curing and storage methods on the quality of hay from six indigenous grass species of southeastern Kenya

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Abstract

The study was carried out to evaluate the effect of stage of maturity at harvesting, curing and storage methods on the quality of hay from six dry-land grasses in southeastern Kenya. The grasses were harvested at three different phonological stages (8, 10 and 12 weeks), cured for 1, 2 or 3 days, and stored either outdoor or indoor. Crude protein (CP) content was also determined using the AOAC (2005) method. The results demonstrated a significant decline ($p \leq 0.05$) in crude protein content in all the species as the plants aged. *S. Sudanense* hand the lowest mean CP content of the six species. Curing period did not affect the CP content. Crude Protein was significantly ($p \leq 0.05$) higher in indoor than outdoor storage for all the species. CF, NDF and ADF increased with increase in maturity in all the species, irrespective of storage method. Outdoor stored hay had significantly lower ($p \leq 0.05$) DM than that stored indoors. Storage method had no effect on the *in sacco* dry matter digestibility (ISDMD). As expected, the hay quality is a function of the age of the grass at harvesting and storage methods with indoor storage being more beneficial than outdoor method. Harvesting grass between 8 and 10 weeks old, curing the hay for 1-3 days and storing it indoors resulted in higher quality hay than the other methods.

Keywords: Grass quality; Range grasses, Semi-arid rangelands, Grass storage; Grass curing; Kenya

1. Introduction

Production and conservation of forages, including crop residues, for feeding during periods of feed scarcity, is an ages-old practice in virtually all livestock producing systems of the world. Hay and silage-making are probably some of the oldest and most popular methods of conserving forages. The main goal in production and conservation of any plant material for feeding to livestock later is to minimize loss of quantity and quality during harvesting, storage and feeding (Buskirk *et al.*, 2003; Mackie, 2004). Under good husbandry practices, forage materials when growing can be of very high quality, but lose most of it between harvesting and feeding, especially during storage (Roberts *et al.*, 2009; Bernués *et al.*, 2011). Prevailing weather conditions during the time of cutting, curing and baling can have huge adverse effect on the forage material. For example, alfalfa hay DM dropped by up to 22% when exposed to about 10mm of rainfall during curing (Rankin & Undersander, 2004). According to Rankin & Undersander (2004) prevailing weather conditions affect forage quality through: (i) plant respiration that reduces soluble carbohydrates and energy content during storage; (ii) leaching of soluble carbohydrates, protein and minerals under unprotected storage (iii) leaf shattering and loss of highly digestible proteins, (iv) microbial activity which metabolizes soluble carbohydrates, reducing forage energy content and possibly producing harmful metabolites, and finally (v) colour change through bleaching and excessive drying reducing palatability of the hay (Roberts, 1995). Mouldy hay can be a health hazard to livestock due to potential toxicity (Tangni *et al.,* 2013). In a few cases, hay baled at high moisture content can spontaneously heat to combustion (Rotz, 1994). During hay storage, microbial activity consumes soluble carbohydrates leading to reduction in nutritional quality through respiration, consequently reducing the DM content. The losses can be more than 10% if moisture levels are 20—30 per cent at storage (Wilcke *et al.*, 1999). Grass production for storage therefore, requires a lot of care from harvesting to feeding. This study, evaluated the effect of stage of maturity at harvesting, duration of curing and storage method on the quality of hay from *Chloris roxburghiana*- (CR), *Eragrostis superb*- (ES), *Enteropogon macrostachyus*- (EM),, *Cenchrus ciliaris*- (CC), *Chloris gayana* - (CG), and *Sorghum sudanense*- (SB), the common indigenous grass species in south-eastern dry lands of Kenya.

2. Materials and Methods

Experimental design and layout are described in chapter two.

2.1 Sample preparation, chemical analyses and Data Collection

Samples of forage materials harvested from plots of a study carried out to determine the effect of varying soil moisture content on aboveground biomass yields and morphometric characteristics of six indigenous grasses, were chemically analysed to determine the effect of maturity stage; and curing and storage methods on feed quality. Treatments comprised three maturity stage (8, 10 or12 weeks), three curing period (1, 2 or 3 days), three storing periods (12, 24 and 36 weeks) and two storing methods (indoor and outdoor). For the maturity stage treatment, one plot (replicate) per species was cut at the end of each growth stage. The material was divided into three equal portions, one portion hand-baled after one day, the other after two days and the other after three days. Half of the material (bales) collected each day was stored outdoor and the other half stored indoor. To avoid mix-ups in the store, the experimental materials were carefully marked before being stored.

To determine the effect of storage period experimental material batches from each of the other treatment levels were sampled at end of the set storage period. The samples were stored separately in paper bags pending analyses. Samples for laboratory analysis were dried at 65ºC for 48h, while those for DM determination were dried at 105ºC for 24h. Sample designated for laboratory analysis were then ground through a 1-mm sieve of a hammer mill and packed in labeled bottles and stored in a cool dry place. Dry matter (DM), ash (A), organic matter (OM) and total nitrogen (N) were determined according to AOAC (1990), while Acid detergent fiber, (ADF), neutral detergent fiber (NDF) and Acid detergent lignin (ADL) were analyzed following the procedures of Van Soest *et al* (1991). Dry mater digestibility was determined using the Nylon bag (Osuji et *al*., 1993). Nylon bags were stuffed with 2gms of the ground material and incubated in the rumen of a fistulated bull for 72hrs. Weight losses were calculated according to the method described by Osuji *et al.,* (1993). All chemical analyses were conducted in the Department of Animal Production; University of Nairobi. The data were analyzed using the General Linear models (GLM) procedure of SAS Version 9 (SAS Institute, 2011).

3. Results

3.1 Crude protein content at different curing and storage methods

The results presented here are only for the 80% FC soil moisture treatment since the other water treatment levels did not have significant effects on forage quality (see Appendix 5). Table 1 presents the percentage crude protein of six range grass species harvested at 12th week, cured for 1, 2 and 3 days before baling and stored for 2, 12, 24 and 36 weeks. There was no significant difference ($p \geq 0.05$) in percentage CP content for all the grasses at the three curing periods at a given storage period (ANOVA - Appendix 5). However, there was a significant ($p \leq 0.05$) decline in percentage CP with storage from 24 weeks onwards for all the grass species at the three curing periods. The two weeks storage period yielded 7-8% CP for all the grass species, 12 and 24 weeks had 5-7% CP while 36 weeks storage had less than 5%. SB had the highest decline (<4%) in CP by 36 weeks storage period.

Table 1 Crude proteins (% CP) of selected grasses at 12th phenological stage, Cured for one, two and three days, before indoor storage for 2, 12, 24 and 36 weeks.

	% CP		
Curing period	**1 day**	**2 days**	**3 days**
WEEK 2			
C R	$7.5^{a} \pm 2.1$	$7.8^{a} \pm 1.4$	$7.5^{a} \pm 3.1$
E S	$7.0^{a} \pm 1.7$	$7.8^{a} \pm 3.2$	$7.7^{a} \pm 2.2$
EM	$7.0^{a} \pm 3.1$	$7.2^{a} \pm 2.1$	$7.1^{a} \pm 2.0$
CC	$7.3^{a} \pm 1.3$	$7.1^{a} \pm 1.3$	$7.1^{a} \pm 1.9$
CG	$7.5^{a} \pm 3.1$	$7.8^{a} \pm 1.4$	$7.4^{a} \pm 1.5$
SB	$7.2^{a} \pm 3.1$	$7.8^{a} \pm 2.7$	$7.3^{a} \pm 2.1$
WEEK 12			
C R	$7.0^{a} \pm 1.1$	$7.1^{a} \pm 2.1$	$6.9^{a} \pm 2.1$
E S	$6.3^{a} \pm 1.7$	$6.5^{a} \pm 1.0$	$6.8^{a} \pm 3.0$
EM	$6.4^{a} \pm 2.1$	$6.8^{a} \pm 1.2$	$6.7^{a} \pm 1.3$
CC	$6.1^{a} \pm 1.0$	$6.6^{a} \pm 2.1$	$6.9^{a} \pm 2.1$
CG	$6.0^{a} \pm 2.1$	$6.5^{a} \pm 3.1$	$6.1^{a} \pm 1.5$
SB	$6.4^{a} \pm 1.3$	$6.3^{a} \pm 1.3$	$6.1^{a} \pm 2.0$
WEEK 24			
C R	$6.4^{a} \pm 2.1$	$5.5^{b} \pm 1.1$	$6.1^{a} \pm 1.6$
E S	$5.8^{b} \pm 1.6$	$5.9^{b} \pm 1.2$	$5.3^{b} \pm 1.2$
EM	$5.8^{b} \pm 2.1$	$5.2^{b} \pm 1.0$	$5.2^{b} \pm 1.1$
CC	$5.3^{b} \pm 1.1$	$5.5^{b} \pm 1.3$	$5.3^{b} \pm 1.4$
CG	$5.6^{b} \pm 1.4$	$5.1^{b} \pm 1.2$	$5.0^{b} \pm 1.8$
SB	$5.3^{b} \pm 1.4$	$5.0^{b} \pm 2.0$	$5.0^{b} \pm 1.0$
WEEK 36			
C R	$4.3^{c} \pm 0.4$	$4.2^{c} \pm 0.7$	$4.1^{c} \pm 1.0$
E S	$4.2^{c} \pm 1.1$	$4.4^{c} \pm 0.3$	$4.0^{c} \pm 1.1$
EM	$4.0^{c} \pm 0.5$	$4.1^{a} \pm 0.0$	$4.8^{c} \pm 0.7$
CC	$4.5^{c} \pm 1.6$	$3.9^{c} \pm 0.2$	$4.1^{c} \pm 1.3$
CG	$4.2^{c} \pm 0.9$	$4.0^{c} \pm 0.7$	$4.1^{c} \pm 1.2$
SB	$3.4^{d} \pm 1.1$	$3.8^{d} \pm 1.1$	$3.3^{d} \pm .09$

Means within the same columns with different superscripts are significantly different at $p \leq 0.05$.
Key: CR=Chloris roxburghiana, ES= Eragrostis superba, EM= Enteropogon macrostachyus, CC= Cenchrus ciliaris, CG= Chloris gayana, SB= Sorghum sudanense

3.2 Effects of storage method on hay quality

Table 2 presents the DM, EE, CP, CF, NDF, ADF and ADL of the grasses species grown singly and in mixtures at 12th week's phenological stage under outdoor storage for 12, 24 and 36 weeks from date of harvest. There was no significant difference in DM and CP at a given storage period for all the grass species and their mixtures. No significant difference ($p \geq 0.05$) was observed in specific species DM at storage duration of 12, 24 and 36 weeks; however a declining trend was observed. Ash and EE did not significantly differ with storage durations among the six grasses and their mixtures. There was significant decline ($p \leq 0.05$) in CP with storage duration for all the grasses and their mixtures. The CF, NDF ADF and ADL increased with storage although were not significantly different at the three storage periods.

Table 2 Nutrient composition of selected grass species at 12th week, grown in pure and in mixtures under outdoor storage period of 12, 24 and 36 weeks from date of harvest

Species	*%DM*	*%ASH*	*%E.E*	*%C.P*	*%C.F*	*%NDF*	*%ADF*	*%ADL*
WEEK 12								
C R	88.2^{a} ±12.2	10.1^{a} ±5.2	1.1^{a} ±0.1	6.4^{a} ±1.3	23.1^{a} ±8.2	54.0 ±7.1	30.1^{a} ±8.2	8.9^{a} ±2.6
E S	81.5^{a} ±11.2	9.8^{a} ±3.5	1.0^{a} ±1.1	5.8^{a} ±7.1	27.1^{a} ±7.9	54.9^{a} ±9.1	32.1^{a} ±7.0	9.8^{a} ±2.1
EM	80.3^{a} ±8.1	11.1^{a} ±4.1	1.2^{a} ±0.6	5.2^{a} ±1.2	28.0^{a} ±2.1	53.1^{a} ±22.6	30.1^{a} ±9.1	10.1^{a} ±4.1
CC	88.1^{a} ±13.5	10.2^{a} ±0.9	1.2^{a} ±1.1	6.1^{a} ±3.2	30.1^{a} ±8.0	59.0^{a} ±8.1	31.0^{a} ±7.3	9.8^{a} ±2.3
CG	83.0^{a} ±17.3	8.6^{a} ±2.1	1.1^{a} ±0.3	6.0^{a} ±2.8	22.1^{a} ±7.1	56.8^{a} ±7.9	33.1^{a} ±6.2	9.5^{a} ±3.1
SB	81.0^{a} ±12.9	7.3^{a} ±4.6	1.0^{a} ±0.4	5.9^{a} ±3.1	21.1^{a} ±4.7	57.1^{a} ±9.2	34.2^{a} ±5.1	10.1^{a} ±2.1
CR/ES	80.8^{a} ±21.2	11.1^{a} ±4.1	0.9^{a} ±0.1	6.2^{a} ±1.5	23.2^{a} ±7.1	58.6^{a} ±7.9	30.1^{a} ±3.7	11.2^{a} ±3.3
CR/ES/EM	79.5^{a} ±9.7	9.3^{a} ±2.2	1.1^{a} ±0.6	5.8^{a} ±3.1	27.1^{a} ±4.1	59.8^{a} ±9.1	32.7^{a} ±5.1	12.1^{a} ±0.8
CR/ES/EM/CC	83.1^{a} ±8.9	12.1^{a} ±3.2	1.3^{a} ±0.1	5.2^{a} ±2.1	23.1^{a} ±7.0	57.8^{a} ±8.1	30.0^{a} ±9.1	10.1^{a} ±2.9
CR/ES/EM/CC/CG	81.4^{a} ±11.0	11.0^{a} ±2.5	1.2^{a} ±0.5	5.4^{a} ±1.5	22.8^{a} ±5.2	59.0^{a} ±9.0	30.1^{a} ±5.2	8.9^{a} ±2.1
WEEK 24								
C R	76.2^{a} ±13.0	9.8^{a} ±2.9	1.1^{a} ±0.1	4.5^{b} ±2.1	29.1^{a} ±6.0	57.1^{a} ±8.7	37.1^{a} ±9.1	10.3^{a} ±5.1
E S	75.1^{a} ±9.7	10.2^{a} ±1.7	1.1^{a} ±0.2	4.2^{b} ±0.8	30.1^{a} ±5.2	59.0^{a} ±11.0	38.0^{a} ±7.3	11.2^{a} ±4.8
EM	78.2^{a} ±9.4	9.7^{a} ±1.0	0.7^{a} ±0.0	4.1^{b} ±2.1	21.1^{a} ±7.0	60.1^{a} ±9.8	37.0^{a} ±8.4	10.3^{a} ±2.4
CC	80.0^{a} ±12.2	10.1^{a} ±2.8	1.1^{a} ±0.1	4.0^{b} ±1.3	24.2^{a} ±6.2	54.8^{a} ±10.3	38.0^{a} ±3.9	9.8^{a} ±3.9
CG	76.1^{a} ±11.8	9.5^{a} ±3.3	1.2^{a} ±0.3	4.2^{b} ±3.2	22.0^{a} ±4.5	58.1^{a} ±11.1	36.4^{a} ±8.0	10.5^{a} ±4.4
SB	77.0^{a} ±9.4	11.1^{a} ±2.1	0.8^{a} ±0.1	5.1^{b} ±2.1	29.1^{a} ±7.1	55.9^{a} ±5.1	35.6^{a} ±6.1	9.8^{a} ±1.2
CR/ES	78.1^{a} ±12.3	10.1^{a} ±3.0	0.7^{a} ±0.0	4.2^{b} ±2.1	24.1^{a} ±4.7	59.3^{a} ±4.6	36.1^{a} ±5.1	10.1^{a} ±3.8
CR/ES/EM	76.9^{a} ±18.0	8.6^{a} ±2.1	0.8^{a} ±0.0	4.3^{b} ±1.5	21.1^{a} ±3.7	59.0^{a} ±7.1	36.5^{a} ±6.2	9.8^{a} ±3.1
CR/ES/EM/CC	74.3^{a} ±9.6	8.1^{a} ±1.1	0.9^{a} ±0.1	4.1^{b} ±0.0	21.0^{a} ±7.0	60.0^{a} ±9.0	37.0^{a} ±8.0	11.1^{a} ±1.6
CR/ES/EM/CC/CG	74.1^{a} ±20.1	7.9^{a} ±0.6	1.2^{a} ±0.4	4.1^{b} ±1.5	25.9^{a} ±8.1	60.0^{a} ±4.1	37.1^{a} ±7.1	9.8^{a} ±2.1
WEEK 36								
C R	75.1^{a} ±12.1	11.2^{a} ±2.3	1.1^{a} ±0.1	4.1^{b} ±1.3	31.1^{a} ±5.0	60.1^{a} ±3.6	38.9^{a} ±7.1	11.5^{a} ±2.4
E S	76.1^{a} ±9.7	10.0^{a} ±2.1	1.0^{a} ±0.2	3.7^{c} ±2.1	33.1^{a} ±2.9	59.9^{a} ±6.1	41.1^{b}±4.1	10.1^{a} ±3.0
EM	79.2^{a} ±9.1	9.8^{a} ±3.1	1.3^{a} ±0.2	4.1^{b} ±2.1	22.1^{a} ±6.1	60.1^{a} ±7.4	40.0^{b} ±9.2	11.2^{a} ±2.1
CC	79.1^{a} ±9.2	7.0^{a} ±2.4	1.1^{a} ±0.0	3.2^{c} ±1.1	29.9^{a} ±3.3	60.2^{a} ±9.9	38.5^{a} ±8.1	9.3^{a} ±3.2
CG	79.7^{a} ±11.1	11.1^{a} ±4.3	1.0^{a} ±0.3	2.9^{c} ±2.1	21.1^{a} ±7.1	60.1^{a} ±9.2	39.6^{a} ±6.7	10.1^{a} ±0.9
SB	71.2^{a} ±10.0	10.0^{a} ±4.1	1.3^{a} ±1.0	3.1^{c} ±0.9	24.1^{a} ±5.1	59.6^{a} ±5.1	41.1^{b}±5.1	9.8^{a} ±2.6
CR/ES	78.1^{a} ±9.1	9.7^{a} ±1.6	1.4^{a} ±0.9	3.1^{c} ±0.3	26.1^{a} ±9.2	60.0^{a} ±6.2	39.0^{a} ±2.4	10.1^{a} ±3.1
CR/ES/EM	76.0^{a} ±6.7	8.1^{a} ±0.7	1.2^{a} ±0.1	4.3^{b}±1.1	24.9^{a} ±3.1	61.2^{a} ±6.1	38.0^{a} ±3.3	10.0^{a} ±3.0
CR/ES/EM/CC	77.7^{a} ±17.2	9.3^{a} ±3.1	0.8^{a} ±0.3	4.2^{b} ±0.9	23.0^{a} ±2.1	56.9^{a} ±8.2	37.9^{a} ±2.4	9.8^{a} ±1.1
CR/ES/EM/CC/CG	77.3^{a} ±11.5	8.1^{a} ±2.1	0.8^{a} ±0.1	2.9^{c} ±1.1	26.9^{a} ±6.1	60.0^{a} ±11.1	38.7^{a} ±8.1	8.7^{a} ±2.1

Means within the same columns with different superscripts are significantly different at $p \leq 0.05$.

Key: CR=Chloris roxburghiana, ES= Eragrostis superba, EM= Enteropogon macrostachyus, CC= Cenchrus ciliaris, CG= Chloris gayana, SB= Sorghum sudanense

Table 3 presents the DM, EE, CP, CF, NDF, ADF and ADL of the six grasses grown singly and in mixtures, harvested at week12 under indoor storage of 12, 24 and 36 weeks. There was no significant change in DM and Ash content across the species at the three storage periods, however a declining trend was observed in DM. There was a decline in CP content for all the six grass species and their mixtures with increase in storage duration ranging from 5.0 to 6.3% but were not significantly different. Slight increase in CF, NDF and ADF content was observed for the grasses and their mixtures with storage periods but was also not significantly different. No significant difference was noted when DM, Ash, CF, NDF, ADF for indoor and outdoor was compared at each storage period. However, DM decline was slightly higher under outdoor storage. The CP for indoor storage was slightly higher at all storage periods although was not significantly different from outdoor.

Table 3 Nutrient composition of selected grass species at12th week phenological stage grown in pure and in mixtures under indoor storage period of 12, 24 and 36 weeks from date of harvest

Species and storage period	*%DM*	*%ASH*	*%E.E*	*%C.P*	*%C.F*	*%NDF*	*%ADF*	*%ADL*
WEEK 12								
C R	91.3^{a} ±8.1	10.7^{a} ±2.1	1.2^{a} ±0.6	6.3^{a} ±2.1	24.8^{a} ±5.5	58.7^{a} ±11.1	30.0^{a} ±7.3	11.1^{a} ±3.1
E S	93.1^{a} ±11.2	11.1^{a} ±3.2	1.0^{a} ±0.2	6.1^{a} ±1.7	29.1^{a} ±6.9	51.3^{a} ±9.7	26.5^{a} ±3.9	10.4^{a} ±2.0
EM	90.5^{a} ±9.2	10.2^{a} ±3.4	1.2^{a} ±0.2	6.2^{a} ±3.2	24.9^{a} ±7.1	59.8^{a} ±7.1	30.1^{a} ±5.0	11.0^{a} ±4.1
CC	89.0^{a} ±10.1	8.1^{a} ±4.5	1.1^{a} ±0.4	5.4^{a} ±3.2	26.1^{a} ±5.5	59.0^{a} ±8.2	33.1^{a} ±7.1	10.4^{a} ±2.3
CG	90.0^{a} ±8.5	10.5^{a} ±4.5	1.0^{a} ±0.3	4.8^{a} ±2.1	30.3^{a} ±3.7	58.7^{a} ±10.0	29.0^{a} ±6.2	10.3^{a} ±4.1
SB	93.0^{a} ±8.2	12.4^{a} ±3.5	1.0^{a} ±0.5	5.0^{a} ±1.2	28.5^{a} ±5.2	56.7^{a} ±8.3	28.0^{a} ±3.1	10.4^{a} ±3.3
CR/ES	91.7^{a} ±11.1	12.1^{a} ±6.1	1.2^{a} ±0.0	5.4^{a} ±1.1	32.2^{a} ±6.1	58.0^{a} ±6.1	30.1^{a} ±5.2	10.4^{a} ±2.4
CR/ES/EM	90.1^{a} ±9.0	11.1^{a} ±7.1	1.2^{a} ±0.3	5.3^{a} ±1.6	35.0^{a} ±6.1	59.9^{a} ±9.2	29.1^{a} ±8.1	10.2^{a}±6.
CR/ES/EM/CC	92.4^{a} ±14.1	10.1^{a} ±5.1	1.1^{a} ±0.4	5.0^{a} ±2.1	33.9^{a} ±4.2	57.2^{a} ±8.1	27.7^{a} ±3.8	11.3^{a} 3.4
CR/ES/EM/CC/CG	90.2^{a} ±17.2	11.2^{a} ±3.2	1.0^{a} ±0.1	5.9^{a} ±1.8	30.0^{a} ±4.7	58.8^{a} ±7.2	26.4^{a} ±6.1	11.4^{a} ±4.1
WEEK 24								
C R	90.3^{a} ±16.1	10.0^{a} ±3.7	1.0^{a} ±0.2	5.8^{a} ±1.4	21.1^{a} ±8.1	68.7^{a} ±7.1	37.4^{a} ±7.2	11.2^{a} ±4.0
E S	88.1^{a} ±9.1	10.1^{a} ±5.1	1.1^{a} ±0.0	6.5^{a} ±1.6	24.0^{a} ±5.1	59.6^{a} ±11.1	30.4^{a} ±6.1	10.3^{a} ±3.7
EM	86.1^{a} ±8.2	10.0^{a} ±7.2	0.8^{a} ±0.1	5.8^{a} ±2.4	26.9^{a} ±5.4	60.3^{a} ±8.3	30.4^{a} ±9.0	11.3^{a} ±6.1
CC	87.0^{a} ±9.4	10.3^{a} ±3.0	1.0^{a} ±0.2	6.0^{a} ±2.8	25.9^{a} ±8.1	62.0^{a} ±9.5	30.1^{a} ±4.8	10.2^{a} ±4.1
CG	85.3^{a} ±9.1	12.3^{a} ±2.1	0.9^{a} ±0.1	5.6^{a} ±0.9	28.9^{a} ±4.9	60.4^{a} ±10.0	34.1^{a} ±6.9	10.2^{a} ±6.1
SB	83.2^{a} ±11.1	11.4^{a} ±4.1	1.2^{a} ±0.0	5.0^{a} ±1.6	32.1^{a} ±6.2	62.9^{a} ±10.0	35.8^{a} ±8.1	10.1^{a} ±2.2
CR/ES	87.1^{a} ±9.6	9.7^{a} ±3.0	1.7^{a} ±1.1	5.1^{a} ±2.2	30.1^{a} ±8.1	64.6^{a} ±9.7	36.7^{a} ±5.9	12.1^{a} ±3.1
CR/ES/EM	81.7^{a} ±11.0	14.2^{a} ±3.1	1.5^{a} ±1.0	4.9^{a} ±2.1	27.9^{a} ±7.2	63.7^{a} ±11.1	35.5^{a} ±9.2	12.1^{a} ±4.1
CR/ES/EM/CC	88.3^{a} ±9.6	11.3^{a} ±3.4	1.4^{a} ±0.4	5.1^{a} ±0.0	22.2^{a} ±8.0	66.8^{a} ±9.5	37.2^{a} ±9.9	11.9^{a} ±2.2
CR/ES/EM/CC/CG	89.3^{a} ±9.1	10.2^{a} ±5.1	1.4^{a} ±1.1	5.7^{a} ±1.1	20.3^{a} ±8.1	68.0^{a} ±12.1	38.1^{a} ±89.0	12.0^{a} ±4.2
WEEK 36								
C R	80.1^{a} ±10.1	10.2^{a} ±3.0	1.3^{a} ±0.3	5.3^{a} ±1.1	26.0^{a} ±5.1	71.3^{a} ±9.1	37.2^{a} ±8.2	11.2^{a} ±4.1
E S	85.2^{a} ±9.3	9.8^{a} ±3.1	0.9^{a} ±0.1	5.1^{a} ±0.7	26.7^{a} ±3.0	70.1^{a} ±11.1	38.9^{a} ±8.0	12.3^{a} ±3.0
EM	81.9^{a} ±10.1	10.0^{a} ±4.1	0.9^{a} ±0.3	5.0^{a} ±1.2	29.1^{a} ±5.4	69.9^{a} ±9.0	36.7^{a} ±11.1	11.2^{a} ±3.7
CC	79.1^{a} ±10.1	10.1^{a} ±2.2	1.0^{a} ±0.3	5.0^{a} ±2.0	30.0^{a} ±3.1	68.2^{a} ±7.3	37.1^{a} ±8.2	11.3^{a} ±4.1
CG	79.1^{a} ±7.1	10.2^{a} ±3.1	1.0^{a} ±1.0	4.9^{a} ±2.0	26.7^{a} ±3.3	68.7^{a} ±7.1	38.0^{a} ±8.0	11.3^{a} ±2.4
SB	83.4^{a} ±9.5	9.9^{a} ±1.3	1.0^{a} ±0.3	5.4^{a} ±1.3	29.0^{a} ±6.1	68.1^{a} ±6.4	39.7^{a} ±7.9	10.0^{a} ±2.1
CR/ES	79.0^{a} ±9.3	10.1^{a} ±2.8	1.6^{a} ±1.2	5.5^{a} ±1.2	30.0^{a} ±3.2	67.1^{a} ±7.3	39.0^{a} ±6.8	11.1^{a} ±4.8
CR/ES/EM	87.0^{a} ±11.1	11.0^{a} ±3.1	1.5^{a} ±0.1	5.3^{a} ±1.1	29.1^{a} ±5.1	67.9^{a} ±13.2	39.1^{a} ±7.2	11.1^{a} ±3.2
CR/ES/EM/CC	83.9^{a} ±9.6	10.4^{a} ±3.2	1.3^{a} ±0.2	5.5^{a} ±1.4	24.8^{a} ±5.1	69.3^{a} ±9.2	37.6^{a} ±8.1	12.0^{a} ±3.7
CR/ES/EM/CC/CG	85.7^{a} ±10.1	9.9^{a} ±2.1	1.0^{a} ±0.3	5.1^{a} ±2.1	34.0^{a} ±4.9	60.4^{a} ±9.6	38.1^{a} ±4.1	11.3^{a} ±2.4

Means within the same columns with different superscripts are significantly different at $p \leq 0.05$.
Key: CR=Chloris roxburghiana, ES= Eragrostis superba, EM= Enteropogon macrostachyus, CC= Cenchrus ciliaris, CG= Chloris gayana, SB= Sorghum sudanense

3.3 Dry matter degradability, growth stages and storage methods

Table 4 presents the percentage *in sacco* dry matter digestibility (ISDMD) of the six grasses and their mixtures at 8th, 10th and 12th weeks' phenological stages (Column 2). The ISDMD for the grasses and their mixtures harvested at 12th week phenological stage under outdoor and indoor storage periods of 12, 24 and 36 weeks post-harvest are presented in Column 3 and 4, respectively. There was a decline in percentage ISDMD for all the grass species and their mixtures with maturity ranging between 20-35% although was no significantly different ($p \geq 0.05$). Pure stand or mixed species did also not show any significant difference in ISDMD percentage content. There was a decrease in ISDMD percentage for outdoor and indoor storage, with the latter having insignificantly higher digestibility than the former.

Table 4 *In Sacco* dry matter digestibility of selected grass species grown individually and in mixtures at 8th, 10th and 12th phenological stage (Column 1), and outdoor and indoor post-harvest storage duration of 12, 24 and 36 weeks harvested at 12 week phenological stage (Column 2 and 3)

		% ISDMD	
		Outdoor storage	**Indoor storage**
	WEEK 8	**WEEK 12**	**WEEK 12**
C R	27.9^{a} ±3.5	23.8^{a} ±4.0	25.7^{a} ±4.1
E S	28.3^{a} ±5.2	25.3^{a} ±4.1	26.5^{a} ±3.0
EM	33.1^{a} ±4.6	23.1^{a} ±2.7	25.3^{a} ±4.0
CC	26.3^{a} ±5.1	24.4^{a} ±3.5	26.6^{a} ±2.8
CG	38.0^{a} ±4.2	28.1^{a} ±4.4	30.2^{a} ±4.5
SB	35.6^{a} ±3.3	25.5^{a} ±4.2	29.3^{a} ±4.2
CR/ES	32.1^{a} ±5.6	23.1^{a} ±3.1	26.6^{a} ±4.4
CR/ES/EM	34.6^{a} ±6.1	25.6^{a} ±3.5	27.5^{a} ±2.5
CR/ES/EM/CC	33.9^{a} ±4.1	23.9^{a} ±3.8	28.7^{a} ±4.1
CR/ES/EM/CC/CG	36.2^{a} ±5.3	27.2^{a} ±4.1	29.1^{a} ±3.7
	WEEK 10	**WEEK 24**	**WEEK 24**
C R	26.9^{a} ±5.1	21.9^{a} ±4.5	24.8^{a} ±2.4
E S	27.0^{a} ±4.3	22.0^{a} ±3.7	25.0^{a} ±3.1
EM	33.8^{a} ±6.1	23.2^{a} ±3.0	26.2^{a} ±2.3
CC	32.5^{a} ±5.2	22.4^{a} ±4.1	24.4^{a} ±4.2
CG	37.0^{a} ±4.1	26.2^{a} ±3.3	27.2^{a} ±2.5
SB	25.1^{a} ±3.0	25.1^{a} ±3.5	26.1^{a} ±5.1
CR/ES	32.0^{a} ±4.0	23.1^{a} ±2.9	27.1^{a} ±4.6
CR/ES/EM	28.1^{a} ±3.2	26.1^{a} ±4.1	29.1^{a} ±4.7
CR/ES/EM/CC	29.8^{a} ±4.1	21.7^{a} ±3.2	28.7^{a} ±4.1
CR/ES/EM/CC/CG	28.2^{a} ±5.1	24.1^{a} ±2.5	27.2^{a} ±3.4
	WEEK 12	**WEEK 36**	**WEEK 36**
C R	24.5^{a} ±4.1	21.3^{a} ±4.1	26.6^{a} ±3.4
E S	23.9^{a} ±3.5	20.7^{a} ±3.4	25.5^{a} ±2.8
EM	20.9^{a} ±2.7	21.2^{a} ±3.1	28.7^{a} ±3.7
CC	31.0^{a} ±3.8	20.1^{a} ±2.2	25.8^{a} ±3.0
CG	25.9^{a} ±5.1	20.5^{a} ±3.1	24.4^{a} ±4.1
SB	26.0^{a} ±4.1	26.1^{a} ±4.1	27.3^{a} ±4.1
CR/ES	23.1^{a} ±2.9	23.1^{a} ±2.7	30.5^{a} ±3.6
CR/ES/EM	24.9^{a} ±3.1	24.6^{a} ±3.1	29.8^{a} ±2.4
CR/ES/EM/CC	27.3^{a} ±4.1	22.3^{a} ±4.1	26.4^{a} ±3.1
CR/ES/EM/CC/CG	23.7^{a} ±3.4	23.8^{a} ±3.1	25.5^{a} ±3.1

Means within the same columns with different superscripts are significantly different at $p \leq 0.05$.
Key: CR=Chloris roxburghiana, ES= Eragrostis superba, EM= Enteropogon macrostachyus, CC= Cenchrus ciliaris, CG= Chloris gayana, SB= Sorghum sudanense.

4.0 Discussion

The observed lack of significant difference in CP content across the three curing periods could be attributed to the lower forage moisture content which did not enhance deterioration. The grasses depicted one day curing moisture content ranging between 14.5-18.5% at the time of storage; two day curing had 8.0-14.3% moisture and three day curing having 5.2-11.2% moisture level. The two and three days curing period had moisture levels below 15% which do not reduce hay quality (Rotz, & Muck, 1994; Coblentz *et al.*, 2000). During bailing, the temperatures were between 26-35^{o}C and this might have reduced hay moisture content for the species and hence the observed no significant difference in quality for the one day curing. The forage colour in the three days curing was brownish at bailing unlike the one and two day curing which remained greenish. This was attributed to excessive moisture loss through evaporation which was also observed to change forage colour by (Dunn & Billinglsley, 2007).

Collins *et al.* (1995; 1997) and Arinze *et al.* (1996) also observed baling at moisture level of greater than 15% to cause some change in hay colour towards brown shades along with microbial growth and heating. Change in colour despite not affecting quality, has a negative effect on palatability (Dunn & Billinglsley, 2007). The observed decline in CP with storage may be attributed to weathering, microbial and fungal activities that resulted to fermentation of soluble carbohydrates and hence decline in CP levels in the process. Elawad *et al.* (2003) observed similar findings where CP declined with storage periods for grasses.

The decline in DM for all the six species under this study could be attributed to the microbial activity that reduced the fermentable carbohydrates. This observation concurs with the findings of Wiselogel *et al.* (1996), who reported a decline in DM with storage periods. Sanderson *et al.* (1997) also reported losses of DM in *P. virgatum* by about 13% in dry weight during six months of outdoor storage. DM for sweet sorghum (*Sorghum bicolor* (L) stored as large round hay also reduced by 18·1% and 10·1% for outdoor and indoor storage, respectively (Coble & Egg, 1987). Outdoor storage condition could have exposed the forage materials to extreme weather conditions that enhanced microbial population resulting to accelerated decline in quality. Scarbrough *et al.* (2004) reported microbial activity to be the cause of DM loss in Bermuda grass and orchard grass. Collins *et al.* (2001) reported a 40% decline in DM under outdoor storage for a year, compared to only 10% for indoor storage. The heat generated during respiration for stored forages has also been reported to contribute in DM losses and forage quality degradation (Han *et al.*, 2004; Mayland *et al.*, 2005).

The losses in CP under outdoor and indoor storage in this study can be attributed to weathering, continued respiration of stored grasses, and microbial activity during storage (Rotz, 2003). Others studies attributed changes in CP content of mixed grass hay stored outside for five months to weathering (Verma & Nelson, 1983; Collins *et al.*, 1997). Enoh *et al.* (2005) attributed a decline in CP for Hyparrhenia species and cultivated *Brachiaria ruziziensis* under shade storage conditions to the same factors. The observed significant higher decline in CP under outdoor storage compared to indoor in this study suggests that outdoor storage conditions exposes forage to much degradation. This could be a result of direct exposure to weather elements, key one being humidity and direct wind. Collins *et al.* (2001) also demonstrated a decline in digestibility from 59% to 43% and CP from 16.4% to 13.5% working with rye grass under outdoor storage. Coblentz, *et al.* (2000)

studied Bermuda grass (*Cynodon dactylon* (L.) Pers) hay and noted that heating of forage during outdoor storage exposed it to reduction in CP which increased with storage duration.

The insignificant difference in ADL for both outdoor and indoor storage for all the grass species can be attributed to the structural nature of the components that does not easily weather or ferment due to microbial activity (Muck *et al.*, 2003). Collins *et al.* (2001) also reported low decline in ADL with storage duration. The observed lower rates of increase in CF, NDF and ADF for indoor storage in this study compared to outdoor could be attributed to the better storage conditions under indoor where forage was not exposed to extreme climatic conditions. Rotz & Muck (1994) also reported that environmental conditions influence the process of weathering and microbial fermentation, where humidity plays a major role. Increase in NDF for both outdoor and indoor stored may be a result of soluble carbohydrates fermentation (Borreani & Tabacco, 2006; Coblentz & Hoffman, 2009). Several studies have also reported microbial activity to consume soluble carbohydrates which increases weathering, resulting to increase in CF, NDF and ADF with the consequence of reduced digestibility (Turner *et al.*, 2002; Hancock & Collins, 2006).

Guerrero & Shenvood (1997) investigated the different hay storage in Sonoran desert under four storage treatments; hays stored in an air conditioned room, hays stored outdoors under a roof, hays stored outside protected by a plastic tarp and hays stored outside in full sunlight. Their findings indicated that hay stored outdoors with a tarp, prevents it from quality decline by virtue of protection from rainfall damage hence reduced bleaching and excessive moisture loss and concluded that protected storage reduces hay degradation. These finding explain the observed lower decline in quality of forage under indoor storage in this study.

Grass forage production in pastoral areas is unpredictable with increasing climatic variability resulting in periods of surpluses and deficits. This is a common phenomenon in semi-arid rangelands that greatly affect animals’ nutritional status. Most of the pastoral communities’ practises pasture harvesting and outdoor storage on top of trees or outside their huts especially in agro-pastoral communities of Kenya (Ndathi *et al.*, 2011). This has a consequence on forage quality as influenced by storage conditions (Coblentz *et al.,* 1996). Outdoor storage of animal feed exposes it to environmental factors like light, wind, moisture and highly variable temperature condition that enhance faster deterioration (Buxton & Fales, 1994). Change in forage quality takes place from the time of harvest to the period of ingestion by animals (Wiselogel *et al.*, 1996; Collins *et al.*, 2001). With the increasing climatic variability, there is great need for pasture preservation and storage as an adaptive measure to climate change and variability by pastoralists (Thornton *et al.*, 2007; Ben Salem & Smith, 2008).

The decline in ISDMD in this study with increase in phenological stages could be due to increase in cell wall contents with grass species maturity. The decline in CP with grass storage could also explain the observed decline in digestibility where grasses with low CP content have low percentage DMD (McDonald, 1996; Jackson *et al.*, 2007). Forage digestibility/degradability is determined by CP content and influences the rate of ingest passage in ruminants, which impacts on the dietary nourishment (Nousiainen *et al.*, 2003; De Klein *et al.*, 2006*)*. The observed increase in CF, NDF, and ADF also explain the declining digestibility with storage duration. The increase in these components increases forage structural carbohydrates that are not easily degradable (Bell, 2006; De Klein *et al.*, 2006; Jackson *et al.*, 2007).

The higher rates of decline in ISDMD under outdoor stored forage could be attributed to the exposure to extreme climatic conditions, which perhaps enhanced microbial activity compared to indoor storage (Rotz & Muck. 1994; Guerrero *et al.*, 2005). Pasture storage exposes it to microbial and fungal respiration that reduces DM, soluble carbohydrates and CP content which in turn reduces digestibility (Bell *et al.*, 2008). Collins *et al.* (1997) also reported that deterioration of hay stored under outdoor conditions is high due to weathering from the exposure to rainfall, sunlight, wind and moisture changes which affect forage quality and reduce degradability. A similar observation was reported by Collins *et al*. (1995) while working on hay preservation duration effects on quality, that respiration, weathering and leaching were responsible for forage quality losses. Shah *et al.* (2011) also observed a decline in dry matter and an increase in cellulose by 4 % under outdoor storage of corn stover bales, while indoor storage had lower decline in DM and slight increase in cellulose compared to outdoor storage. These components reduce forage degradability.

5. Conclusion

This study demonstrated that outdoor storage reduces CP and consequently the digestibility of hay more than indoor storage for all the six grass species and their mixtures. Curing had no effects on forage CP; however, it had effects on forage colour when done on day three after harvest, where forage turned to brown which may affect palatability. Therefore, this study has shown that indoor storage preserves forage quality better than outdoor and deterioration increases with storage duration, where 12 weeks indoor storage maintains CP above 6% which is the recommended minimum content for livestock maintenance. Finally, hay curing for one or two days preserves the green colour which is associated with higher palatability.

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References

AOAC, (2005). Official Methods of Analysis of the Association of Analytical Chemists. 18th Edn. AOAC, Gathersburg, MD. USA.

AOAC. 1990. Official methods of analysis. 15th ed. Association of Official Analytical Chemists, Arlington, VA.

Arinze, E. A., Sokhansanj, S., Schoenau, G. J., & Trauttmansdorff, F. G. (1996). Experimental evaluation, simulation and optimization of a commercial heated-air batch hay drier: Part 1, drier functional performance, product quality, and economic analysis of drying. *Journal of Agricultural Engineering Research*, *63*(4), 301-314.

Bell A. (2006) Pasture assessment and livestock production. *Primefact 323. (NSW Department of Primary Industries: Orange)*

Bell, L. W., Robertson, M. J., Revell, D. K., Lilley, J. M., & Moore, A. D. (2008). Approaches for assessing some attributes of feed-base systems in mixed farming enterprises. *Animal Production Science*, *48*(7), 789-798.

Ben Salem, H., & Smith, T. (2008). Feeding strategies to increase small ruminant production in dry environments. *Small Ruminant Research*, *77*(2), 174-194.

Bernués, A., Ruiz, R., Olaizola, A., Villalba, D., & Casasús, I. (2011). Sustainability of pasture-based livestock farming systems in the European Mediterranean context: Synergies and trade-offs. *Livestock Science*, 139(1), 44-57.

Borreani, G., & Tabacco, E. (2006). The effect of a baler chopping system on fermentation and losses of wrapped big bales of alfalfa. *Agronomy Journal*, *98*(1), 1-7.

Buskirk D. D., Zanella A. J., Harrigan T. M., Van Lente J. L., Gnagey L. M. & Kaerche M. J. (2003). Large round bale feeder design affects hay utilization and beef cow behaviour. *Journal of Animal Science* 2003, 81:109-115. http://jas.fass.org/content/81/1/109. Accesses 17th March, 2014.

Buxton, D. R. & Fales S. L., (1994). Plant environment and quality. In: G. C. Fahey, Jr.

Coble, C. G., & Egg, R. (1987). Dry matter losses during hay production and storage of sweet sorghum used for methane production. *Biomass*, *14*(3), 209-217.

Coblentz, W. K., & Hoffman, P. C. (2009). Effects of bale moisture and bale diameter on spontaneous heating, dry matter recovery, in vitro true digestibility, and in situ disappearance kinetics of alfalfa-orchardgrass hays. *Journal of dairy science*, *92*(6), 2853-2874.

Coblentz, W. K., Fritz, J. O., Bolsen, K. K., & Cochran, R. C. (1996). Quality changes in alfalfa hay during storage in bales. *Journal of dairy science*, *79*(5), 873-885.

Coblentz, W. K., Turner, J. E., Scarbrough, D. A., Lesmeister, K. E., Johnson, Z. B., Kellogg, D. W., & Weyers, J. S. (2000). Storage characteristics and nutritive value changes in bermudagrass hay as affected by moisture content and density of rectangular bales. *Crop science*, *40*(5), 1375-1383.

Collins, M., Ditsch, D., Henning, J. C., Turner, L. W., Isaacs, S., & Lacefield, G. D. (1997). Round bale hay storage in Kentucky. *Univ. of Kentucky, Coop. Ext. Publ., Leaflet AGR-171*.

Collins, M., Lacefield, G. D., Martin, N. P., Mertens, D. A., Olson, K. E., Putnam, D. H., & Wolf, M. W. (2001). *Understanding forage quality*. Park Ridge, IL: American Farm Bureau Federation. http://forages.oregonstate.edu/resources/publications/foragequality.pdf. Accesses 27th March, 2014.

Collins, M., Swetnam, L. D., Turner, G. M., Hancock, J. N., & Shearer, S. A. (1995). Storage method effects on dry matter and quality losses of tall fescue round bales. *Journal of production agriculture*, *8*(4), 507-514.

De Klein, C. A. M., Smith, L. C., & Monaghan, R. M. (2006). Restricted autumn grazing to reduce nitrous oxide emissions from dairy pastures in Southland, New Zealand. *Agriculture, ecosystems & environment*, *112*(2), 192-199.

Dunn, M. T., & Billingsley, J. (2007, December). The use of machine vision for assessment of fodder quality. In Mechatronics and Machine Vision in Practice, 2007. M2VIP 2007. 14th International Conference on (pp. 179-184). IEEE

Elawad, S., Kumagai, H., & Mitani, K. (2003). Measurement and estimation of changes in nutrient composition and nutrient losses during hay and silage making in field curing. *Grassland Science*, *49*(2), 117-124.

Enoh, M. B., Kijora, C., Peters, K. J., Tanya, V. N., Fonkem, D., & Mbanya, J. (2005). Investigation on change of forage quality at harvesting, during hay making and storage of hay harvested at different growth stages in the Adamawa plateau of Cameroon. *Livestock Research for Rural Development*, *17*(5), 1-6.

Guerrero, J. N., & Shenvood, W. S. (1997). Summertime storage of alfalfa hay in the irrigated Sonoran Desert affects hay quality. *Journal of production agriculture*, *10*(3), 495-501.

Guerrero, J. N., M. I. Lopez, and M. Cervantes. 2005. Covering hay in the irrigated Sonoran Desertdecreases heat damage. *California Agriculture journal*. 59(4):252-255.

Han, K. J., Collins, M., Vanzant, E. S., & Dougherty, C. T. (2004). Bale density and moisture effects on alfalfa round bale silage. *Crop science*, *44*(3), 914-919.

Hancock, D. W., & Collins, M. (2006). Forage preservation method influences alfalfa nutritive value and feeding characteristics. *Crop science*, *46*(2), 688-694.

Jackson, R. D., Bell, M. M., & Gratton, C. (2007). Assessing ecosystem variance at different scales to generalize about pasture management in southern Wisconsin. *Agriculture, ecosystems & environment*, *122*(4), 471-478.

Mackie, P. G. (2004). *U.S. Patent No. 6,711,996*. Washington, DC: U.S. Patent and Trademark Office. **http://tinyurl.com/n7mef3e.** Accessed on 10th Jan 2014

Mayland, H., Mertens, D., Taylor, T., Burns, J., Fisher, D., Gregorini, P., & Griggs, T. (2005). Diurnal changes in forage quality and their effects on animal preference, intake, and performance. In *California Alfalfa and Forage Symp., 35th, Visalia, CA* (pp. 12-14).

McDonald, W. (1996). Matching pasture production to livestock enterprises in the Northern Tablelands and North West Slopes and Upper Hunter. *Agnote DPI/139. NSW Agriculture, Orange*.

Muck, R. E., Moser, L. E., & Pitt, R. E. (2003). Postharvest factors affecting ensiling. *Silage science and technology*, (silagesciencean), 251-304.

Ndathi, A. J., Nyangito, M. M., Musimba, N. K., & Mitaru, B. N. (2011). Climate variability and dry season ruminant livestock feeding strategies in Southeastern Kenya.

Nousiainen, J., Rinne, M., Hellämäki, M., & Huhtanen, P. (2003). Prediction of the digestibility of the primary growth of grass silages harvested at different stages of maturity from chemical composition and pepsin-cellulase solubility. *Animal Feed Science and Technology*, *103*(1), 97-111.

Osuji P., Nsahlai, I. V., & Khalili H. (1993). Feed evaluation. ILCA Manual 5. ILCA (International Livestock Centre for Africa), Addis Ababa, Ethiopia. 40 pp.

Rankin, M., & Undersander, D. (2004). Rain damage to forage during hay and silage making. *http://www. cce. cornell. edu/scnyag/dairy/newsletter.* Accessed on 12th June 2013.

Roberts, C. A. (1995). Microbiology of stored forages. Page 21 In Post-Harvest Physiology and Preservation of Forages. CSSA Special Publication No. 22. K. J. Moore and M. A. Peterson, ed. Am. Soc. Agron., Crop Sci. Soc. Am., and Soil Sci. Soc. Am., Madison WI

Roberts, C. A., Kallenbach, R. L., Hill, N. S., Rottinghaus, G. E., & Evans, T. J. (2009). Ergot alkaloid concentrations in tall fescue hay during production and storage. *Crop Science*, *49*(4), 1496-1502.

Rotz, C. A. (2003). How to maintain forage quality during harvest and storage. *Advances in Dairy Tecnology*, *15*, 227-239.

Rotz, C. A., & R. E. Muck. (1994). Changes in forage quality during harvest and storage. Pages 828-868 in Forage Quality, Evaluation, and Utilization. 13-15 April 1994, Nat. Conf. on Forage Quality, Evaluation, and Utilization, G. C. Fahey, M. Collins, D. R. Mertens, and L. E. Moser, eds. Univ. Nebraska, Lincoln. ASA-CSSASSSA, Madison, WI.

Sanderson, M. A., Egg, R. P., & Wiselogel, A. E. (1997). Biomass losses during harvest and storage of switchgrass. *Biomass and Bioenergy*, *12*(2), 107-114.

Scarbrough, D. A., Coblentz, W. K., Humphry, J. B., Coffey, K. P., Sauer, T. J., Jennings, J. A., & Kellogg, D. W. (2004). Estimating losses of dry matter from simulated rainfall on bermudagrass and orchardgrass forages using cell wall components as markers. *Agronomy journal*, *96*(6), 1680-1687.

Shah, A., Darr, M. J., Webster, K., & Hoffman, C. (2011). Outdoor storage characteristics of single-pass large square corn stover bales in Iowa. *Energies*, *4*(10), 1687-1695.

Tangni, E. K., Pussemier, L., & Van Hove, F. (2013). Mycotoxin contaminating maize and grass silages for dairy cattle feeding: Current state and challenges. *Journal of Animal Science. Adv*, 3(10), 492-511.

Thornton, P. K., Herrero, M., Freeman, H. A., Mwai, A. O., Rege, E., Jones, P. G., & McDermott, J. (2007). Vulnerability, climate change and livestock–opportunities and challenges for the poor.

Turner, J. E., Coblentz, W. K., Scarbrough, D. A., Coffey, K. P., Kellogg, D. W., McBeth, L. J., & Rhein, R. T. (2002). Changes in nutritive value of bermudagrass hay during storage. *Agronomy Journal*, *94*(1), 109-117.

Van Soest, P.J., Robertson, J.B., & Lewis, B.A. (1991) Methods for dietary fiber, neutral detergent fiber, and non starch polysaccharides in relation to animal nutrition. *Journal of Dairy Science* 74, 3583 – 3597.

Verma, L. R., & Nelson, B. D. (1983). Changes in round bales during storage [Ryegrass, alfalfa, losses; Louisiana]. Transactions of the ASAE. *American Society of Agricultural Engineers]*, *26*.

Wilcke, B., Cuomo G., & Fox C. (1999). Preserving the Value of Dry Stored Hay. Univ. of Minnesota Coop. Ext. Serv. Pub. FO-07404-GO. WI. pp. 828-868.

Wiselogel, A. E., Agblevor, F. A., Johnson, D. K., Deutch, S., Fennell, J. A., & Sanderson, M. A. (1996). Compositional changes during storage of large round switchgrass bales. *Bioresource technology*, *56*(1), 103-109.

CHAPTER SEVEN

Water Use Efficiency of Six Rangeland Grasses under Varied Soil Moisture Content Levels in the Arid Tana River County, Kenya

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Abstract: This study evaluated water use efficiency of six range grasses grown at 80, 50, 30% FC and rain-fed soil moisture treatment levels. The changes in soil moisture content were measured by Gypsum Block which aided in determining the irrigation schedules. WUE was calculated on the basis of amount of biomass yields in relation to evapotranspired moisture during growth periods. The grasses demonstrated varied levels of WUE. The three soil moisture content treatments had higher WUE than rainfed conditions. There was a declining trend in WUE with maturity in all the species, where *S. sudanense* exhibited the higher WUE on 8, 10 and 12th weeks (> 15) across all the treatments, followed by *C. gayana* and *E. macrostachyus* than *E. superba, C. ciliaris* and *C. roxbhurghiana* which had a less than 10 index . The 30% FC soil moisture content had higher WUE (>20) in all the phenological stages for *S. sudanense, C. gayana* and *E. macrostachyus* than 80, 50% FC and rainfed. These three species are the best choices in pasture production under irrigation in semi-arid lands where water supply is limited and irregular.

Keywords: Water Use Efficiency (WUE); Water Stress Tolerance; Range Grasses; Pasture Irrigation; Water Deficit; Kenya

1. Introduction

Water-use efficiency (WUE) is an important consideration of plant productivity under water-deficient environments (Blum, 2009). Under rainfed condition, WUE refers to rain water that is directly used by the plant during growth with higher value resulting in “more yield per drop” of rain water. Conversely, WUE under irrigation systems refer to plant productivity per amount of irrigation water supplied (Pereira *et al.,* 2002). WUE is computed in two ways. One is the consideration of the amount of plant yields per unit volume of water used over given land area. The second one considers the amount of plant yields per unit of water that goes through evapotranspiration during growth (Caviglia *et al.,* 2001). The latter has a better representation of WUE in terms of accounting for the exact water used by the plant during photosynthesis and transpiration and was therefore, used in this study.

The increasing scarcity of water resource in the semi-arid rangelands is further constrained by increasing human and livestock population which calls for plants with higher WUE (Rosegrant & Cline, 2002; Falkenmark, 2007). Practicing irrigation in drylands requires sustainable use of the little available water if productivity is to be increased or maintained (Pereira *et al.*, 2002; Yang et al., 2006). This creates the need for research on how to maximize on WUE of the various plants species grown. Water constraint in semi-arid rangelands is exacerbated by climate variability and change, threatening the livelihoods of communities living in these areas. Despite these constraints, adaptation of production systems to efficiently utilize the little available water for irrigation is important and must be encouraged (Falkenmark, 2007).

Livestock production is the major land use activity in the semi-arid rangelands while the industry faces many challenges in supplying adequate forage due to the prevailing water deficit that reduces reliable feed supply for the livestock. There exist three options for efficient utilization of available water to increase productivity in these areas. (i) Increasing water productivity by reducing losses, (ii) improving the use of rainfall and expanding rainfed agriculture, and (iii) pursuing other water sources for pasture and crop production (Allan, 1997; WWC, 2004; Hoekstra & Hung, 2005; Falkenmark, 2007). These options may contribute to improved WUE, reduced water losses and increase productivity of pastures and crops in the semi-arid rangelands. Innovative technologies such as cultivation of drought tolerant grass species with higher WUE and soil moisture retention to increase crop productivity are other promising interventions in the semi-arid rangelands (Allan, 1997).

The challenge facing many farm managers is determining how much water to apply during irrigation for optimum productivity of pastures, more so, when its supply is limited (Orloff *et al.*, 2003). The other challenge is applying water that does not raise the water table which causes secondary salinization of soil surface (Kitamura, *et al.*, 2006). Proper irrigation is a critical decision if productivity is to be improved and maintained, and at the same time conserves water and soil nutrients (Celano *et al.*, 2011). Lack of adequate moisture for pasture growth affects both the yields and quality forage. However, determining when to irrigate and how much water to apply to attain highest WUE is not a simple task, but if properly done there is high potential to drastically improve on productivity (Kang'au *et al.*, 2011).

The decision of when to irrigate is usually based on previous experiences, use of weather based information such as evapotranspiration or soil moisture measurements (Centeno *et al.*, 2010;

Naik *et al.,* 2012). The use of past experiences for moisture management is not applicable in rangelands due to unpredictable weather changes over the recent past. This becomes even more difficult under established pastures where multiple harvests in a year or season is realized and hence this makes irrigation planning difficult compared to one season cropping systems. Timing of irrigation in pastures is critical and it cannot be done close to harvest period or during curing (Playan & Mateos, 2006). The use of weather based information in irrigated pastures has further challenges of accuracy and reliable evapotranspiration data for the extensive fields with wide spatial-temporal variability (Playan & Mateos, 2006). Because of these difficulties and shortcomings, the commonly used and preferred irrigation scheduling techniques are soil based (Beetz & Rinehart, 2006) that involves use of tension meters and gypsum blocks to monitor field soil moisture changes (Wood & Finger, 2006). Such techniques help in determining appropriate time for irrigation and amount of water to apply to attain higher WUE (Wood & Finger, 2006). The simplicity of electrical resistance blocks provides a cost-effective technique for improving irrigation management for growers (Gómez-del-Campo, 2013). This was therefore selected for ease of measuring soil moisture changes for effective recharge at desired levels of 80, 50 and 30% FC soil moisture content.

The need for proper pasture management and choice of species to give higher WUE and ensure reliable supply of good quantity and quality forage in the face of climate change and variability is critical. This study evaluated the WUE of *Chloris roxburghiana* – (CR), *Eragrostis superb* –(ES*), Enteropogon macrostachyus* –(EM), *Cenchrus ciliaris* –(CC), *Chloris gayana* –(CG) and *Sorghum sudanense* –(SB) at different growth stages under varied soil moisture contents to determine which species performs better at lower moisture levels for potential selection in pasture production water deficit environments. This six species were chosen being the dominant species in the arid and semi arid environments of Kenya and were also found to be the available in the natural grazing fields in the study area, indicating their adaptability to the drier conditions. The same species are also being recommended and promoted for pasture establishment in the Kenyan arid environments.

2. Materials and Methods

The experimental design and layout are described in chapter two.

2.1 Data Collection

Data collection was done during the growing season between sowing and 16 weeks maturity.

2.1.1 Determination of water use efficiency

Water use efficiency was estimated by water productivity (WP) approach which is an efficiency term, expressing the amount of marketable product (e.g. kilograms of grain/ grass biomass etc) in relation to the amount of input needed to produce that output (cubic meters of water). Soil Water balance of the root zone was used to estimate the evapotranspiration (ET). This was based on the changes in soil moisture content (ΔS) of the crop root zone, which is equal to the difference between the amount of water added to the root zone (Qi) and that withdrawn from it (Qo) in a given time interval (Hillel, 1998; Kendy *et al.*, 2003) as expressed in Equation (1).

$$\Delta S = Qi - Qo \qquad (1)$$

Equation (1) was used to determine (ET) of grass species as follows;

$$ET = P + I + U - R - D - \Delta S \qquad (2)$$

where, ΔS = change in root zone soil moisture storage, P = Rainfall, I = Irrigation, U = capillary rise into the root zone, R = Runoff, D = Deep percolation beyond the root zone, ET = Evapotranspiration (Evaporation + Transpiration). All quantities were expressed as volume of water per unit land area (length units).

In order to use Eqn. (2) to determine ET in this study, the parameters measured were amount of water added to the field by rain and irrigation. In the study area, the gradient was flatish (<5%) and runoff was negligible, The water table is deep (Maingi, & Marsh, 2002) hence capillary rise 'U' was deemed negligible. There was no deep percolation in this study since irrigation was below the field capacity. Therefore, Eqn. (2) was rewritten for the purpose of this study to give Eqn 3;

$$ET = P + I - \Delta S \qquad (3)$$

The change in soil water storage (ΔS) was measured using calibrated GBs readings to give volumetric water change. The estimated WUE was computed as the dry matter yield per unit of water evapotranspired by the grass following Eqn. (4).

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$$WUE\left(kg\,DM\ ha^{-1}\,mm^{-1}\right) = \frac{Yield\left(kg\ DM\ ha^{-1}\right)}{ET_{grass}\,(mm)} \qquad (4)$$

Where, WUE is water use efficiency in (kg DM ha-1 mm-1), ETgrass is amount of evapotranspiration by each grasses (mm) species. The values for rainfall, irrigation, soil moisture changes and evapotranspiration used in the calculations are presented in Appendix 8.

2.1.1 Rainfall data

Monthly rainfall data for Tana River County was sourced from the Kenya National Drought Management Authority (KNDMA) for the year 2004 to 2013 to help in understanding the county's rainfall distribution pattern, and rainfall distribution over the 2012-2013 experimental periods. Daily rainfall data was also collected within the National Irrigation Board research site located 200m from the experimental site which was later used to calculate water supplied by rainfall to the grasses presented as (P) in Eqn (2) and (3). The amount of water supplied to the grasses during the experimental period is presented in Appendix 8. While the rainfall distribution patterns during the season is presented in Appendix 7.

2.2 Data analysis

Data collected was subjected to 2 ways Analysis of Variance (ANOVA) using SAS Version 9 to determine the significance of the treatment effects of varied soil moisture content on productivity and WUE of the different grass species. Where significant difference was detected, the means were separated by Least Significant Difference (LSD) at 5% probability level.

3 Results

3. 1. Water use efficiency (WUE)

Table 1 presents the biomass yields used to calculate the Water Use Efficiency (WUE) of the selected grasses at different phenological stages under varying soil moisture content. Rainfed treatment had significantly lower WUE compared to the three soil moisture content. There was a declining trend in WUE with grass species at maturity where SB had higher WUE at 8, 10 and 12th weeks (> 15) in all the treatments followed by *CG* and EM and were significantly ($p<0.05$) different from ES, CC and CR that had WUE less than10 index among the six grass species. The 30% FC soil moisture content had higher WUE at all the phenological stages for SB, CG, CC and EM compared to 80, 50% FC and rainfed with all having WUE index greater than 20.

Table 1. Biomass yields (kg/ha^{-1}) and Water Use Efficiency (WUE) in (KgDMha^{-1} mm^{-1}) of six range grass species grown at 80, 50 and 30% FC soil moisture content and rainfed

	80% FC		**50% FC**		**30% FC**		**Rainfed**	
Week 8	**Biomass**	**WUE**	**Biomass**	**WUE**	**Biomass**	**WUE**	**Biomass**	**WUE**
C R	2000.4	7.3^{a}	3264.2	14.7^{b}	1264.3	7.6^{a}	164.5	7.8^{a}
E S	1668.6	6.1^{a}	1164.3	5.2^{a}	1132.4	6.8^{a}	132.3	6.2^{a}
EM	3664.2	13.4^{b}	5400.5	24.3^{c}	4332.9	25.9^{c}	332.7	15.7^{a}
CC	2200.5	8.0^{a}	5064.1	22.8^{c}	4264.5	25.5^{c}	264.3	12.5^{b}
CG	8400.6	30.6^{c}	3932.1	17.7^{b}	6400.2	38.3^{d}	240.5	11.3^{b}
SB	7800.6	28.4^{c}	5200.3	23.4^{c}	5800.6	34.7^{d}	410.7	19.4^{b}
Week 10								
C R	3120.4	6.3^{a}	1544.4	3.8^{a}	2264.1	9.6^{a}	264.4	1.8^{a}
E S	1532.1	3.1^{a}	932.2	2.3^{a}	1732.5	7.3^{a}	332.6	2.3^{a}
EM	3532.3	7.1^{a}	5464.1	13.6^{b}	4732.1	20.0^{c}	432.5	3.0^{a}
CC	2532.5	5.1^{a}	3732.2	9.3^{a}	5664.1	24.0^{c}	464.8	3.2^{a}
CG	4532.2	9.1^{a}	7732.5	19.2^{b}	6600.5	27.9^{d}	305.1	2.1^{a}
SB	10064.5	20.2^{c}	7732.6	19.2^{b}	7400.6	31.3^{d}	540.4	3.7^{a}
Week 12								
C R	3600.4	6.6^{a}	2532.3	5.7^{a}	2732.3	9.5^{a}	732.5	3.2^{a}
E S	3468.3	6.4^{a}	1800.5	4.1^{a}	3264.1	11.3^{b}	364.1	3.1^{a}
EM	6600.6	12.1^{b}	7400.7	16.7^{b}	5400.1	18.7^{b}	500.3	4.2^{a}
CC	4064.6	7.4^{a}	6532.9	14.7^{b}	5932.4	20.5^{c}	532.5	4.5^{a}
CG	7932.2	14.5^{b}	9400.6	21.2^{c}	9000.7	31.1^{d}	707.5	5.9^{a}
SB	9464.4	17.3^{b}	9200.5	20.8^{c}	7264.8	25.1^{d}	764.6	6.4^{a}
Week 14								
C R	2400.2	3.4^{a}	1800.5	2.8^{a}	3264.5	14.3^{b}	764.2	4.4^{a}
E S	4332.5	6.1^{a}	1200.6	1.8^{a}	3600.7	15.8^{b}	381	2.2^{a}
EM	5132.9	7.2^{a}	9000.8	13.8^{b}	6400.9	28.1^{d}	604.3	4.4^{a}
CC	2532.4	3.6^{a}	8400.2	12.9^{b}	5332.1	23.4^{c}	558.2	3.2^{a}
CG	9000.3	12.7^{b}	9532.1	14.6^{b}	9400.5	31.3^{d}	767	4.4^{a}
SB	12664.7	17.9^{b}	6864.2	10.5^{b}	7124.3	31.3^{d}	824.9	4.7^{a}
Week 16								
C R	3320.6	3.6^{a}	2532.3	2.9^{a}	2132.6	4.4^{a}	759.8	3.1^{a}
E S	5600.3	6.1^{a}	1532.2	1.8^{a}	3132.7	6.4^{a}	372.3	2.0^{a}
EM	6464.5	7.0^{a}	10464.4	12.1^{a}	6664.8	13.6^{b}	664.8	3.6^{a}
CC	2464.8	2.7^{a}	9132.6	10.6^{b}	6864.8	14.0^{b}	664.5	3.6^{a}
CG	10864.1	11.8^{b}	10200.1	11.8^{b}	10132.1	20.7^{c}	832.7	4.5^{a}
SB	13664.2	14.8^{b}	11600	13.5^{b}	7664.5	15.7^{b}	964.8	5.2^{a}

Means within the same columns with different superscripts are significantly different at ($p<0.05$).

Key: CR=*Chloris roxburghiana*, ES= *Eragrostis superba*, EM= *Enteropogon macrostachyus*, CC= *Cenchrus ciliaris*, CG= *Chloris gayana*, SB= *Sorghum sudanense*

4 Discussion

These results demonstrated that grasses have varied WUE which is influenced by water availability, stage of maturity and the unique genetic make-up of the species. The superior WUE exhibited by SB, CG and EM, is a positive indication that these species are potentially more productive even under limited soil moisture levels and more suitable for pasture production in drylands. The extremely low WUE in all the species under rainfed treatment, compare to the watered treatments amplifies the role of water in productivity of grass plants. It accounts for nearly 100% of the forage shortage in these areas. The water stress affects plant growth and development as a result of reduced transpiration (Munns, 2002). Guenni *et al.* (2002) evaluated responses of five species of *Bracharia* to droughts and observed that water stress affects root: shoot ratio in many tropical grasses resulting in high reduction in overall WUE. Photosynthesis and other plant physiological processes are very sensitive to limited water supply, in addition to other factors. Knowledge of the absolute WUE of grasses is important for making efficient irrigation schedules necessary for the use of scarce water resource (Blum, 2005; Khan *et al.,* 2008). The information is also necessary in making choices of the most appropriate grasses. In this study SB and CG out-performed the other species in terms of WUE. Eneji *et al.* (2008) noted that SB was least affected by water deficit which they attributed to large average root masses and which gave it a competitive advantage over the other species. A study by Snyman (1994) assessed the WUE of *Anthephora pubescens, Cenchrus ciliaris, Chloris gayana, Digitaria eriantha, Eragrostis curvula* and *Panicum maximum* species in the semi-arid rangelands of South Africa over a period of three years. He reported that *CG* was more productive in terms of above ground biomass than the other five species in both wet and drier conditions. His findings revealed higher WUE (7.2 kg DM ha^{-1} mm^{-1}) in CC than the five grass species. In another study (Snyman,1994) CG still had higher yields and WUE than *CC* at all treatments.

The observed superior WUE in SB and EM under limited soil moisture content can be accounted for in part by fast germination rates coupled with deeper and extensive rooting systems which, in turn, boost their ability to effectively use the available water (Craine *et al.,* 2012).   Craine *et al.* (2012) also reported that out of the 11000 grass species in the world, 426 of them are well distributed both climatically and phylogenetically with high diversity to drought tolerance. Thus the grassland ecosystems throughout the world have the potential of being more resilient to drought in the face of climate change. .

5 Conclusion

This study provides insights into the WUE of the six grasses under varying soil moisture content profiles. The results show that grass species have different capacities to utilize water (WUE). The findings demonstrate that range grasses have potential for high productivity under low moisture supply. SB, CG and EM with the highest WUE at the lower soil moisture profiles would be the most suitable species for pasture production and rangeland rehabilitation. Other factors which are known to affect WUE such as species ecotypes require evaluation. This study was only carried out for one year and in one site and therefore its inference is limited in time and space. There is also need for long term monitoring of WUE for the same species.

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References

Allan J A. 1997. Virtual water: a long term solution for water short Middle Eastern economies? In: Paper Presented at the 1997 British Association Festival of Science, Water and Development Session. September 9th, 1997. Water Issues Group, School of Oriental and African Studies (SOAS), University of London.

Beetz A, Rinehart L. 2006. Pastures: sustainable management. *Pastures: sustainable management*. http://snohomishcd.org/links-and-resources/sustainable%20pastures.pdf, Accessed 2nd April 2013.

Bhattarai P, Fox J, Gyasi-Agyei Y. 2008. Enhancing buffel grass seed germination by acid treatment for rapid vegetation establishment on railway batters. *Journal of Arid Environments*, *72*(3), 255-262.

Blum A. 2005. Drought resistance, water-use efficiency, and yield potential—are they compatible, dissonant, or mutually exclusive?. *Crop and Pasture Science*, *56*(11), 1159-1168.

Blum A. 2009. Effective use of water (EUW) and not water-use efficiency (WUE) is the target of crop yield improvement under drought stress. *Field Crops Research*, *112*(2), 119-123.

Campbell I, Dalrymple S, Craig R, et al. 2010. Climate change and conflict: lessons from community conservancies in northern Kenya.

Caviglia O. P, Sadras V O. 2001. Effect of nitrogen supply on crop conductance, water-and radiation-use efficiency of wheat. *Field Crops Research*, *69* (3), 259-266.

Celano G, Palese A , Ciucci A, et al. 2011. Evaluation of soil water content in tilled and cover-cropped olive orchards by the geoelectrical technique. *Geoderma*, *163*(3), 163-170.

Centeno A, Baeza P, Lissarrague J R. 2010. Relationship between soil and plant water status in wine grapes under various water deficit regimes. *HortTechnology*, *20*(3), 585-593.

Craine J M, Ocheltree T W, Nippert J B et al. 2012. Global diversity of drought tolerance and grassland climate-change resilience. *Nature Climate Change*, *3*(1), 63-67.

Eneji A E, Inanaga S, Muranaka S, et al. 2008. Growth and nutrient use in four grasses under drought stress as mediated by silicon fertilizers. *Journal of Plant Nutrition*, *31*(2), 355-365.

Falkenmark M. 2007. Shift in thinking to address the 21st Century hunger gap, moving focus from blue to green water management. Water Resource Management, 21(1): 3–18.

Gómez-del-Campo M. 2013. Summer deficit-irrigation strategies in a hedgerow olive orchard cv.'Arbequina': effect on fruit characteristics and yield. *Irrigation Science, 31*(3), 259-269.

Guenni O, Marín D, Baruch Z. 2002. Responses to drought of five Brachiaria species. I. Biomass production, leaf growth, root distribution, water use and forage quality. *Plant and soil, 243*(2), 229-241.

Hillel D. 1998. Environmental soil physics. Academic press. 771 pp. Elsevier (USA).

Hoekstra A Y, Hung P Q. 2005. Globalization of water resources: international water flows in relation to crop trade. *Global Environmental Change*, 15(1): 45–56.

ISTA. (1976). International rules for seed testing. *Seed Science and Technology* 4(2)3-28.

Kang'au S N, Home P G, Gathenya J M. 2011. Farm water use efficiency assessment for smallholder pumped irrigation systems in the arid and semi-arid areas of Kenya. *Agricultural Engineering International*: *CIGR Journal*. 13 (4).

Kendy E, Gérard-Marchant P, Todd Walter M, et al. 2003. A soil-water-balance approach to quantify groundwater recharge from irrigated cropland in the North China Plain. *Hydrological Processes, 17*(10), 2011-2031.

Khan I A, Ayub N, Mirza S N, et al. 2008. Yield and water use efficiency (WUE) of *Cenchrus ciliaris* as influenced by vesicular *arbuscular mycorrhizae* (VAM). *Pakistan Journal of Botany, 40,* 931-937.

Kitamura Y, Yano T, Honna T, et al. 2006. Causes of farmland salinization and remedial measures in the Aral Sea basin—Research on water management to prevent secondary salinization in rice-based cropping system in arid land. *Agricultural Water Management, 85*(1), 1-14.

Koech O K., Kinuthia R N, Mureithi S M, et al. 2014. Effect of Varied Soil Moisture Content on Seed Yield of Six Range Grasses in the Rangelands of Kenya. Universal Journal of Agricultural Research 2(5): 174-179, 2014.

Koech O K., Kinuthia R N, Mureithi S M, et al. 2014. Effect of Different Soil Water Content and Seed Storage on Quality of Six Range Grasses in the Semi-Arid Ecosystems of Kenya. Environment and Ecology Research, Vol 2, No 7

Maingi J K, Marsh S E. 2002. Quantifying hydrologic impacts following dam construction along the Tana River, Kenya. *Journal of Arid Environments,* 50(1), 53-79.

Munns R. 2002. Comparative physiology of salt and water stress. *Plant, cell & environment, 25*(2), 239-250.

Naik B, Behera P, Das B. M. 2012. Hardware Implementation of Soil Moisture Monitoring System (Doctoral dissertation). http://ethesis.nitrkl.ac.in/3342/1/Hardware_Implementation_of_Soil_Moisture_Monitoring_System.pdf. Accessed on 6th June 2012.

Orloff S, Hanson B, Putnam D. 2003. Utilizing soil-moisture monitoring to improve alfalfa and pasture irrigation management. Online. Crop Management doi:10.1094/CM-2003-0120-01-MA. Accessed on 6th June 2012).

Pereira L S, Oweis T, Zairi A. 2002. Irrigation management under water scarcity. *Agricultural Water Management*, *57*(3), 175-206.

Playan E, Mateos L, 2006. Modernization and optimization of irrigation systems to increase water productivity. *Agricultural water management*, 80(1-3): 100–116.

Rosegrant M W, Cai X, Cline S A. 2002. *World water and food to 2025: dealing with scarcity*. Intl Food Policy Res Inst. http://tinyurl.com/nvdl39u. Accessed 15th Jan 2014.

Snyman H A. 1994. Evapotranspiration, water-use efficiency and quality of six dryland planted pasture species and natural vegetation, in a semi-arid rangeland 1. *African Journal of Range & Forage Science*, *11*(3), 82-88.

Wood M L, Finger L. 2006. Influence of irrigation method on water use and production of perennial pastures in northern Victoria. *Animal Production Science*, *46*(12), 1605-1614.

World Water Council (WWC). 2004. E-conference Synthesis, Virtual Water Trade— Conscious choices. WWC publication No. 2.

Yang H, Wang L, Abbaspour K, et al. 2006. Virtual water and the need for greater attention to rain-fed agriculture. Water Magazine Int. *Water Association.* 21: 14–15.

CHAPTER EIGHT

General Conclusions and Recommendations

Evaluation of the six grass species under different soil moisture conditions generated very varied results, but useful information around which recommendations regarding their cultivation for hay production can be made.

1. Biomass yields and morphometric characteristics

In terms of biomass production, *SB, CG* and *EM* had the highest potential (>10t ha^{-1}) under limited soil moisture content (30% FC), an equivalent of 700 bales of hay of 14kgs. This study showed that CC performs better under medium soil moisture content (50% FC), while CC and SB gve higher biomass under both high and low soil moisture content. *CG* was the second best species although its productivity was not highly responsive to changes in soil moisture levels. CG and SB were the best choices for pasture production in moisture deficit environments.

2. Seed Yields

The findings revealed that watering of grasses increased the seed yields with different responses at the different soil moisture contents. SB had the highest seed yields (1.25t ha^{-1}) at 80% FC followed by CG and EM. Under rainfed conditions, SB still performed better than the other species. CG demonstrated greater potential of seed production under low water availability (1t ha^{-1}).

3. Storage and Qualityof Seeds

The results of this study showed that a storage period of at least 12 weeks was necessary for reasonable germination rates for all the six species. SB was the most prolific with >50% germination percentage even when stored for only two weeks. EM and CG had the poorest (<15%) germination rate when stored for the same period, while ES, CC and CR could not germinate at all. It was therefore recommended that farmers should not use recently harvested seeds for pasture production; be stored for at least 12 weeks before planting.

4. Stage of maturity, curing and storage methods

Outdoor storage reduced CP content and digestibility of the hay than indoor storage for all the six grass species. The decline in quality (CP) also increased with storage duration in both indoor and outdoor storage. Therefore, indoor storage preserves grass quality better than outdoor and deterioration increases with storage duration. About where 12 weeks indoor storage maintained CP above 6% which is the recommended level for which is associated with higher palatability. It was therefore recommend that bailing be done after 2 days under normal dry conditions of Tana River and the hay stored indoors.

5. Water Use Efficiency (WUE)

The results were highly varied in term of WUE by the various species WUE growing under varying soil moisture contents. SB CG and EM demonstrated higher WUE at 30% FC soil moisture content than 80 and 50% FC positioning them higher under limited moisture conditions. However, there are other factors that may be affecting WUE such as species ecotypes which require further studies for evaluation of the three species. There is also need for long term monitoring of WUE for the same species, to capture at least three growing seasons which was not considered in this study.

APPENDICES

Appendix 1: Soils chemical properties before and after the experiment

	Experimental plots watering levels	% C	% N	P ppm	CEC me/100g	K me/100g	ECe dS·m^{1}	pH
Before Experiment	Control/rainfed	0.82^{a} ±0.11	0.10^{a} ±0.00	83.25^{a} ±7.03	10.97^{a} ±6.01	2.10^{a} ±1.30	0.40^{a} ±0.21	7.82^{a}
	30% FC	1.03^{a} ±0.02	0.10^{a} ±0.01	81.75^{a} ±9.01	11.86^{a} ±7.91	1.85^{a} ±1.21	0.41^{a} ±0.08	7.26^{a}
	50% FC	1.13^{a} ±0.12	0.11^{a} ±0.07	87.10^{a} ±6.09	12.51^{a} ±4.03	2.05^{a} ±1.17	0.40^{a} ±0.14	7.31^{a}
	80% FC	0.92^{a} ±0.01	0.12^{a} ±0.06	87.51^{a} ±10.1	11.24^{a} ±3.21	2.15^{a} ±1.41	0.38^{a} ±0.11	7.09^{a}
After Experiment	Control/rainfed	1.61^{b} ±1.01	0.11^{a} ±0.09	20.00^{b} ±11.1	13.21^{b} ±3.51	1.45^{b} ±1.01	0.42^{a} ±0.16	7.68^{a}
	30% FC	1.67^{b} ±0.10	0.13^{a} ±0.01	26.51^{b} ±9.61	13.97^{b} ±5.42	1.90^{ab} ±1.21	0.40^{a} ±0.12	7.25^{a}
	50% FC	1.83^{ab} ±1.11	0.10^{a} ±0.01	22.12^{b} ±8.57	14.12^{ab} ±4.81	1.95^{ab} ±0.11	0.53^{a} ±0.22	7.21^{a}
	80% FC	1.61^{b} ±1.00	0.09^{a} ±0.00	24.63^{b} ±4.21	16.33^{ab} ±6.11	1.90^{ab} ±0.04	0.61^{a} ±0.31	7.70^{a}

Column means with different superscripts are significantly different at $p \leq 0.05$

Appendix 2: Two way ANOVA of the yields of the six grass species and their mixtures at varied soil moisture levels

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Grass species (GS)	9	14056.5333	1561.8370	4.9499	0.0001
Soil moisture level (SM)	3	93244.4444	31081.4815	98.5059	0.0159
GS*SM	27	27450.0000	1016.6666	3.2221	0.0003
Error	39	12305.63	315.5289		
Corrected Total	44	147056.60773			

DF=Degree of freedom; Pr=Probability of significance at 95% Confidence level

Appendix 3: Two way ANOVA of the grass seed yields of the six grass species at varied soil moisture levels

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Grass species (GS)	5	158414.4444	31682.8889	1.3954	0.0003
Soil moisture level (SM)	3	68800.0000	22933.3333	1.0101	0.0001
GS*SM	15	227214.4444	15147.6296	0.0682	0.0005
Error	23	52216.6667	22705.0725		
Corrected Total	46	506645.5555			

DF=Degree of freedom; Pr=Probability of significance at 95% Confidence level

Appendix 4: Two way ANOVA of the seed quality (GP) of the six grass species and their mixtures at varied soil moisture levels

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Grass species (GS)	5	14056.5333	2811.3066	5.2545	0.0001
Soil moisture level (SM)	3	93244.4444	31081.4815	58.0932	0.0559
Storage periods	3	78933.4200	26311.1400	49.1772	0.0001
GS*SM	15	27450.0000	1830.0000	3.4204	0.1881
Error	23	12305.6300	535.0274		
Corrected Total	46	147056.60773			

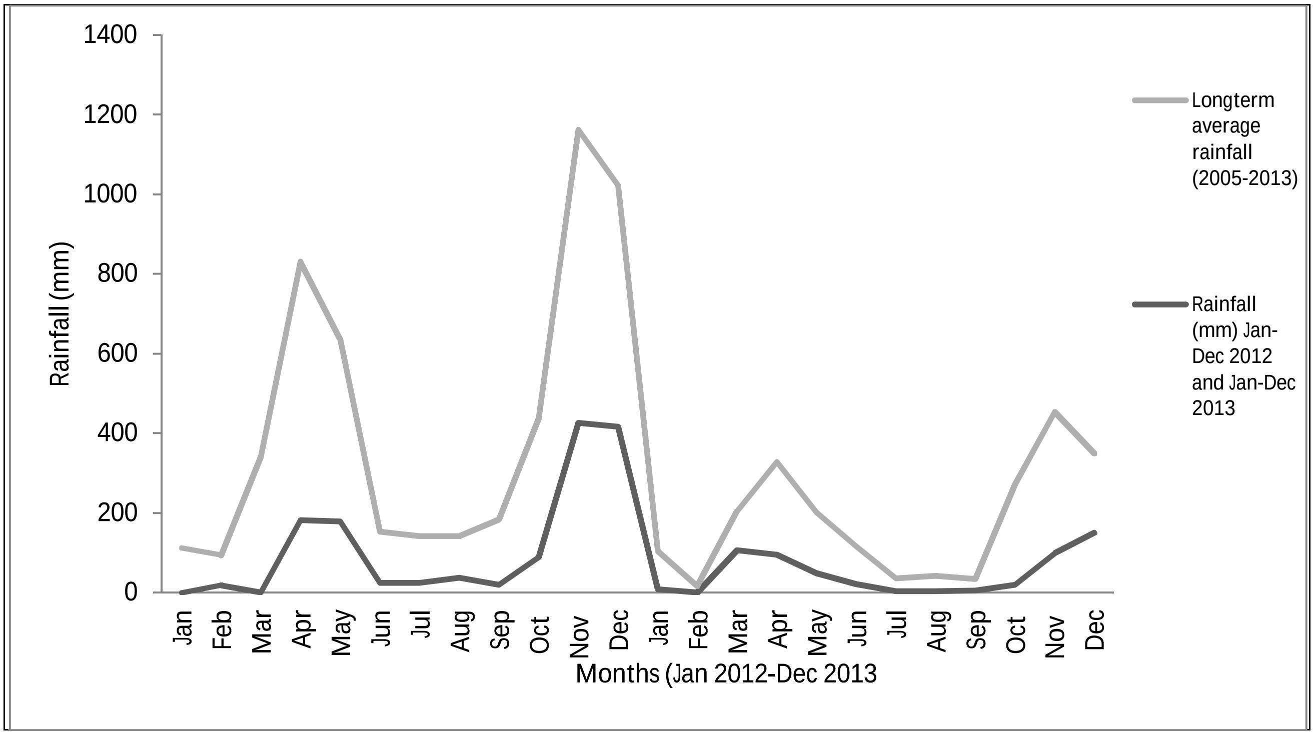
DF=Degree of freedom; Pr=Probability of significance at 95% Confidence level

Appendix 5: Two way ANOVA of the forage quality at different curing and storage periods from the six grass species and their mixtures at varied soil moisture levels

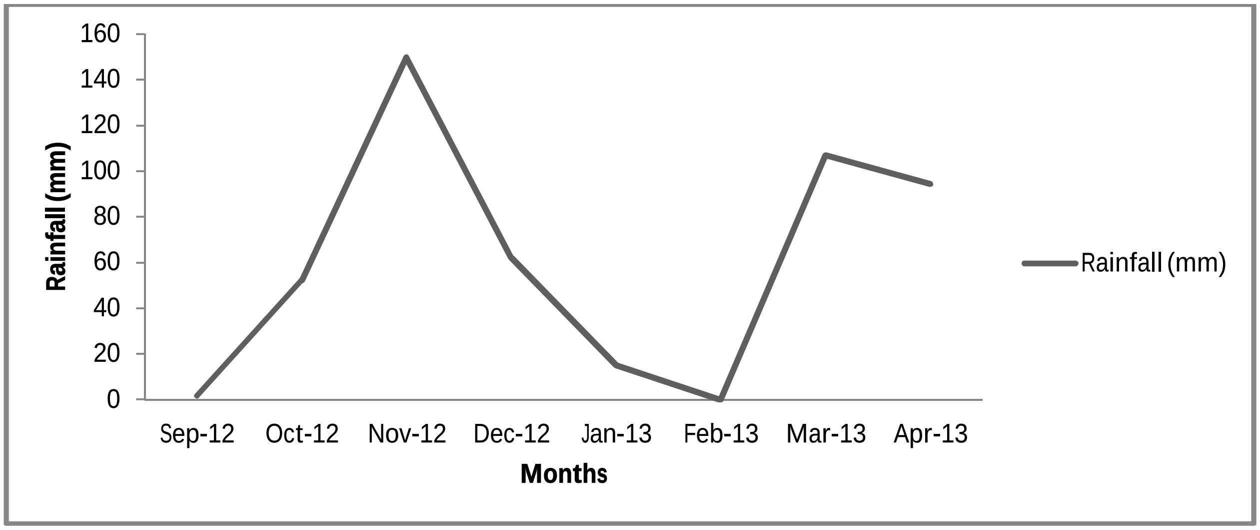
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Grass species (GS)	5	14056.5333	2811.307	5.93988062	0.0001
Soil moisture level (SM)	3	93244.4444	31081.48	65.67063353	0.0559
Storage	3	78933.4200	26311.14	55.59159832	0.0001
Curing	2	17683.1800	8841.59	18.68098911	0.0612
Curing*storage	6	25350.3333	4225.056	8.926925667	0.0021
GS*SM	15	27450.0000	1830	3.866522884	0.1881
Error	26	12305.6300	473.2935		
Corrected Total	60	269023.541			

DF=Degree of freedom; Pr=Probability of significance at 95% Confidence level

Appendix 6 Tana River County monthly rainfall trends for 2012 and 2013 compared to long term average rainfall for 2005-2013



Appendix 7 Eight months rainfall trends and amounts (mm) during experimental growing period and drought tolerance (Sep 2012 to Apr 2013)



Appendix 8 Amount of water from Rainfall, irrigation water received by the grasses, soil moisture changes and evapotranspiration at the four moisture treatments during the 16 weeks experimental period

80% FC					
	WEEK 8	**WEEK 10**	**WEEK 12**	**WEEK14**	**WEEK 16**
RAINFALL (P) (mm)	54.2	224.2	204	242.5	281.1
IRRIGATION (I) (mm)	367	484	556	664	770
CHANGE IN SOIL **ΔS**	147	210	214	198	144
ET_{grass} (mm)	274.2	498.2	546	708.5	907.1
50% FC					
RAINFALL (P) (mm)	54.2	224.2	204	242.5	297.9
IRRIGATION (I) (mm)	289	366	442	524	669
CHANGE IN SOIL **ΔS**	121	187	203	113	105
ET_{grass} (mm)	222.2	403.2	443	653.5	861.9
30% FC					
RAINFALL (P) (mm)	54.2	224.2	204	242.5	297.9
IRRIGATION (I) (mm)	211	280	310	215	456
CHANGE IN SOIL **ΔS**	98	268	225	230	265
ET_{grass} (mm)	167.2	236.2	289	227.5	488.9
RAINFED					
RAINFALL (P) (mm)	54.2	224.2	204	242.5	297.9
IRRIGATION (I) (mm)	0	0	0	0	0
CHANGE IN SOIL **ΔS**	33	79	85	67	113
ET_{grass} (mm)	21.2	145.2	119	175.5	184.9