A COMPARATIVE STUDY OF THE PRODUCTIVITY OF *BRACHIARIA* HYBRID CV. MULATO II AND NATIVE PASTURE SPECIES IN SEMI-ARID RANGELANDS OF KENYA

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DECLARATION

I, Clara Machogu, hereby declare that the work contained in this thesis is my original work and has never been submitted for a degree in any other university.
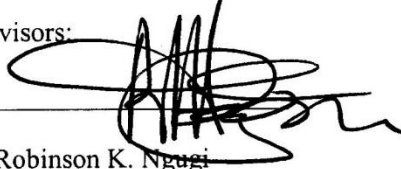
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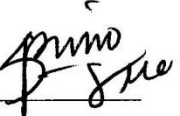This thesis has been submitted to the Board of Postgraduate Studies with our approval as supervisors:

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DEDICATION

This work is one of the greatest achievements of my life and I dedicate it

to:

My parents: Mr. R. M. Monda and Mrs. J.B. Machuka, for their love and

interest to educate me.

My siblings: Ibrahim, Maggie and Lydia for encouraging me to pursue

this course.

God bless you all.

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ABBREVIATIONS AND ACRONYMS

ADF	Acid Detergent Fiber
AOAC	Association of Official Analytical Chemists
ASAL	Arid and Semi-Arid Land
AUMS	Animal Unit Months
CAN	Calcium Ammonium Nitrate
CC	*Cenchrus ciliaris*
CF	Crude Fiber
CR	*Chloris roxburghiana*
CIAT	International Center for Tropical Agriculture
CP	Crude Protein
DDM	Digestible Dry Matter
DM	Dry matter
DMD	Dry Matter Digestibility
DMI	Dry Matter Intake
EM	*Enteropogon macrostachyus*
ER	*Eragrostis superba*
IPCC	Intergovernmental Panel for Climate Change
ITCZ	Inter-Tropical Convergence Zone
IVDMD	In-Vitro Dry Matter Digestibility
KARI	Kenya Agricultural Research Institute
MU II	*Brachiaria* hybrid cv. Mulato II
NARS	National Agricultural Research Systems
NDF	Neutral Detergent Fiber
RVF	Relative Feed Value
TDN	Total Digestible Nutrients
TLUs	Tropical Livestock Units

ABSTRACT

This study was conducted to evaluate the relative productivity and nutritional quality of *Brachiaria* hybrid cv. Mulato II grass species, *Cenchrus ciliaris*, *Enteropogon macrostachyus*, *Chloris roxburghiana* and *Eragrostis superba* in semi-arid rangelands of southern Kenya. Experimental trials were set at KARI-Kiboko Research Station in Makueni County. Comparisons of the five grass species were done with reference to plant growth parameters that included plant height, tillers,cover and density; aboveground biomass production, seed yield, seed viability and nutritional quality.

Out of the five grass species in this study, *Brachiaria* hybrid (Mulato II), although a late seeder, emerged superior in dry matter (DM) yield (c. 17t/ha). The species also had the highest nutritional quality, exhibiting the lowest fibriosity (c. 29%) and the highest proportion of digestible dry matter (DDM) (65%). Of the local species, *C.ciliaris* was the best in DM yield (c. 10t/ha), while *E. macrostachyus* had the highest seed viability (100% germination within 48 hours). *Eragrostis superba* had the highest seed production (803.2Kg/ha) as *C. roxburghiana* was the overall inferior species in terms of productivity.

These results show that Mulato II has a potential in the semiarid southern rangelands of Kenya, as a reliable and nutritious source of forage. However, further research on its performance on varied soils and moisture conditions is crucial to inform its adoption. On-farm trials beyond the field experiment undertaken in this study are also necessary to determine its adaptability under real field conditions across multiple temporal and spatial scales.

1   INTRODUCTION

1.1   Background

More than 80% of the Kenyan land mass is classified as either arid or semi-arid and has low agricultural potential (Hansen *et al.* 1986; GoK, 2002). These areas are characterized by high moisture deficits, variable as well as erratic rainfall and are mainly used for livestock production. Agro-pastoralism and pastoralism are the main economic activities in these areas and majority of the people derive their livelihoods from them (Mbogoh and Shaabani, 1999). However, livestock productivity from these lands is very low and is projected to get even lower in the foreseeable future, due to the impact of climatic variability on these production systems. The inherently low livestock productivity is attributed to low quantity and quality of feed for the livestock (Mnene *et al*., 2006; Nyangito *et al*., 2008). Declining availability of palatable and nutritious forage plant species, as a result of prolonged over-utilization of the rangeland pastures is also common. Generally, poor quality forage plant species dominate many pasturelands for the better part of the year, and up to 60% of the pasturelands remain almost bare (Mnene, 2006). In East African rangelands, the status of natural pastures is generally on a downward trend (Coughenour *et al*., 1990; McPeak, 2001; Coughenour, 2004).

This situation can be improved through land rehabilitation practices such as reseeding to increase availability and quality of fodder for increased livestock productivity, soil erosion control, among others. This may be combined with forage seed bulking and forage conservation, including hay production. The appropriateness of the available grass species in terms of drought tolerance, growth rates, biomass production and seed production, is however not well understood and documented (Mnene, 2006). Therefore, there is need to study the promising indigenous and

exotic pasture species in order to provide them with the right management so as to increase their productivity. One such species is *Brachiaria* hybrid cv. Mulato II, a perennial grass whose mother germplasm is native to East and Central Africa. Germplasm collected include *Brachiariabrizantha*, *Brachiariahumidicola* and *Brachiariaruziziensis*. These were later introduced into the humid tropical regions of Latin America, Southeast Asia, and Northern Australia where they were developed into superior breeds which have revolutionized grassland farming and animal production. In this region, its potential in the native land, however, still needs to be explored and established, with a view to introducing the newly developed superior *Brachiaria* cultivar 'home'.

This study was undertaken to evaluate the performance of *Brachiaria* hybrid cv.Mulato II in the southern rangelands of Kenya. Specifically, comparison in growth characteristics and productionagainst the dominant indigenous species namely,*Cenchrus ciliaris* L*, Enteropogon macrostachyus* Monro ex Benth, *Eragrostis superba* Peyrand *Chloris roxburghiana* (Schult) was also undertaken.

1.2   Problem statement and justification

Traditionally, livestock have been a key component of farming systems and an important source of livelihood for the resource-poor farmers in developing countries. Natural range pastures constitute the highest source of forage for ruminant livestock. Other forage sources include browse and crop residues. However, due to the unpredictable weather patterns, increase of human population, overutilization of range resources among others, many range areas have been degraded to the point where they are no longer able to support livelihoods. Due to limited

alternative livelihood sources, people living in these areas continue to languish in abject poverty (IPCC, 2007).

Despite these challenges, livestock production remains the most feasible source of livelihood in the ASALs of East Africa. Its sustainability has been hindered by low supply of livestock feed and water, particularly during the dry season. This low supply of feed does not allow full potential of animal products such as milk and meat to be expressed. Current dry seasons have been characterized by extended periods of drought conditions that results in high mortality rates of livestock. This situation has resulted in the ASAL communities being frequently under famine (IPCC, 2007). Scenes of food aid programmes by government and non-government organisations, malnourished children and environmental refugees have become common features in the ASALs. National governments have been forced to put in place mechanisms to deal with the emerging crisis in these areas. Research can play a key role in the search for solutions to the emerging crisis in these areas. For instance, drought tolerant and early maturing crop varieties which are suitable for these areas must be bred if food security is to be enhanced. Pasture improvement must also be promoted in order to sustain the agro-pastoral and pastoral economies in these areas.

Various pasture improvement efforts have been initiated through national research institutions. These efforts include identification of high yielding, drought tolerant and nutritious fodder species. For instance, efforts have been made to promote indigenous grasses such as *C. ciliaris, E. superba, E. macrostachyus,* and *C. roxburghiana* in southern and central-northern rangelands of Kenya. These indigenous species are perceived to have evolved under the harsh climatic

conditions of the ASALs and are therefore, well adapted. In spite of all this, there still exists a need to seek more grass species to increase the varieties available for use by livestock in order to meet their nutritional requirements (Gitunu *et al*., 2003).

Studies on *Brachiaria* hybrid (Mulato II) conducted in South America under humid and sub-humid conditions have shown that it possesses desirable attributes such as rapid growth, high nutritive value and rapid establishment. Other studies indicate that *Brachiaria* hybrid (Mulato II) is the single most important foraging grass for pastures in the tropics (Holmann *et al*., 2004). In the past 25-30 years, *Brachiaria* species cultivation for export has become a booming business in the America's, with Brazil being the leading user and producer of *Brachiaria* seeds. Sales accrued from export of *Brachiaria* seeds in the region exceed 30 million. The Brazilian seed market is the largest in the world with an estimated volume of commercialized seeds yearly amounting to 90,000 tons, with a gross value of about 250 million dollars. The tonnage is entirely dominated by *Brachiaria* cultivars, which account for approximately 80% of the market (Tsuhako, 1999).

Brachiaria originated from Africa, and it is within the same continent,particularly,in Kenya, that pasture supply in terms of quality and quantity is now inadequate. Against the foregoing background, efforts towards reintroducing it back 'home' are being made especially in the agropastoral and pastoral systems inorder to arrest the escalating forage crisis. This study is contributing to this process by evaluating its performance under local conditions. It is also meantto assess its productivity relative to the native species such as *C. ciliaris, E. superba, E. macrostachyus,* and *C. roxburghiana*. The fundamental question is whether the effort towards

reintroducing it is worthwhile, or are the farmers better-off with the local species they are currently using?

1.3 Objectives

The general objective of this study was to evaluate the performance in growth characteristics, forage yield and quality of *Brachiaria* hybrid cv. Mulato II relative to four local range grasses for increased forage production in the ASALs of East Africa. The specific objectives of this study were to:

1. Determine the productivity (biomass, seed yield, cover, plant density, tiller density, plant height and seed viability) of*Brachiaria* hybrid cv. Mulato II relative to that of *C. ciliaris, E. superba, E. macrostachyus*, and *C. roxburghiana*;

2. Determine the nutritional quality of *Brachiaria* hybrid cv. Mulato II forage relative to that of *C. ciliaris, E. superba, E. macrostachyus, and C. roxburghiana*.

1.4 Hypotheses

The overarching hypothesis of this study was that *Brachiaria* hybrid cv.Mulato II is in all aspects, superior to the key local range grass species.

2   LITERATURE REVIEW

2.1   Introduction

Livestock production is a key component in many rural households in the developing countries across the globe. This activity is based on extensive production schemes in pastures of low productivity, which, together with the pressure exerted by crop farmers for land, has forced livestock production to be extended to the more fragile, less productive ecosystems (Serrão and Toledo, 1989). The major limitation of livestock production, particularly, in the less productive ecosystems, is the lack of suitable fodder crops that can produce green forage throughout the year. This situation is severe in the ASALs. Adapted forage species has the potential to enhance the productivity and resilience of crop-livestock systems. Improved *Brachiaria* grasses are exceptionally tolerant to drought (Miles *et al*., 2004) and could play a critical role in crop-livestock systems in the ASALs. Furthermore, high yields, quality and ease of propagation of improved *Brachiaria* grasses are central to their establishment and utilization in pastoral and agro-pastoral systems for improved milk and meat production.

Studies that have been done to evaluate forage species have used various attributes in comparing their productivity performance. These attributes comprise of plant biomass, nutrient quality, seed yield, seed quality, digestibility, livestock preference among others. For example, Bulle *et al*., (2011) and Ogillo, (2010) used biomass yield, seed yield, and forage quality in their studies to evaluate forage performance. The former conducted a comparative evaluation study of *Chloris gayana*, *E. superba* and *C. ciliaris* in Marsabit County, Northern Kenya, while the latter evaluated the performance of *C. ciliaris*, *C. roxburghiana*, *E. superba* and *E. macrostachyus* under different micro-catchments in Kibwezi, Southern Kenya.

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2.2 *Brachiaria* hybrid (Mulato II)

Brachiaria grasses are tropical warm-season forages native to Africa. *Brachiaria* grasses were first introduced in tropical Australia in the early 1960s and subsequently in tropical South America in the early 1970s (Parsons, 1972; Sendulsky, 1978).

Currently, *Brachiaria* grasses are the most widely grown forages in tropical South America, occupying over 80 million hectares (Boddey *et al.*, 2004). They are extensively used as pasture grasses, but mainly for *in situ* grazing and much less for cut and carry or hay making. Exceptions include creeping signal grass (*Brachiaria humidicola*) and a few other species that are used for hay (Boonman, 1993; Stur *et al.*, 1996). The growing interest in *Brachiaria* grasses has prompted a need to develop new cultivars with outstanding agronomic characteristics such as greater range of adaptation, greater biomass production, high nutritional quality and resistance to Rhizoctonia (a disease-causing fungus) and spittle bug disease.

Morphologically, Mulato II is a semi-erect perennial apomictic grass that can grow up to 9 ft tall. It is established by seed, although it could be propagated vegetatively with stem segments. It produces several cylindrical stems (some with a semi-prostrate habit) capable of rooting at the nodes when they come into contact with the soil. They have lanceolate and highly pubescent leaves of 35 to 65 cm in length and 2.5 to 4 cm width (Guiot and Melendez, 2003). This grass species is also adapted to many soil types, ranging from sands to clays; however, it does not tolerate poorly drained soils (Vendramini *et al.*, 2010).

Mulato II is the result of three generations of crosses and screening conducted by the International Center for Tropical Agriculture (CIAT) in Colombia, including original crosses between *Brachiaria ruziziensis* R. Germ. &Evrard clone 44-6 (sexual tetraploid) x *Brachiariadecumbens*Stapf cv. Basilisk (apomictic tetraploid). Sexual progenies of this first cross were exposed to open pollination to generate a second generation of hybrids. From the second generation of hybrids, a sexual genotype was selected for its superior agronomic characteristics and was again crossed, to produce Mulato II. Subsequent progenies of this clone confirmed their apomictic reproduction, and results with molecular markers (microsatellites) showed that Mulato II has alleles that are present in the sexual mother *B. ruziziensis*, in *B. decumbens* cv. Basilisk, and in other *B. brizantha* accessions, including cv. Marandu (Argel *et al.*, 2007).

Comparative studies so far conducted have shown that *Brachiaria* hybrid cv.Mulato II is superior in dry matter yield compared to other cultivars within the same species (Guiot and Melendez, 2003). It also offers considerable potential to alleviate feed shortage and complement feeding value of other grasses if introduced in the farming systems. Its benefits as a livestock feed have been quantified clearly in humid and sub-humid climate (Urio *et al.*, 2006). These benefits have, however, not been comprehensively evaluated in the ASALs.

In other studies conducted in the ASAL environment in Thailand, Mulato II has shown the potential to produce more than 500kg/ha of pure seed, in experiments where an effort has been made to recover all pure seed produced, either by bagging inflorescences or by collection of fallen seeds (Hare *et al.*, 2007). How much of this potential is realized in practice will depend on

many factors, including harvest method. The attribute of high seed productivity provides an opportunity to solve the current shortage of seeds which cannot satisfy the demand for reseeding the rangelands.

It can be concluded from the growing interest to promote Mulato II, particularly in South America to be attributed to its benefits. Currently, *Brachiaria* grasses dominate the market, accounting for 84% of seed sales in Mexico and Honduras, 90% of those in Nicaragua, 85% in Costa Rica, and 97% in Panama (SAG, 2004; SENASA, 2004; DIGESA, 2004; MAG, 2004; IDIAP, 2004).

Since the release of Mulato II, a series of agronomic experiments have been conducted. Many trials demonstrated the superiority of Mulato II. It is a vigorous, semi-erect grass species with very deep and branched roots giving it superior drought resistance. According to Pizarro *et al.*, (2008), Mulato II holds the key to improve livestock productivity in the tropics. Furthermore, its performance remains unknown, particularly in the ASALs that receive relatively less rainfall than the humid and sub-humid tropical areas where it has been bred.

2.3   Native range pasture species

Within the tropics, rainfall is the major hydrological input to soil moisture. Its quantity and availability to growing plants contributes to the geographical distribution of plants species (Herlocker, 1999). Local perennial grasses have evolved adaptive mechanisms for survival under scarce moisture conditions and are preferred to introduced or exotic species for reseeding purposes because they give best results in East African rangelands (Pratt and Gwynne, 1977;

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Opiyo, 2007). On the other hand, annual grasses are more appropriate for reseeding in eco-climatic zones VI and VII where rainfall is low and cannot support perennial grasses (Pratt and Gwynne, 1977; Mnene, 2006). According to Mnene (2006) and Opiyo (2007) the grass of choice for reseeding should have the following attributes: (i) drought tolerant to survive and perpetuate itself, (ii) good quantity of herbage of good grazing value, (iii) produce adequate amount of viable seed that can be easily harvested, and easy to establish.

Bogdan and Pratt (1967) recommended 32 grass species suitable for reseeding denuded rangelands in Kenya. Pratt and Gwynne (1977) identified six of these 32 species (*C. ciliaris,C. roxburghiana, Chloris gayana, E. macrostachyus, E.superba and Cynodondactylon*), as the most useful in reseeding rangelands. Later on, ten important grass species were also identified and ranked by stakeholders in a participatory manner within the southern Kenya rangelands (Mbogoh and Shaabani, 1999; Mnene, *et al*., 2000). The ten grass species based on farmer perception about animal preference, palatability and nutritive value, were namely: *E. superba, C. ciliaris, E. macrostachyus, C.roxburghiana, Bothriocloainsculpta, Cymbopogonpospischilii, Cynodonplectostachyus, Digitariamacroblephara, Panicum maximum* and*Themedatriandra*. Of these ten grasses, the first four ranked species (*C. ciliaris*, *C. roxburghiana*, *E. superba* and *E. macrostachyus*) have been used in various studies by KARI Kiboko researchers (Mnene, 2006) and (Ogillo, 2010). Other studies involving reseeding have used either all or some of the species in monocultures or in mixtures. For example, Opiyo (2007) and Mganga (2009) both used *C. ciliaris*, *E. superba* and *E. macrostachyus* in their studies. Opiyo (2007) investigated the effect of two types of land preparation – tractor-ploughed and hand-cleared; on the morphometric

characteristics of the grasses while, Mganga (2009) studied the impact the grasses on rehabilitation of the degraded rangelands.

2.3.1 Cenchrus ciliaris L.

Cenchrus ciliaris (Buffel grass or African foxtail) is a persistent tufted, perennial, and occasionally stoloniferous species. It occurs in a wide variety of types, some of which have become reputed cultivars (strains or varieties in cultivation) and it is one of the most drought-tolerant perennial grasses (Pratt and Gwynne, 1977). The grass is native to tropical and sub-tropical Africa (Bogdan, 1977). The species is well adapted to the hotter regions and enjoys wide distribution over the drier parts ofIndia, Pakistan and South Africa. It is one of the most drought-tolerant of perennialgrasses (Pratt and Gwynne, 1977). In Australia, it is considered among the best drought resistant grasses (Opiyo, 2007). According to Duke (1983), the grass species wasprobably introduced in Western Australia about 1870-1880. Currently, it has been widelynaturalized in sub-humid and semi-arid tropics and sub-tropics.

Numerous cultivars have been created in order to improve productivity and vigour in extreme conditions of drought, disease, frequent fire and other factors (Duke, 1983). This species is extremely variable, tufted (sometimes rhizomatous) perennial with types ranging from ascendant to erect, and branching culms with linear leaf-blades, flat or having enrolled margins. The species grows to a height of 12-120cm (Harker and Napper, 1960). The branching culms range from 0.3m to 2.0m at maturity, often forming mats or tussocks; culms erect or decumbent, with a knotty crown; sheaths glabrous to sparingly pilose. The inflorescence is dense and cylindrical, 2–12 cm long, 1–2.6 cm wide and purplish. The roots are dense, fibrous and long; and can reach to a depth of up to 160cm below the soil surface (Reed, 1976; Pratt and Gwynne, 1977).

Cenchrus ciliaris has been recommended for reseeding areas receiving 350-900mm of rainfall per year. Whole seeds of this species have been sown to result in better grass stands than when hulled seeds are used (Opiyo, 2007). The seeds have been reported to germinate better after pre-drying for 10 days at 40ºC than pre-chilling for the same period at 5ºC (Maze *et al*., 1993; Hussey and Bashaw, 1996). Arid and semi-arid rangelands are reseeded with *C. ciliaris* to enhance productivity, prolong grazing period and increase carrying capacity.

Cenchrus ciliaris is highly nutritious grass and is considered excellent for pasture in hot, dry areas and is valued for its production of palatable forage and intermittent grazing during drought periods in the tropics. When fed green, as silage or hay, the grass is known to increase flow of milk in cattle. Fresh*C. ciliaris*forage is reported to contain 11.0% protein, 2.6% fat, 73.2% total carbohydrate, 31.9% fibre, and 13.2% ash while *C. ciliaris* hay is reported to contain 7.4% protein, 1.7% fat, 79.2% total carbohydrate, 35.2% fibre, and 11.7% ash (Gohl, 1981).

2.3.2 Enteropogonmacrostachyus (Hochst. ex. A. Rich.) Monro ex Benth

Enteropogonmacrostachyus (bush rye – Kenya, mopane grass – Zimbabwe), is a widely distributed grass species, very common in the ASALs where it grows in bush, in forest edges and to a lesser extent in open grassland (Kitalyi*et al*., 2002). This species occurs naturally in grasslands and rocky outcrops in ASALs of tropical Africa from 300-1600m above sea level. It is abundant between Sultan Hamud and Voi, Kenya (Bogdan and Pratt, 1967); and on Kongwa ranch, Tanzania (van Rensburg, 1969).

Enteropogon macrostachyus is tufted annual or perennial grass with erect culms of 30-100cm high. The leaf sheaths do not have a keel. The surface of the sheath and the outer margins are glabrous. The leaf blades are narrow and flat, 10-60cm long and 1.5-10mm wide; and depending on the environment they are found, they may be leafy or stemmy. The grass is found in bushlands and grasslands on clay or sandy clay soils of the basement system plains but rare on soils derived from lava. In Kenya, the grass is commonly found growing within dense bush where it is somewhat protected from grazing (Hatch *et al*., 1984). It is a very high seed-producer and seed can be collected rapidly by cutting the seed-heads or stripping the heads by hand. It lends itself easily to mechanical harvesting. The forage is highly palatable with 9-12% CP content.

2.3.1   *Eragrostis superba Peyr.*

Eragrostissuperba (Maasai love grass - eastern Africa, heart-seed love grass – Zimbabwe, flat-seed love grass – southern Africa, Wilman love grass – United States) occurs naturally in South Africa and northwards throughout East Africa to Sudan in open thickets and grasslands on poor sandy soils. It is often seen as a weed in cultivated land. It is wide spread in the semi-arid areas of East Africa. The grass is very common in various vegetation types mainly grassland and savanna types throughout its distribution range. In Kenya, the grass occurs below 2100m above sea level in well-drained soils and it is of moderate grazing because of the rather hard stems (Hatch *et al*., 1984).

The grass is a tufted perennial 20-120cm high (Bogdan, 1958; Opiyo, 2007). The leaves are mainly basal and the culms are sturdy and erect. The leaf blades are up to 400mm long and 3-

12mm wide. The inflorescence is 100-300mm long, with spikelets 6-16mm long and 3-10mm wide, purple tinted, ovate and jagged in outline, strongly flattened from the sides. Spikelets disarticulate below the glumes at maturity and fall as entire units. This grass species has a high shoot/root ratio (Taerum, 1977; Opiyo, 2007) which is a disadvantage during drought periods but has an advantage of having deep root system which go as far as 2.2m with 73% of the roots limited to the upper 0.4m from the soil surface, which enables the grass to make full use of light showers of rain (Opiyo, 2007).

Eragrostis superba does well in sandy soils but also occurs on clay loams and clays. It has been reported to have high tolerance to salinity and alkalinity (Ryan *et al*., 1975). The grass has high ability to spread naturally and has high seed production (Millington and Winkworth, 1970). *Eragrostis superba* along with *C. ciliaris* have been the basis of seed mixtures used for large scale reseeding in Kitui, Machakos and Baringo in Kenya (Bogdan and Pratt, 1967). It has also been used in reseeding in the southern rangelands of Kenya (Mnene, 2006; Opiyo, 2007; Mganga, 2009; Ogillo, 2010).

Eragrostis superba contains has an averageof 12% CPat early-flowering stage with 30-35 % CF, and it is highly palatable. Its seeds can be easily harvested from open grassland or at roadsides by stripping the ripe panicles. Mature spikelets each with numerous florets; detach easily with the caryopses enclosed (Bogdan and Pratt, 1967).

2.3.4 Chloris roxburghiana (Schult)

Chloris roxburghiana (horse tail grass or plume chloris) is a tufted perennial that grows 40-150 high at maturity; the lowest leaf-sheaths usually white or straw-coloured; panicle 5-15cm long, straw coloured or purple; spikelets long-awned (Meredith, 1955). It has characteristically flat shoot bases and dense, feathery panicles which are pale green or purple when young (Bogdan and Pratt, 1967). The inflorescence is yellow to purplish in colour. It is distributed between 0-1500m above sea level but occasionally occurs at higher level.

Chloris roxburghiana is tolerant to drought, palatable and it is found abundantly in dry areas in Kenya and other parts of Africa in Botswana and South Africa (Skerman and Riveros, 1990). The grass has been used successfully in reseeding eroded rangelands in Kitui and Baringo districts (Jordan, 1957; Pratt and Knight, 1964) and Makueni district (Mnene, 2006) of Kenya; where rainfall ranges between 500 to 625mm per year and does well on sandy soils loams and alluvial silts. It is severely affected by burning which reduces crown area, herbage weight and seed number compared to other range grasses like *Pennisetummezianum* and *Themedatriandra* (Skovlin, 1971).

Chloris roxburghiana has up to 16% CP and 30% CF on dry matter basis at early flowering stage (Bogdan and Pratt, 1967). The grass produces millions (about 6.6 million) of naked caryopses per kilogram, which can easily be harvested by hand. Bogdan and Pratt (1967) recorded that the spikelets are not easily detached from the panicles due to the mating of the long, fine awns and so it is more convenient to cut the panicles and thresh the seeds later by rubbing the panicles between two pieces of rubber.

These four range grasses have been widely adopted and promoted in the southern rangelands of Kenya. Constraints related to feed such as quality and quantity, however, still exist and mechanisms such as diversification of forage sources and increasing the forage germplasm in these areas have not been documented. Comparison of these species to *Brachiaria* hybrid cv. Mulato II was, therefore, necessary to determine whether it has an advantage over the local species.

3

METHODOLOGY

3.1 Study area

The study was undertaken at KARI-Kiboko Research Station situated in Makueni County, approximately 160 Km southeast of Nairobi City, along the Nairobi-Mombasa highway (Figure 3.1). It is located approximately 1000m above sea level, within latitudes 2º10'S and2º25 S', and longitudes 37º 40'E and 37º55'E.
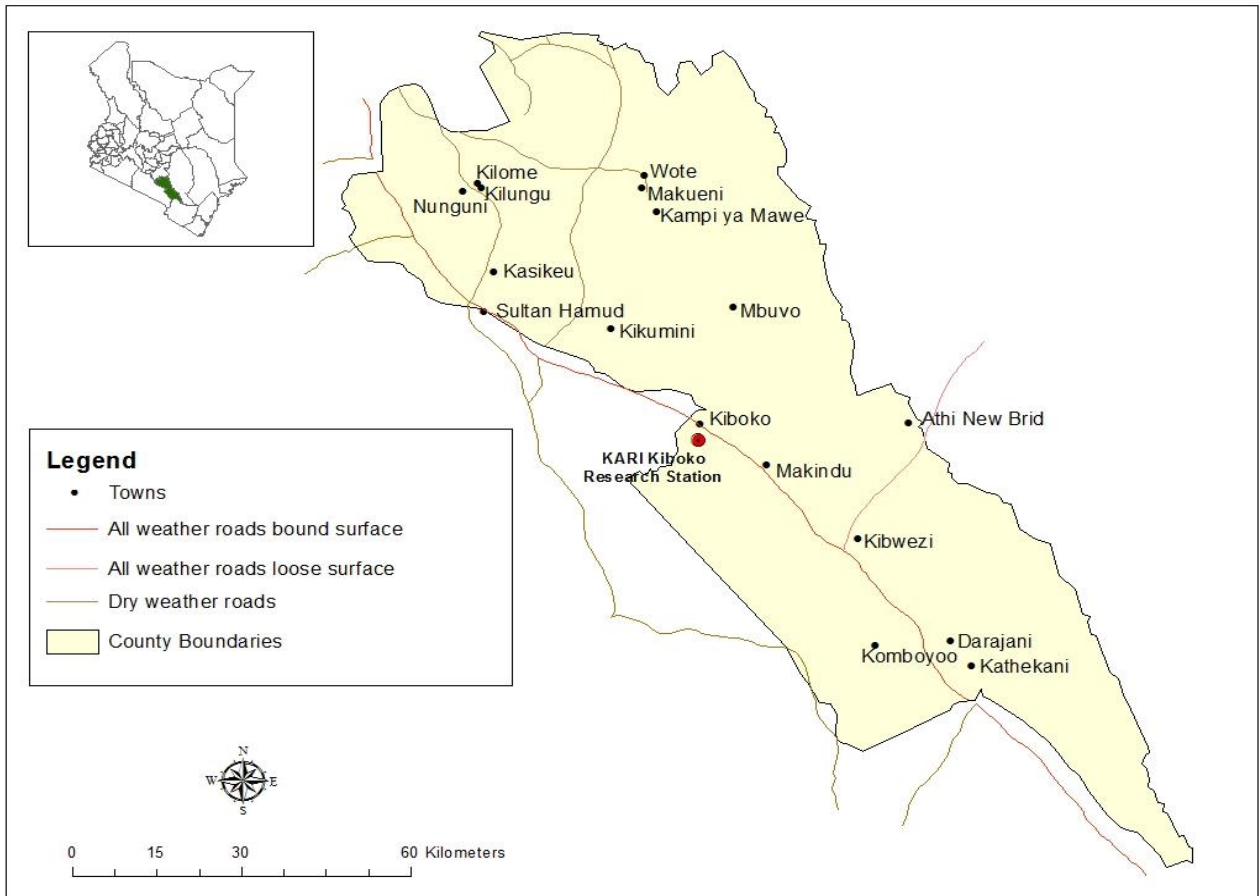
Figure 3.1. Map showing the location of KARI Kiboko Research Center (Study location)

The climate of Kiboko is heavily influenced by the Inter -Tropical Convergence Zone (ITCZ) (Biamah,2005) characterized by bi-modal distribution of wet and dry seasons. January to

February period is a short dry spell, while June to October is a protracted dry season. This is closely replaced by a rather short wet season from November to December. Mean annual rainfall, evaporation and temperature are 600mm, 2000mm and 23°C, respectively (Michieka and van der Pouw, 1977; Braunn, 1977).

The soils at the station are mainly ferralsols, which are deep, well drained, dark red-brown to dark brown; and luvisols which are red--dark reddish brown, ranging from firm sandy clay to loamy sand). Most of these soils are compact with a massive structure and strong surface sealing, which causes much run-off during heavy rains. They are generally low in organic matter (0.1--0.5% C content) and hence highly vulnerable to degradation through physical erosion as well as chemical and biological degradation (El Beltagy, 2002).

The natural vegetation of the study area is woodland and savanna, with several tree species, mainly: *Acacia*spp. (A) e.g. *A. tortilis* (Forsk) *A. mellifera* (Vahl) Benth, *A. brevispica*, *Commiphoraafricana* (A. Rich), *Combretum apiculatum* and *Tamarindus indica* L. Shrubs include *Apissenegal* (L) Willd and *Grewia*spp. The major perennial grasses in the area include *C.ciliaris*,*C. roxburghiana, Panicum maximum*, *E. superba*, *Digitariamilanjiana* (Rendle) Stapf and *E. macrostachyus*(Michieka and van der Pouw, 1977).

3.2   Materials and Methods

3.2.1   *Experimental Design*

The experimental design was a Completely Randomized design with 10 replications. Five grasses, *Brachiaria* hybrid cv.Mulato II, *C. ciliaris, E. macrostachyus, E. superba, C.*

roxburghiana were planted in 5 plots of5m x 5m plots, 1m between plots and 1.5m between replications(Figure 3.2). The grass species were randomly allocated to the plots within each replication. A total of 50 plots were generated which were divided in two sets of 25 plots (5 replications). One set of 25 plots was used for above ground biomass data determination. The other 25 plots were used for determination of flowering attributes and seed production. The layout of one of sets of 25 plots is represented in Figure 3.2.

CC	EM	MU II	ES	CR	Rep 1
ES	CC	CR	MU II	EM	Rep 2
ES	CC	EM	CR	MU II	Rep 3
ES	MU II	CC	CR	ES	Rep 4
CC	CR	MU II	ES	EM	Rep 5

CC=*Cenchrus ciliaris*, EM= *Enteropogon macrostachyus*, MU II=Mulato II (*Brachiaria* hybrid), ES=*Eragrostis superba*, CR=*Chloris roxburghiana.*
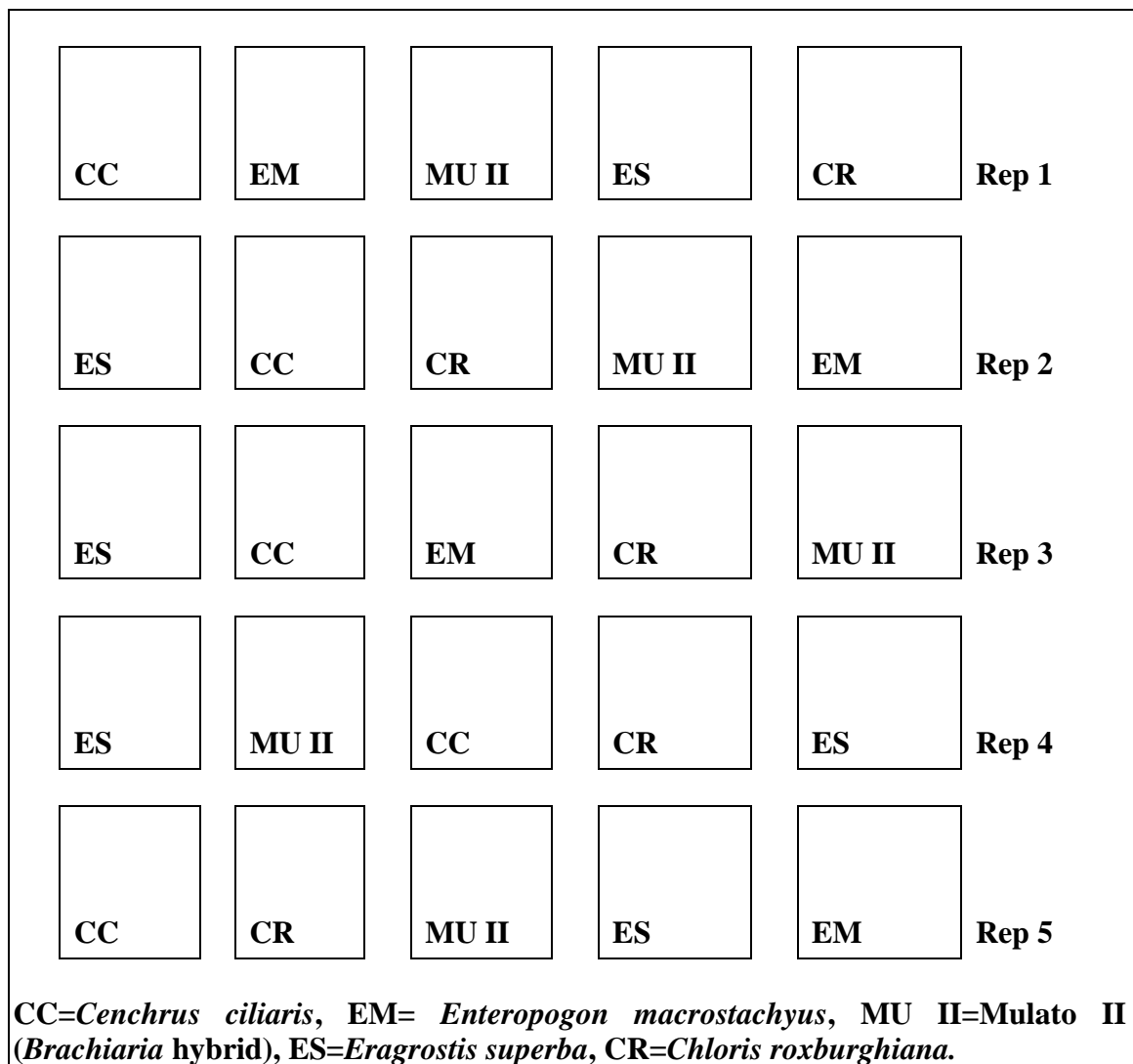
Figure 3.2. Layout of experimental plots

3.2.2 Seedbed preparations

The study area was previously uncultivated piece of land out of which approximately 1.0 hectare was delineated. Existing trees and shrubs were cleared and thereafter the area was ploughed and harrowed to a fine tilth. The 1.0 hectare plot was sub-divided into 50 sub-plots (two sets of 25 pots) measuring 5m x 5m. Furrows of about 2cm depth were made where the seeds were planted. A seeding rate of 5kg/ha of viable seeds was used. Triple super phosphate fertilizer was also applied prior to planting in furrows at rate of 200kg/ha.

3.2.3 Sowing and other husbandry practices

Sowing was done manually by placing the seeds in the furrows and covering them with a thin layer of soil. The plots were watered regularly after planting using overhead sprinkler irrigation at approximate 2mm/hr/day for a period of 16 weeks. Irrigation was done to enable pasture growth and establishment, since the trial was set during the dry season (beginning of July). Weeding was done on a weekly basis. The plots were top- dressed using CAN fertilizer at the rate of 100kg/ha of N on the 8th week after sowing. To ensure the trials were not destroyed by wild or domestic animals, the entire experimental area was fenced off using chain-link and barbed wire.

3.3 Data collection

3.3.1 Plant attributes and biomass

Figure 3.3 shows the various plant attributes that were assayed in this study. Data were collected at weeks four, eight, twelve, sixteen and twenty four after sowing, representing the following stages; seedling, vegetative elongation, flowering, seed-setting and seed maturity.
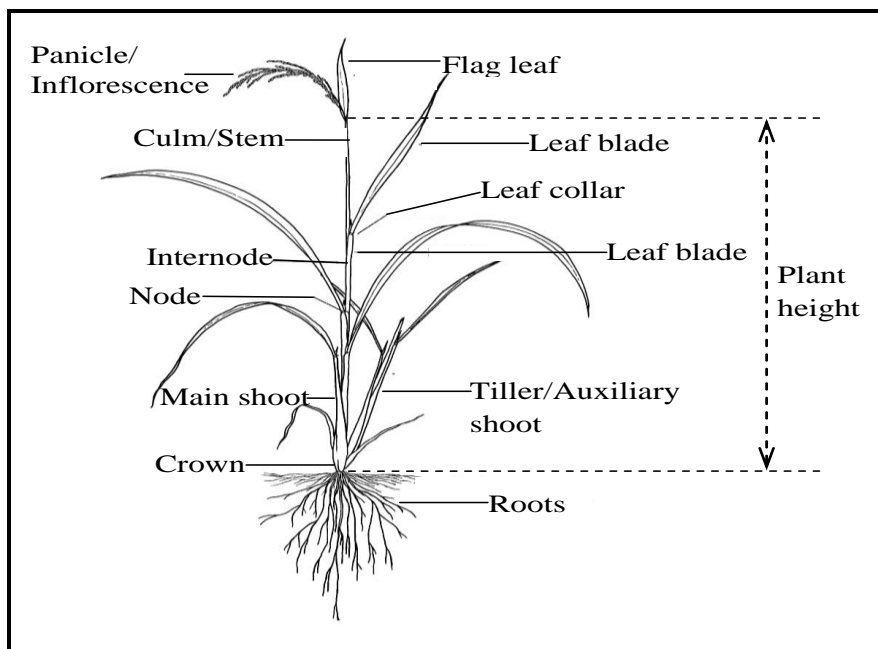
Figure 3.3 Parts of a grass plant
Source: Ogillo (2010)

The following plant parameters were assayed:cover (%), plant density (No. of plants/m^2), tiller density (No. of tillers/crown), plant height (cm)(Figure 3.3) that were measured within $1m^2$quardrat at the centre of each $5m^2$ plot. Dry matter yield (kg/ha) was measured within $4m^2$quardrat centrally placed within the plots while seed production (kg/ha) was measured on the entire $25m^2$ plot. Tiller density and cover, were not determined until week 8 since less than 8 weeks, these parameters were absent (Plate 3.1).

Plate 3.1.A section of the experimental plot at week 4 after sowing
Source: Author

Percent cover was estimated using the gridded ocular method where the area covered by a species was expressed as a percentage of area of the quadrat. Plant density was estimated by counting the individual plants within the quadrat and then expressed as number of plants per metre squared. To determine tiller density and plant height, four grass plants per plot were tagged using a coloured (for ease of identifying the selected plants) string that was lightly tied on the plant to allow normal physiological plant functions. Tiller density was determined by counting the number of visible tillers in each of the four randomly selected plants in the plots. Tillers are shoots that grow from buds at the base of the 'mother' plant. Each tiller consisted of a

leaf, stem node, stem inter-node and a bud. Plant height was determined using a steel ruler and measuring the vertical height of the plant from the base (crown) of the plant to the last leaf (flag leaf) of the main shoot (Figure 3.3). Each plant's height and tiller density were recorded separately.

Plate 3.2A section of the experimental plots at week 12
Source:Author

Above ground biomass yield was determined using the clipping method. Clipping was done at week 12 and 16 at 5cm stubble height within the 1m^2 quadratfor primary biomass yield determination.Quadrats were centrally placed within the experimental plots and herbage harvested. Different locations were harvested at week 12and 16 to get primary biomass yield.After harvesting in week 16, all the herbage in the 5m^2 plots used was clipped at 5cm

stubble height (Plate 3.2) to allow for regrowth determination in week 24. Measurements taken at week 24 were done within a 1m^2 quadrat to evaluate the regrowth thereafter under natural conditions since irrigation was stopped. Materials harvested were weighed in the field to obtain the total harvested fresh weight. A sample was then taken and placed in labelled collection bags, which were weighed in the field to have the samples fresh weight. These samples were separated into the various grass types in different blocks before they were moved to the laboratory. They were oven-dried at 65ºC to a constant weight at KARI Kiboko laboratory. The oven-dry weights were used to calculate dry matter (DM) yield per plot which was then extrapolated to kg/ha. These oven dried sample included the leaves and stems harvested at 5cm stubble height.

Plate 3.3Biomass yield determination in the field
Source: Author

After DM computation, calculations of Animal unit months (AUMs), stocking rates,and the number of animals the 5 grasses would support over a period of one year was determined. The animal weight used was Tropical livestock units (TLU) equivalent to 250kg. The following equationsas used by Mindy and Allen, (2001)were adopted:

Animal Unit Months (AUMs) = Average Animal Size X 0.02667 X 30 days/month   (3.1)

Stocking Rate = Available forage/Animal Unit Months   (3.2)

To determinethe number of animals to be grazed over one year

Number of Animals = Stocking Rate for class of livestock/ 12 Months   (3.3)

3.3.2 Flowering and Seed production

Flowering and seed production in the 5 grass species were assessed from the first week of the inflorescence appearance in each species. This was monitored within a $1m^2$ quadrat centrally placed on each plot. Shoots within the quadrat which had flowered were counted and recorded. Inflorescence heads were counted from first appearance (week 8 for *C. ciliaris*) of flowers upto 13 weeks post sowing when majority of the plants had already started having mature seeds also attaining maximum inflorescence recruitment. Monitoring of these flowers was meant to explain differences in time of seed maturity and also in terms of seed yield. Seeds harvesting was done manually each time they were found to be ripe. They were stored in labelled bags according to species and plot. Seed yield per plot was then extrapolated to yield per hectare as shown in the equation below.

Seed yield (Kg/ha) =Quantity of seeds harvested (kg)* Area (1 ha)/Plot area   (3.4)

3.3.3 Seed viability

A seed viability test was performed for four local range grass types (*C. ciliaris, C. roxburghiana, E. macrostachyus* and *E. superba*). *Brachiaria* hybrid cv. Mulato II seeds were not used to perform this evaluation trial. This was because at the time of harvesting *Brachiaria* hybrid (Mulato II) was at its vegetative state and, therefore, had no seeds harvested. A total of 100 seeds per grass species per block were tested. Different sandpaper grades according to the size of the seeds of each species were used to extract the caryopses. The sandpaper grades used for the grasses were as follows: No. 1 for *C. ciliaris* and *E. macrostachyus,* No. 0 for *C. roxburghiana*, and No. 2 for *E. superba* (Mnene, 2006). Extraction of the grass seed caryopses followed the procedures as described by Mnene (2006) elaborated below:

1. A sheet of sandpaper measuring about 148mm X 210mm was placed flat on a stable bench with the abrasive side of the paper facing upward.

2. A pinch of grass seeds was placed at the center of the sandpaper.

3. A second piece of sandpaper was placed on top of the seeds with its abrasive side facing down.

4. While holding the lower piece of sandpaper down with one hand, gently but firmly the second sandpaper was used to rub against the other sandpaper in circular motions.

5. By checking now and then, the caryopses, which were mostly yellowish brown, were removed using a fine point pair of forceps without squeezing too hard to minimize chances of

getting them damaged. The caryopses were placed in a petri dish. Additional seeds were placed and rubbed until the desired amount of caryopses – 100 in number were obtained.

At least 25 caryopses of each grass species were placed on a wet Whitman filter No. 91 in standard laboratory petri-dishes. These were replicated four times to make 100 seeds per sample of species for each plot.

The petri-dishes were placed at room temperature. The filter paper was moistened with a few drops of distilled water when it appeared dry. Germination was taken to have occurred when there was a visible emergence of the grass seed radical (HSU, 1994). Observations were made over a period of 14 days after which all germinated seeds were expressed as shown in equation below.

Percent seed germination = Total number of seeds germinated*100/Seeds per petri-dish*Replicates   (3.5)

3.3.4   Forage quality evaluation

Materials that were harvested for above ground biomass yield at week 12 were sub- sampled for feed quality assessment. These samples were oven dried at $65^{o}C$ for 48 hours and then ground through a 1mm Wiley mill in preparation for the proximate method (AOAC, 1990), the van Soest and Robertson (1980) feed analysis. These analyses were done at the University of Nairobi's Animal Nutrition Laboratory. In proximate procedures, crude protein (CP), crude fiber (CF), ether extracts (EE) and nitrogen free extracts (NFE) of the various grass types were determined while, Acid detergent fiber (ADF) and neutral detergent fiber (NDF) were also determined using the Van Soest methods.

The results obtained from the forage analysis particularly ADF and NDF were used to compute Total Digestible Nutrients (TDN), Relative Feed Value (RFV),Digestible Dry Matter (DDM), and the potential intake of corresponding forages. The following equations which were used by the Minnesota Extension NIRS project (Linn and Martin, 1999) for predicting the energy content of different forages were adopted for this study:

Estimates of TDN were made using the following formula:

1. TDN% = DDM %   (3.6)

2. DDM% = 88.9 − (0.779 × ADF %)   (3.7)

RFV is computed using the formulae below.

RFV=DDM *DMI/1.29   (3.8)

Digestible Dry Matter (DDM) was computed using (Linn and Martin, 1999) method:

3. DDM% = 88.9 − (0.779 x ADF %)   (3.9)

Dry Matter Intake (DMI) was computed as follows using (Linn and Martin, 1999) method as follows:

4. DMI (%of body weight) =120/Forage NDF (% of DM)   (3.10)

3.4   Data analysis

To compare significant differences in response variables, ANOVA analysis was done using procedures for generalized linear models (PROC GLM) of SAS (SAS Institute Inc., 2001). ANOVA was also used to assess the contribution made by species and blocks on the responses measured. The contributions were considered significant at $p < 0.05$. The treatment (species) was considered as fixed effect. PROC GLM was used to correct for unbalanced data and show variations in the response variables. Response variables were morphological characteristics

(plant height, plant density, tiller density and ground cover), dry matter (DM) yield, seed yield, seed germination rates and nutritional quality (Crude Protein CP, Ash, EE, NFE CF ADF and NDF).

For statistical analysis, the model used was:

$$Y_{ij} = \mu + S_i + \varepsilon_i \tag{3.11}$$

where:

Y_{ij} = dependent variable

μ = constant/intercept

S_i = the treatment effect (Species)

ε_i = the error associated with ith treatment

Responses were considered significantly different when $p < 0.05$. The treatment means reported are Least Squares Means and were compared using procedure for differences (PROC DIFF) (SAS Institute Inc., 2001) (Tukey's test).

4   RESULTS AND DISCUSSION

4.1   Results

4.1.1   *Morphological characteristics*

Table 4.1 presents the average responses of the five grass species in terms of plant height (cm), plant density (plants/m^2), tiller numbers per crown, ground cover (%) and dry matter yield (kg/ha), from 4 to 24 weeks after sowing. Apart from plant density, all the other parameters varied significantly $p<0.05$ across species. The response of each parameter is presented in the subsequent sections.

4.1.2   *Plant height*

At the end of 12 weeks, *Brachiaria* hybrid (Mulato II) and *C. roxburghiana* were the shortest species (c.65.0cm and 67cm), while *C. ciliaris* was the tallest (c.91.0cm) (Table 4.1). *Eragrostis superba* and *E. macrostachyus* attained similar mean heights (c.78.8 and 78.1cm).

4.1.3   *Plant density*

Brachiaria hybrid (Mulato II) ranked third in terms of plant density (c.12 plants/m^2) after *E. macrostachyus* and *C. ciliaris* which had the highest plant density c.15plants/m^2 and c.13plants/m^2, respectively. However, there were no significant differences between plant densities of *Brachiaria* hybrid (Mulato II) to the best ranked species. *Eragrostis superba* and *C. roxburghiana* had significantly $p<0.05$ lower plant densities (c.8 plants/m^2). All the species attained the maximum plant density around the 8$^{\text{th}}$ week, after which, they exhibited a decrease with *Brachiaria* hybrid (Mulato II) and *C. roxburghiana* recording the lowest and highest drop - 13-12 plants/m^2 vs. 18 ‾ 8 plants/m^2 (Figure 4.1 and Table 4.1).
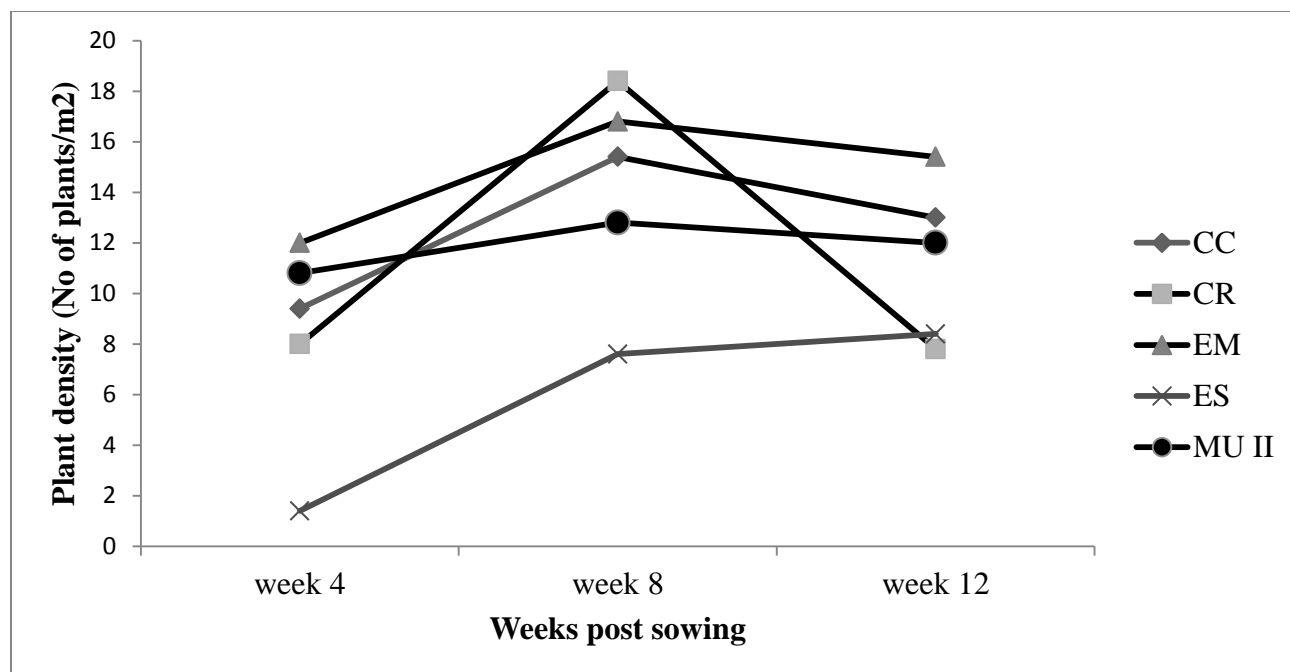
Figure 4.1. Plant densities of *Brachiaria* hybrid (Mulato II), *C. ciliaris C. roxburghiana, E. superba* and *E. macrostachyus*
Key: CC = *Cenchrus ciliaris*, CR = *Chloris roxburghiana*, EM = *Enteropogon macrostachyus*, ES = *Eragrostis superba*, MU II = *Brachiaria* hybrid (Mulato II)

4.1.4   Tiller density

In terms of tiller recruitment by the 12th week, *Brachiaria* hybrid (Mulato II) perfomed poorly (c.30 tillers/plant) compared to *E. macrostachyus* (c. 69 tillers/plant) and *C. ciliaris* (c.46 tillers/plant). There were no significant differences in tiller recruitment between *E. superba* and *C. roxburghiana* and *Brachiaria* hybrid (Mulato II). All five species exhibited prolific tillering between 8 and 12 weeks (Table 4.1).

Table 4.1. Mean plant height (cm), plant density (1m^2), tiller density(No of tillers per crown), foliage cover and dry matter yield (Kg/ha) of *Brachiaria* hybrid (Mulato II) and four native range grasses at weeks 4, 8, 12, 16, and 24 post sowing

Plant growth parameters + S.E

Species	Plant height	Plant density	Tiller density	Cover	Dry matter yield
Week 4 post sowing					
C. ciliaris	8.5^a ± 0.7	9^a ± 1.6	_	_	_
C.roxburghiana	2.1^e ± 0.7	8^a ± 5.6	_	_	_
E.macrostachyus	6.0^b ± 1.2	12^a ± 3.7	_	_	_
E. superba	3.8^d ± 0.4	1^b ± 0.6	_	_	_
***Brachiaria* hybrid**	**5.0^c ± 0.7**	**11^a ± 1.5**	_	_	_
P-value	0.01	0.12	_	_	_
Week 8 post sowing					
C. ciliaris	27.2^a±4.5	15^a ± 3	13^a ± 1	66.1^a ± 7.6	_
C. roxburghiana	7.1^c±1.7	18^a ± 10	4^b ± 1	15.5^d ± 3.2	_
E. macrostachyus	12.4^b±3.7	17^a ± 4	9^{ab} ± 1	25.6^c ± 3.3	_
E. superba	7.8^c±1.8	8^b ± 2	8^{ab} ± 1	15.9^d± 1.6	_
***Brachiaria* hybrid**	**8.5^{bc}±1.0**	**13^a ± 2**	**11^a ± 3**	**46.4^b ± 8.9**	_
P-value	0.0005	0.5206	0.0105	<.0001	_
Week 12 post sowing					
C. ciliaris	91.0^a±5.2	13^{ab}±2	46^b±5	93.3^a ± 5.6	5071.5^a± 430.5
C. roxburghiana	66.7^{bc}±9.0	8^b ±4	29^c±6	42.5^c ± 7.2	1920.7^{cd}± 357.3
E. macrostachyus	78.1^{bc}±5.1	15^a±2	69^a±6	62.8^b ± 8.2	2180.9^c± 258.2
E. superba	78.8^b±3.3	8^{ab}±2	35^c±7	59.0^b ± 7.0	1640.4^d± 238.0
***Brachiaria* hybrid**	**65.0^c±8.8**	**12^{ab}±1**	**30^c±4**	**96.0^a ± 1.9**	**2941.2^b± 718.5**
P-value	0.0922	0.0642	0.0001	<.0001	0.0003
Week 16 post sowing					
C. ciliaris	_	_	_	100	10811.7^b±974.8
C. roxburghiana	_	_	_	100	5779.0^c±242.3
E. macrostachyus	_	_	_	100	7610.9^b±734.2
E. superba	_	_	_	100	8392.9^b±390.7
***Brachiaria* hybrid**	_	_	_	100	**17333.6^a±2680.5**
P-value	_	_	_		0.0002
Week 24post sowing					
C. ciliaris	_	_	_	_	4219.1^b ±495.8
C. roxburghiana	_	_	_	_	3997.2^c ± 430.6
E. macrostachyus	_	_	_	_	6371.1^a ± 815.1
E. superba	_	_	_	_	6509.2^a± 566.4
***Brachiaria* hybrid**	_	-	_	_	**4127.4^b ± 1049.3**
P-value	_	_	_	_	0.065

Means within the same columns with different superscripts are significantly different at $p<0.05$. Superscripts a to d indicate the high to low values.

4.1.5   Ground cover

Brachiaria hybrid (Mulato II) was the most prolific in terms of colonizing the ground (c.96%). However, this was not significantly different from *C. ciliaris,* with c 93.3%, but was significantly $p < 0.05$ different from the rest of the species. *Chloris roxburghiana* was the least at c.42.5% (Table 4.1). All the species attained 100% ground cover between week 13 and 16.

4.1.6   Dry matter yield

Dry matter yield upto 16 weeks represented primary production, while 16-24 weeks, was regrowth. In terms of primary production, *Brachiaria* hybrid (Mulato II) outperformed all the other species (c.17.0t/ha; $p < 0.05$), followed by *C. ciliaris* (c.10.8t/ha). In terms of regrowth, all the grasses exhibited a decline (Figure 4.2). Mulato II recorded the largest drop (c.76%) followed by *C. ciliaris* (c.61%), *E. superba* (c.23%) and *E. macrostachyus* (c.17%). However, Mulato II's regrowth DM was not significantly different from all the local species. The species with the least amount of regrowth DM was *C. roxburghiana* (c.3.9t/ha) (Table 4.1 and Figure 4.2). On average across week 12, 16 and 24, Mulato II gave the highest yield of 8.1t/ha (Figure 4.2).
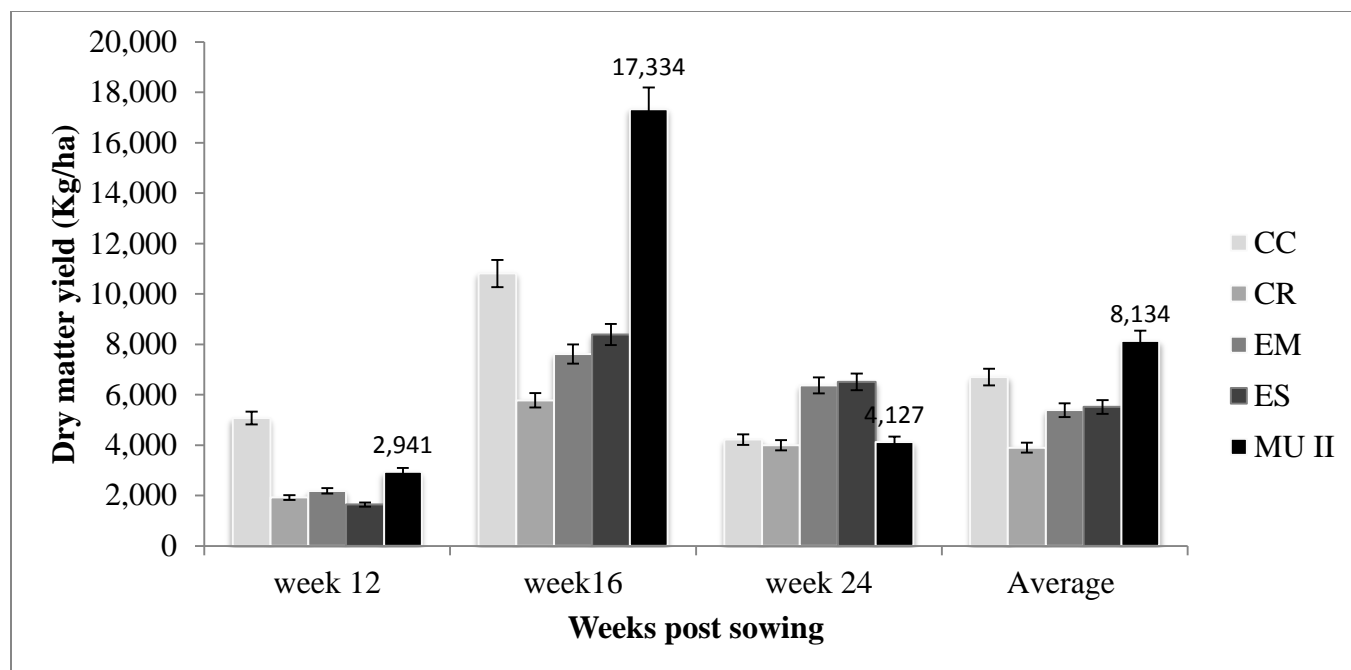
Figure 4.2. Mean dry matter yields of *Brachiaria* hybrid (Mulato II) and four local grass species at the end of weeks 12, 16 and 24
Key: CC = *Cenchrus ciliaris*, CR = *Chloris roxburghiana*, EM = *Enteropogon macrostachyus*, ES = *Eragrostis superba*, MU II = *Brachiaria* hybrid (Mulato II)

4.1.6.1 Derivedstocking rates

Computed stocking rates of expected TLUs from the DM harvested at week 12, 16 and 24 post

sowing were as shown in table 4.2 below. The highest TLUs of 86.7 at week 16 wererealizedby

Brachiaria hybrid Mulato II, followed by C. ciliaris with 54.1 TLUs.*Chloris roxburghiana* was

the species that supportedthe least TLU's across the different weeks.

Table 4.2Mean stocking rates (TLUs/ha) of 5 experimental grass species as at week 12, 16 and 24 post sowing

Stocking rates (TLUs/ha)			
Species	**Week 12**	**Week 16**	**Week 24**
C. ciliaris	25.3	54.1	21.1
C. roxburghiana	9.6	28.9	20.0
E. macrostachyus	10.9	38.1	31.9
E. superba	8.2	42.0	32.5
Brachiaria hybrid	**14.2**	**86.7**	**20.6**

4.1.7   Reproduction parameters

4.1.7.1   Flowering

Less than 2% of the *Brachiaria* hybrid (Mulato II) shoots flowered even after 13 weeks (Figure 4.3) compared with*C. ciliaris* and *E. superba* achieved c. 40% flowering on the 8th week. *Enteropogon macrostachyus* and *C. roxburghiana* dramatically increased in blooming on the 8th and 10th week, respectively. *Cenchrus ciliaris*, *E. superba* and *E. macrostachyus* attained 100% flowering on the 13th week, while *C. roxburghiana* attained 60% flowering at about the same time. Among the local species*, E. superba* had the highest number of inflorescence heads per crown (c. 31) followed by *C. ciliaris* with c. 18 and *C. roxburghiana* with c.8 (Figure 4.4).
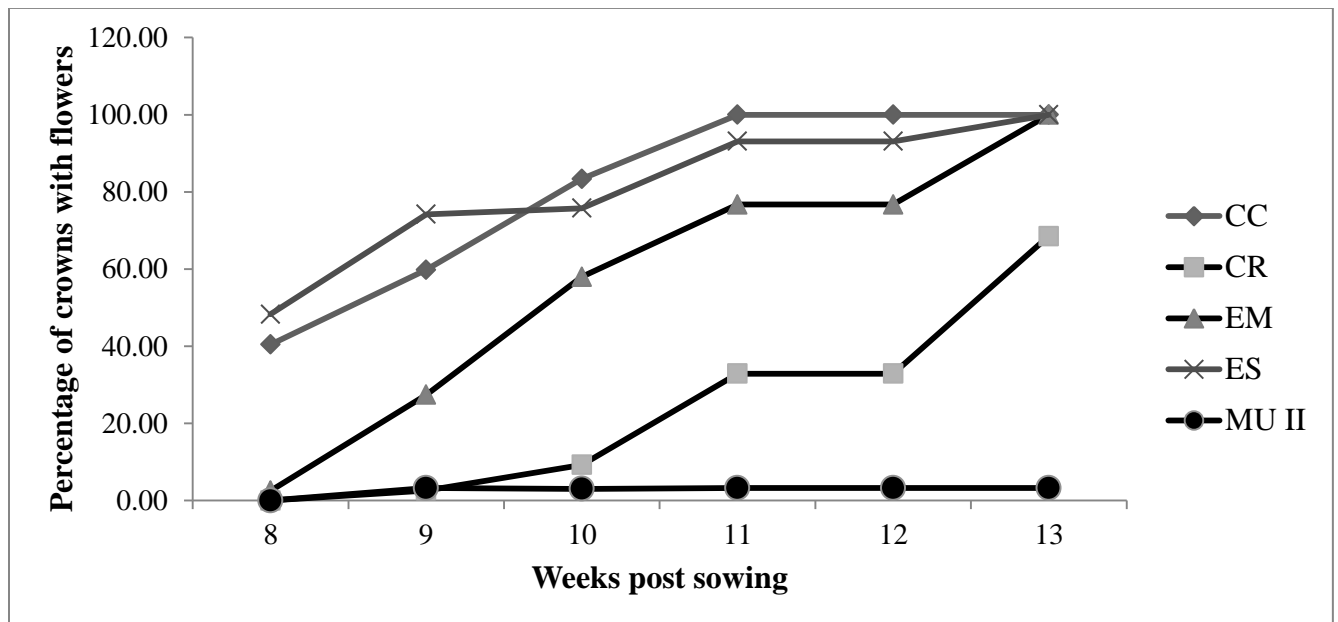
Figure4.3. Mean percentage number of crowns with inflorescence of 5 experimental grasses between week 8 and 13
Key: CC = *Cenchrus ciliaris*, CR = *Chloris roxburghiana*, EM = *Enteropogon macrostachyus*, ES = *Eragrostis superba*, MU II = *Brachiaria* hybrid (Mulato II)
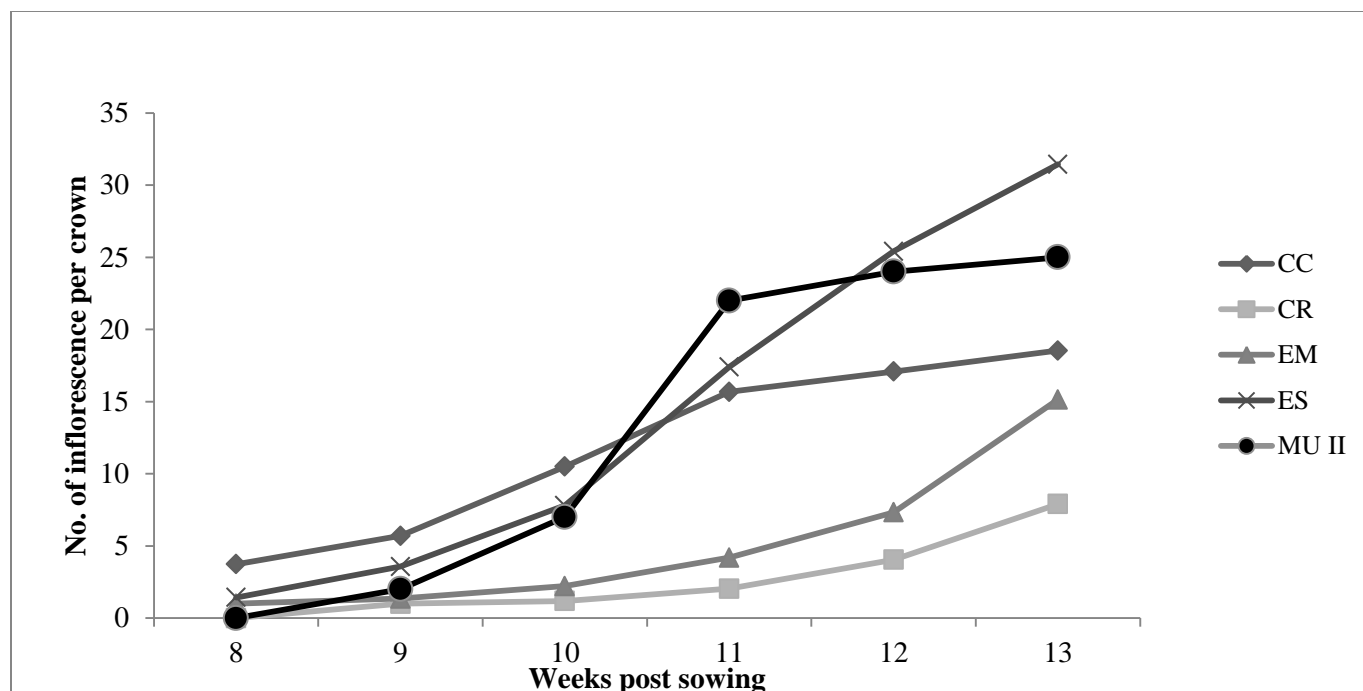
Figure 4.4. Mean number of inflorescence heads per crown of 5 experimental grasses between 8 and 13 weeks post sowing
Key: CC = *Cenchrus ciliaris*, CR = *Chloris roxburghiana*, EM = *Enteropogon macrostachyus*,
ES = *Eragrostis superba*, MU II = *Brachiaria* hybrid (Mulato II)

4.1.7.2 Seed production

Since very few (<2%) of the *Brachiaria* hybrid shoots flowered, no seeds were harvested for the entire study period. Among the local species, *E. superba* produced the highest amount of seeds (c.803.2kg/ha) followed by *E. macrostachyus* (c.542.8kg/ha). *Chloris roxburghiana* (c.128.4kg/ha) and *C. ciliaris* (c. 53.6kg/ha) ranked third and fourth, respectively (Table 4.3). The interval between blooming and seed maturity varied among the species. *Cenchrus ciliaris* and *E. macrostachyus* took about 3 weeks; *C. roxburghiana* took 4 weeks and *E. superba* 5 weeks.

Table 4.3. Mean seed yield (Kg/ha) of 5 grass species at 13 weeks post sowing

Species	Seed yield (Kg/ha) + S.E
C. ciliaris	$53.6^d \pm 10.1$
C. roxburghiana	$128.4^c \pm 25.3$
E. macrostachyus	$542.8^b \pm 38.4$
E. superba	$803.2^a \pm 92.8$
***B*. hybrid (Mulato II)**	-
P-Value	<0.0001

Means within the same column with different superscriptsare significantly different at p<0.05.

4.1.7.3   Seed germination

Mulato II hybrid seeds were not available for this test since none were harvested. For the other four species, germination rates varied significantly (p<0.05) (Figure 4.5) with *E. macrostachyus* seeds showing extremely early and high germination rate. About 98% of the seeds germinated within 24 hours. *Cenchrus ciliaris* and *E. superba* were the next most prolific, germinating after 24 hours, and attaining about 58% germination rate after 14 days. *Chloris roxburghiana* was the slowest in germination rate, attaining c.20% after 3 days and not exceeding 28% germination after 14 days.
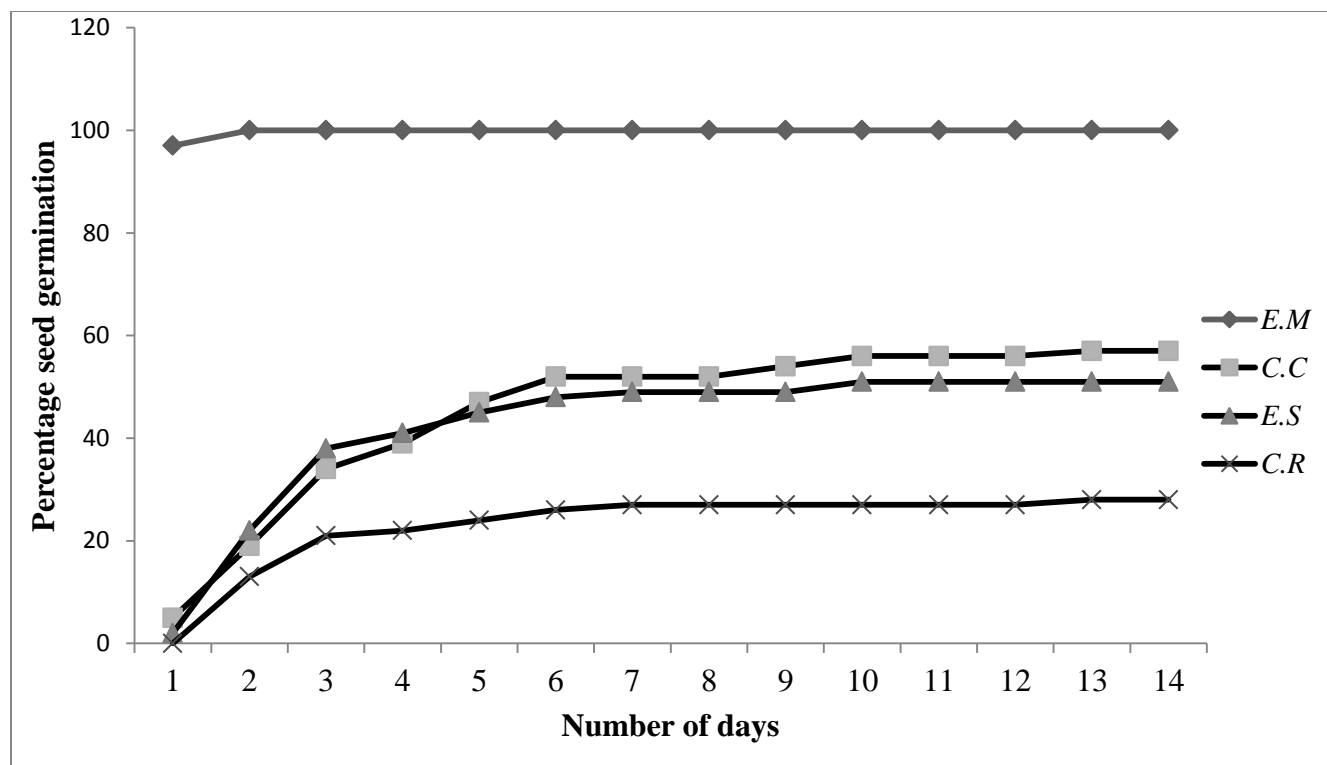
Figure 4.5. Cumulative seed germination rate (%) of 5 grasses over 14 day period
Key: CC = *Cenchrus ciliaris*, CR = *Chloris roxburghiana*, EM = *Enteropogon macrostachyus*,
ER = *Eragrostis superba*

4.1.8   Forage quality

In terms of forage quality, *Brachiaria* hybrid (Mulato II) outperformed the local species having

attained significantly (p<0.05) higher ash and EE content than all the local species (15.8% and

2.5%). It was at par with *E. superba* and *E. macrostachuys* in CP content (c.13%) but second to

C. roxburghiana (c.14%). In terms, of NFE composition, it was second after *E. macrostachyu*s

(38.3% vs 39.5%). It was least in CF(c.29.9%) and ADF (c.30.1%) (Table 4.4).

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Table 4.4. Mean(%) of Proximate Feed Composition (DM, Ash, EE, CP, NFE AndCF) and Detergent Fiber (NDF And ADF) of *Brachiaria*Hybrid and 4 Native Range Grasses at 12 Weeks

Species	DM	ASH	EE	CP	NFE	CF	NDF	ADF
E. Superba	95.9[c]±0.5	10.2[d]±0.2	1.9[c]±0.1	13.0[b]±0.3	38.3[b]±0.2	35.5[a]±0.3	79.9[c]±0.4	33.4[c]±0.4
Brachiaria hybrid	**99.6[a]±0.1**	**15.8[a]±0.2**	**2.5[a]±0.1**	**13.3[b]±0.4**	**38.0[b]±0.3**	**29.9[b]±0.4**	**81.2[b]±0.4**	**30.1[d]±0.5**
E. macrostachyus	98.2[b]±0.2	11.4[c]±0.4	2.3[ab]±0.1	13.4[b]±0.2	39.5[a]±0.2	33.9[ab]±0.5	80.4[c]±0.5	37.1[b]±0.4
C. ciliaris	93.4[d]±0.4	14.5[b]±0.2	2.2[b]±0.1	10.8[c]±0.2	37.1[c]±0.1	34.7[a]±0.4	84.7[a]±0.4	41.0[a]±0.4
C. roxburghiana	94.9[c]±0.2	13.6[b]±0.1	1.4[d]±0.1	14.8[a]±0.1	35.4[c]±0.2	35.1[a]±0.3	78.9[d]±0.1	37.2[b]±0.5
P-value	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001

The table is headed by **% Feed components + SE**.

Means within the same column with different superscripts are significantly different at P<0.05. Superscripts a to d indicate high to low values**.**

Key: DM=Dry matter, EE= Ether extract, CP= Crude protein, CF= Crude fiber, NFE= Nitrogen free extracts, NDF= Neutral detergent fiber, ADF= Acid detergent fiber

4.1.8.1 Dry matter intake, digestible dry matter and relative feed value

Mulato II had the highest DDM and RFV followed by *E. superba,* while *C. ciliaris* had the

lowest. In terms of DMI, Mulato II compared favourably with the local species with an intake of

about 1.5% of animal's body weight (Table 4.5).

Table 4.5. Mean(%) Dry Matter Intake (%), Digestible Dry Matter (%)And Relative Feed Values Of The 5 Grass Species

	DMI%	DDM% (TDN)	RFV
Species			
Eragrostis superba	1.5	62.9	73.2
Brachiaria hybrid	**1.5**	**65.5**	**75.0**
Enteropogon macrostachyus	1.5	60.0	69.4
Cenchrus ciliaris	1.4	57.0	62.6
Chloris roxburghiana	1.5	59.9	70.6

Key: DMI=Dry matter intake, DDM= Digestible dry matter, RFV=Relative feed value

Figure 4.6 shows how the 5 grass species fared in terms of crude protein, fiber fractions (ADF and NDF), and digestible dry matter fractions.
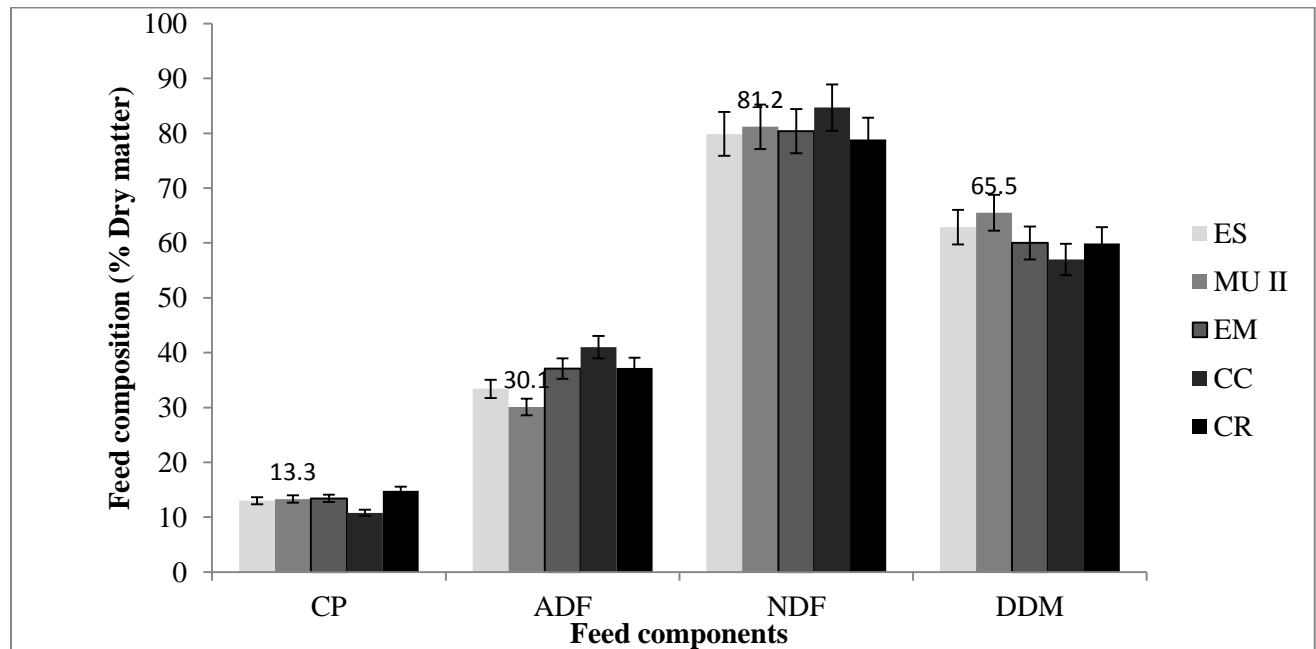

Figure 4.6. Mean Crude protein (CP), Acid detergent fiber (ADF), Neutral detergent fiber (NDF) and Digestible dry matter (DDM) of B. hybrid (Mulato II) and 4 local range grasses
Key: ES = *Eragrostis superba*, MU II = *Brachiaria* hybrid (Mulato II), EM = *Enteropogonmacrostachyus*, CC = *Cenchrus ciliaris*, CR = *Chloris roxburghiana*

4.2   Discussion

4.2.1   *Plant height*

The morphological and physiological differences among five grass species in this study can be attributed to their genotypic and phenotypic differences. The vertical growth habit of *C. ciliaris*, for example, explains in part why it was the tallest, while *Brachiaria* hybrid (Mulato II), which has semi erect culms (Pizarro *et al*., 2008) was the shortest. Normally, species that germinate and grow fast with erect culms tend to be taller than those with slower germination and growth rate and semi-erect culms. As reported by Opiyo (2007), Mganga (2009) and Ogillo (2010), pasture species which grow fast and tall are more efficient in use of resources and therefore, are more competitive. Such species eventually shade out the other species if planted in mixed stands thereby, suppressing their growth. In this case, if Mulato II was to be planted in mixtures with the local grasses, its growth may be suppressed due to shading from taller grasses such as *C. ciliaris*. However, height may not be an important estimate on the expected biomass yield, as it has been clearly demonstrated that the shortest species (Mulato II) at the end of week 12, had the second best primary DM yield after *C. ciliaris*.

4.2.2   *Plant density*

Plant density is a function of seed germination rate, seedling establishment and survival. In this study, the marked difference in plants density between week 4 and 8 was attributed to species differences in seed germination rates. This is evident in *C. roxburghiana* and *E. superba* which had a lower density than the other three species due to delay in breaking their dormancy. Local species with high plant density like *E. macrostachyus* have been shown to have higher seed viability (Opiyo, 2007; Mganga, 2009) which has been attributed to their faster seed germination

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and establishment. Other studies (Went, 1973; Ogillo, 2010) have attributed low density of plants species to suppression by the more competitive ones. The decrease in density of all the grass species in this study observed between week 8 and 12 can therefore, be attributed to species competition that may result in phasing out of weaker seedlings. In addition, the variations in plant density could also be partly explained by the amount of seeds a species has per unit weight. In this study, the sowing rate was based on weight of seed material (5 kg/ha) rather than the number of seeds per unit weight. It is known that the same quantity of seed materials contains different number of seeds, which accounts for differences in plant density after germination. Nakamanee et *al.* (2008) reported that Mulato II contains 140,000 seeds/kg which could probably explain in part why it had the lowest plant counts in this study. Bogdan and Pratt (1967) reported 6.6 and 0.7 million seeds/kg for *C. roxburghiana and C. ciliaris*, respectively. It therefore, follows that grass species with light seeds (higher seed per unit weight) will most likely have higher plant density than those with bigger and heavier seeds(lower seeds/unit weight). All this is based on the assumption that seed viability and other factors are similar, which is highly unlikely.

4.2.3   Tiller density

This is an important attribute of grasses as it increases the chances of survival and amount of available forage (Skerman and Riveros, 1990; Laidlaw, 2005). Moreover, it is an indicator of resource use efficiency by the different grass species. The large numbers of tillers produced by some grass species allows them to attain maximum growth at an earlier age and recover faster after defoliation (Laidlaw, 2005). Tillering is also important in forage plants, because of its influence on leaf-area production and dry matter yield. A high rate of tillering complements both

yield and resilience of a grass stand under defoliation (Mganga, 2009). The distinct variation in tiller densities exhibited by the five grass species examined in this study implies that *E. macrostachyus* and *C. ciliaris* would recover faster than the other three species after defoliation. This is contrary to the findings of Ogillo (2010) who observed no significant variation among the local species he studied. Thefinding of this study was, however, similar to findings by Mganga (2009) who found out that the tiller density differed among the local range grasses.

4.2.4   *Ground cover*

Ground cover is an important attribute of any vegetation, especially in relation to soil and water conservation. It is also an important parameter in restoration of degraded areas, where moisture is the main limiting factor. Species which spread rapidly on the ground are more desirable than those which have more vertical growth. In this study, *Brachiaria* (Mulato II) and *C. ciliaris* exhibited the fastest rate of lateral spread (ground cover) and enhance higher soil and water conservation. The mean ground cover differences noted at the end of week 8 were attributed to the differences in seed germination and establishment rate among the species. *Brachiaria* (Mulato II) demonstrated a sharp increase in ground cover between week 8 and 12. This was partly attributed to the CAN fertilizer which was applied around week 8 after sowing. Similar observations were reported by Urio et *al*. (1988) and Argel *et al*. (2007). Mganga (2009) reported similar results among local species, with *C. ciliaris* being the best of four local grasses in terms of rate of horizontal spread.

4.2.5 *Dry matter production*

Dry matter productivity by all herbaceous plants holds the key to livestock productivity (Hare et al., 2009). Grasses which yield the highest DM should be the most sought since they can supply the highest amount of forage to livestock.This supports stocking rates derived from DM yielded by various grass species in this study. Mulato II high stocking rates as at week 16 is owed to its high DM produced.

Variations in DM production across the species can be attributed to differences in growth rate and growth habit, which are mediated through the genotypic and phenotypic differences. This is a common phenomenon in grasses (Chelishe and Kitalyi, 2002; Mnene, 2006; Opiyo 2007; Mganga, 2009; Ogillo, 2010). In this study, the high primary DM yield by*Brachiaria* hybrid (Mulato II) can be largely attributed to its large size leaves (15-2" long) and thick stems (1-1.5" width) (Guiot and Melendez, 2003). However, the leafy nature might be a disadvantage in dry areas where water supply is limited, as it facilitates rapid water loss through transpiration (Pratt and Gwynne, 1977; Mnene, 2006). Results of studies in Thailand by Hare *et al.* (2009) and in Rwanda by Mutimura and Everson, (2012) showed that *Brachiaria* cultivars, Mulato and Mulato II attained the highest primary forage productions. Mutimura and Everson (2012) found that the two cultivars outperformed *C. ciliaris,*which had the lowest DM, yield. Mulato II yielded approximately 8.3t/ha compared to *C. ciliaris* with 1.6t/ha. *Cenchrus ciliaris* high DM yield obtained from this study was due to its faster growth and establishment rate than the other local grasses. It has also been reported as one of the most adapted and prolific species in the ASALs of Makueni Countyin Kenya (Mganga, 2009; Ogillo, 2010).

The dramatic decrease in regrowth dry matter yield was largely attributed to moisture stress because the plots were not irrigated after week 16. In addition, the time interval was shorter (16 weeks vs. 8 weeks). Generally, all the species tested exhibited higher primary and secondary (regrowth) DM yields than reported in several other previous studies (Mutimura and Everson, 2012; Opiyo, 2007; Ogillo, 2010). Mutimura and Everson (2012) reported higher DM yield of Mulato II than those that of the local species in the low rainfall areas of Rwanda. However, primary DM yield in Mutimura and Everson's study were much lower than those of this study (c.16t/ha Vs c.10 t/ha). Ogillo (2010) reported lower DM yield from three local grasses, (*C. ciliaris*, *E. macrostachyus* and *E .superba*) than those reported in this study. *Cenchrus ciliaris* yielded c. 4.3t/ha at the end of week 12, compared to c.5.1t/ha recorded in this study.

Generally, higher regrowth biomass yields are expected from most grasses than those found in this study, a phenomenon largely attributed to three factors: i) higher tiller production (Eckard and Wasserman, 2000; Wolfson, 2000). Wolfson (2000) reported that shoots or tillers that remain undefoliated for long become moribund and may cease to produce other stems; ii) increased light penetration through the pasture sward. Several workers reported that increased light intensity after clipping stimulated the regrowth of grass tillers and secondary branches from legume plants (Humphreys, 1978; Boonman, 1993; Wolfson, 2000). This enhanced light intensity may also stimulate germination of seeds and growth of other seedlings which later produces additional biomass; iii) the stage of maturity of grasses. The effect of this factor was expounded by Pratt and Gwynne (1977) who argued that when grass plants are about to shift from vegetative to reproductive phase, close cutting can prevent formation of flowering shoots, and instead promote faster growth of leaves and production of more secondary branches.

4.2.6 *Flowering, seed production and seed quality*

Future survival of grasses is determined by their ability to produce seeds and other reproductive organs like tillers. Seed production is a function of the genotypic and the environmental conditions prevailing during the growth period. Therefore, grasses with high numbers of reproductive tillers and which later produce more seeds. The type of inflorescence (panicle, raceme and spike), its size, pollination, seed harvesting methods, among others, affect seed yield. The failure of Mulato II to produce seeds in this study was largely attributed to its late seeding characteristics. A number of previous studies have reported this seeding pattern (Hare *et al*., 2007; Argel *et al*., 2007).

The different quantities of seeds produced by the different grass species in this study were therefore attributed to the different genetic characteristics of the grasses as well as species interaction with the environmental conditions. Although Mulato II did not produce any seeds during the study period, this does not mean that it does not seed at all. It is a late seeder as it produced some seeds after 40 weeks. Plants which flower late in the season are considered more beneficial than those species those which flower early. Early flowering lowers the quality of forage on offer by having a low leaf: stem ratio and the proliferation of floral stems. The growth of Mulato II is completely vegetative during the rainy season (Argel *et al*., 2007) and this offers more stable grazing. The development of Mulato II cultivar was aimed at producing a more prolific *Brachiaria* cultivar in seed production (Hare *et al*., 2009). In that light, some substantial amount would have been harvested if the study would have gone beyond week 40 when Mulato II was observed to set seeds.

Eragrostis superba's high seed yield was attributed to: i) the high number of reproductive shoots, and; ii) the long panicle type of inflorescence (c. 16mm long) (Ogillo, 2010). The species further exhibited a high rate of flowering spread over a relatively longer period than the other species. The low seed yield observed in *C. ciliaris,* on the other hand, was attributed to the morphological nature of inflorescence and seeds. The hairy nature of the seeds makes them light (cotton like). Previous studies have also reported *E. superba* as a superior range grass in terms of seed production (Mganga, 2009; Ogillo, 2010; Bulle *et al.*, 2011). However, in this study, all species had higher seed yields than those reported by Mganga (2009) and Ogillo (2010). The results of this study match those of Bulle *et al*. (2011), who found E. superba to yield high seed quantities (over 700kg/ha) compared to the other local grasses.

4.2.7   *Seed Germination*

The huge differences in seed germination rates among the four local grass species is attributable to the varying intrinsic properties of the seeds such as dormancy and tegumental hardness. Higher percent seed germination of *E. macrostachyus* may be explained by its dormancy mechanism which involves only the integument while the other three species may have both the embryo and the integument related dormancy (Bryant, 1985; Keya, 1998; Mnene, 2006; Opiyo, 2007; Mganga, 2009; Ogillo, 2010). The hairy bristle coat of the *C. ciliaris* fascicles is likely to have also aided its germination by maintaining high humidity within the fascicle which helps in minimizing loss of water from the caryopsis (Silcock and Smith,1982; Sharif-Zadeh and Murdoch, 2001), compared to that of *E. superba* and *C. roxburghiana*. Grasses have innate different tolerances to moisture stress (Veenendaal, 1991; Opiyo, 2007), which may also further explain the difference in germination rates among the four grasses.

Seed germination is a function of among other factors seed viability. High seed viability means high seed germination. Highly viable seeds are desirable since they give the plant seedlings a competitive advantage other plants with low seed viability (Kadmon and Schimida, 1990; Keya, 1998). The faster any seed germinates, the higher the chances of its survival and subsequent establishment (Ernest and Tolsma, 1998; Chin and Hanson, 1999). It is therefore, expected that *E. macrostachyus* could stand a better chance of survival and establishment than *C. ciliaris*, *E. superba* and *C. roxburghiana* under the same field conditions. However, conditions in the laboratory may not mirror those in the field. Other factors in the field such as soil moisture, suface hard crustand predation may make quality seeds not to germinate. Delay in seed germination can sometimes be beneficial in cases where rainfall patterns have initial storms followed by a protracted dry spell. This results in fewer seedlings being affected by drought and that a substantial amount of seeds will still be available. Contrary to this argument, however, plant species which germinate late may miss the rainy season before they reach maturity (Mnene, 2006).

4.2.8   Forage Quality

4.2.8.1   Crude Protein (CP)

Crude protein (CP) and digestible dry matter (DDM) are the most important components of a feed (Afzal and Ullah, 2007). Crude protein content from all the plant materials analyzed met the miniumum requirements for ruminants (>7%), i.e., 6.9 % for maintenance, 10.0 % for beef production and 11.9 % for milk production; Humphreys, (1978). *Brachiaria* hybrid cv. Mulato II had a CP content which was almost double the minimum requirement. These values were higher than those reported byMutimura and Everson (2012) which had a CP of 11.1%. Higher CP

reported in this study can be partly attributed to the CAN fertilizer that was applied. Such relationship has been reported by Minson (1992) and Whitehead (2000), who found that the CP content of grasses depends on soil N availability and that N fertilization increases it.

4.2.8.2   Crude Fiber Content

Brachiaria hybrid cv. Mulato II would be the species that would best meet ruminant nutritional requirements based on its digestibility. This follows its relatively lower fibre content compared to the local species. According to Topps (1996), fibrosity of forages indicates the extent to which it can be degraded by rumen micro-organisms. In addition, various authors (Church, 1980; McDonald *et al*., 1981; Crowder and Chheda, 1982; Topps, 1996; Theron and Snyman, (2004) and Nsinamwa*et al*.(2005) concur on the fact that the fibre content in forage increases with age and that the higher the fibre fractions, the lower the digestibility. In this study, all the species were of the similar age (12 weeks old). However due to differences in species genetic makeup, mediated through, among other things, growth rate, and age, fibrosity was different. The higher fiber content in the local grasses, therefore, can be attributed to their phenological stage. They attained reproductive stage earlier than Mulato II. Furthermore, increase in CF content is accompanied by increase in lignin content in forages. The forages, therefore, become less digestible because they are inaccessible to digestive enzymes (Crowder and Chheda, 1982).

The NDF content of forage varies widely, depending on species, maturity, and growing environment (Nelson and Moser, 1994; Buxton and Fales, 2004; Mahyuddin, 2007). Therefore, each plant species presents a unique NDF-ADF ratio in the feed. For legumes, <40% NDF content is classified as good quality forage, while > 50% (van Saun, 2006) is considered as poor

quality forage. For grasses, < 50% NDF is considered high quality and > 60% as low quality forage. In this study, forage materials from all the grass species had >60% NDF which may account for the low intake and digestibility.

4.2.8.3   Ash Content

The ash quantity of ash in any feed is a positive indicator of the inorganic (minerals) content. Generally, most forages have ash content ranging from 3% to 12% (Linn and Martin, 1999). All the five species investigated in this study had more than 12% ash content. Mulato II had 16% ash content, which was much higher than those reported by Kungwan *et al*. (2010), of 6%. Mutimura and Everson, (2012) have reported calcium (Ca.) content of 2.1 % and 0.8% phosphorus (P) in Mulato II ash.

4.2.8.4   Nitrogen Free Extract

Nitrogen free extract (NFE) represents the proportion of a feed that is made up of non-fiber carbohydrates mainly sugars and starches (Hall, 2003). Forages with high levels of NFE are desirable and valuable since they provide highly digestible carbohydrates. In this case, *E. macrostachyus* would be the species of choice followed by *Brachiaria* hybrid (Mulato II). However, for ruminants, this proportion may not be very significant as ruminants are able to digest fiber carbohydrates. It has also been documented that different forages with the same fiber content may differ substantially in terms of rate of degradation in the rumen (Grant *et al*., 1995; Dado and Allen, 1996). High growth rates of cattle and high milk production in cattle have been reported from feeds that were considered poor (low levels of digestible carbohydrates)

(Tinshuang and Zhenhai, 1994: Dolbergand Finlayson, 1995). Therefore, low non-fiber content of forages, *per se*, may not account for the entire increase or decrease in ruminant performance.

4.2.8.5   *Ether Extracts (EE)*

Ether extract (EE) represents the lipid or crude fat fraction of a feed. It is an important energy source in the diet with over 2% more energy than carbohydrates. The relatively higher EE content of *Brachiaria* hybrid cv. Mulato II implies that it provides higher energy to livestock than normal carbohydrates if consumed in large enough quantities. Ether extracts have been considered as both beneficial and detrimental feed ingredients for ruminants, depending on the level of inclusion in the feed (Palmquist, 1988). They are reported as nutritionally beneficial at 4-5% level. Forages with more than 5% EE depress digestibility of feed in the rumen (van Houtert&Leng, 1993). However, forages with higher than 5% EE require calcium supplementation to increase digestibility and energy supply (Leng, *et al*., 1992).

In this study, forage materials from all the species contained less than the optimum recommended EE content. This implies that the quantities of EE in these forages would be an important energy source if consumed by ruminants. However, *Brachiaria* hybrid cv. Mulato II would provide the highest energy source. Previous studies by Kungwan *et al*. (2010) reported much lower values of EE of 1.2 %. This could be attributed to, among other factors, the age of forage material and environmental differences.

4.2.8.6   Relative Feed Value

Relative feed value (RFV) is an index which combines important nutritional factors such as intakes and digestibility into one unit which provides an indication for the quality of the feed(Linn, and Martin, 1999). Although, the index value has no biological meaning, Ørskov (2000) suggested that forage with an index of 30 can provide enough energy for maintenance. The forage quality ranking of grasses were justified by dry matter intake (DMI), digestible dry matter intake (DDMI) and Index value. The results of this study agree with those found by Kungwan *et al*. (2010), which suggested that Mulato II had the highest RFV index among the *Brachiaria* species study in Thailand. However, those results were much lower than ones in this current study (RFV c. 53.1 Vs.75).

5   CONCLUSIONS AND RECOMMENDATIONS

5.1   Conclusions and Recomendations

In conclusion,*Brachiaria* hybrid cv. Mulato II isa superior species in both forage quantity and quality. It has a big potential to provide better ruminant nutrition if promoted in the study area. The high quantity of biomass from Mulato II of high quality would mean high livestock returns in the study area.Livestock productivity depends on forage quality and quantity. Findings from this study show that *Brachiaria* hybrid (Mulato II) has the potential of providing a good source of livestock feed in the semi-arid rangelands of Kenya. This is supported by its high DM yield, high number of livestock units it can support and superior nutritional quality to local species (*C. ciliaris, E. macrostachyus, E. superba* and *C. roxburghiana*). If similar results will be maintained under field conditions, then problems of inadequate quality and quantity in the ASALs will be partly solved.

Mulato II seed production was not successful at the end of the study period. This delayed seed production by Mulato II, would imply alternative means on its propagation. The use of vegetative propagation may be considered on instances where seed may not be harvested. Furthermore, Mulato II is a hybrid grass species, its adaptation, habit and growth may be different from the other natural occurring pastures. Studies on new gene and environmental interactions are necessary to find out whether is a suitable species to avoid instances of invading introduced areas.

Cenchrus ciliaris was the superior local species overall in terms of biomass production, stocking rates and growthparameters while *C. roxburghiana* emerged as the inferior species overall.However, studies on how to improve the performance of the all four grasses should be undertaken especially for *C. roxburghiana* which recorded the lowest performance.The feed

quality reported on this study is only laboratory analysis, therefore,studies on feeding trials by range animals will be necessary to compare its preference and marginal output (body weight/ milk yield) if it mirrors these results. Additionally, feeding trials and chemical analyses need to be conducted to authenticate the nutritional value of the forage species.

Studies on competitive interactions among grass species should be done for a longer period to conclusively ascertain the seasonal competitive interactions among the grass species.The grass species tested in this study had different characteristics. They all had different desirable attributes. This study, therefore, recommends their production in mixed stands in cases where pure seeds are not required for harvesting.

Finally, this study has not been replicated in space and time and, therefore, it cannot be inferred across the ASALs of Kenya. Hence, future research on performance of Mulato II on various soil types, as opposed to on station experiments undertaken under this study, prevailing moisture conditions and at different locations is needed to determine further adaptability of Mulato II to Kenya's rangelands

5.2   Study limitations

The findings in this study have limited inference space, since the study was not replicated in time and space. It was conducted at KARI-Kiboko Station and for only one season. Furthermore, because the study was conducted under irrigation, the results may not be directly applicable to rain-fed conditions, which is prevalent under normal farming conditions.

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