

**EVALUATION OF INDIGENOUS GRASS SPECIES
SUITABILITY FOR REHABILITATION OF
DEGRADED SEMI-ARID RANGELAND IN
SUSWA, KENYA**

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DECLARATION AND APPROVAL

This thesis titled “*Evaluation of indigenous grass species suitability for rehabilitation of degraded semi-arid rangelands in Suswa, Kenya*” is my original work and has not been presented a degree in any other academic institution.

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DEDICATION

To my parents Samuel and Naomi for your love and the gift of education

To my siblings Carol and Ndung'u for being the cushion when this journey soar 😊

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I most importantly thank God for granting me wisdom and health through this journey. Forever I will praise His name, Amen!

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ACRONYMS

ASALs	Arid and Semi-Arid Lands
CRD	Completely Randomised Design
FGDs	Focus Group Discussions
GEF	Global Environmental Facility
ILRI	International Livestock Research Institute
RD	Root Density
RLD	Root Length Density
SDR	Sediment Detachment Rate
SLM	Sustainable Land Management
SWC	Soil and Water Conservation
UNDP	United Nations Development Programme

ABSTRACT

Increasing soil erosion in Africa's arid and semi-arid rangelands calls for requisite measures to reverse the trend. Although physical soil and water conservation (SWC) structures are effective in controlling soil erosion, they are capital intensive and therefore often not affordable to a majority of local communities. Pastoral communities require cheaper, labour effective and use of locally available materials that are adapted for rehabilitation of degraded land. In response, grasses with good rooting ability and adapted to the local climatic conditions could be one of the cost-effective measures to rehabilitate the degraded lands. The study aimed at evaluating the efficacy of different range grasses to reduce soil erosion as well as provide fodder for livestock. The study objectives were to 1) find out the grass species suitable for rehabilitation of degraded land from the community perspective; 2) evaluate the efficacy of the selected grasses for erosion control and, 3) determine the morphometric characteristics and above ground biomass yields of the preferred grasses.

Using household survey, focus group discussions (FGDs), key informant interviews (KIIs) and direct observation, grasses suitable for rehabilitation of degraded lands were selected by the community. *Cynodon plectostachyus* (76%), *Chloris gayana* (73%), *Pennisetum clandestinum* (69%), *Cymbopogon citratus* (46%) and *Themeda triandra* (42%) were perceived as suitable for rehabilitation of the degraded rangelands. Fodder provision by the grasses came primary to soil conservation.

A completely randomised design (CRD) experiment with three replications was conducted to determine the potential of *C. plectostachyus*, *C. citratus*, *C. gayana*, *Cenchrus ciliaris*, *Enteropogon macrostachyus* and *Eragrostis superba* for soil erosion control. Simulated rainfall of 116 mm hr⁻¹ intensity was used to determine runoff and sediment yield from soil blocks

measuring 25cm x 25 cm x 30 cm under simulation experiment. After erosion simulation, the soils were washed off the selected grass species to get the belowground biomass. Percolation, sediment yield and runoff were significantly ($p \leq 0.05$) influenced by grass species. Sediment yields varied between 1.01t ha⁻¹ and 27.50 t ha⁻¹ among the grasses species, while sediment detachment rate (SDR) decreased with maturity of the grasses. The root biomass was significantly ($p \leq 0.05$) different among the treatments with the control (naturally regenerated areas) having the highest (8.22 kg m⁻³) among the treatments, and *C. gayana* the lightest (0.455 kg m⁻³) among the grass species. The average root diameter of the treatments was 0.6059 mm. *Cynodon plectostachyus* had the longest fine roots of <1 mm in diameter (1119cm), while *E. superba* had the shortest (646cm). *Cynodon plectostachyus* had the highest root density (0.3924 km m⁻³), while *E. macrostachyus* had the lowest (0.0677 km m⁻³).

Aboveground biomass production was relatively low but significant ($P \leq 0.05$) in all the treatments as compared to other studies that have been done. *Cynodon plectostachyus* had the highest biomass yield (0.9 t ha⁻¹) while *E. superba* had the lowest (0.424 t ha⁻¹). Plant height measured from the base of the plant to the tip of the leaf of the primary shoot varied amongst the grass species with the tallest being *C. plectostachyus* with 36.6 cm and the least being *E. superba* with 2.47 cm. The number of tillers and leaves per tiller increased with the maturity of the grasses. *Cynodon plectostachyus*, *C. ciliaris* and *E. macrostachyus* produced more tillers than the other four grass species. This study found positive significant correlation between the biomass yield and the morphometric characteristics.

The results of the study show that communities' indigenous knowledge on species suitable for rehabilitation and for fodder provision is very precise and important as community perceptions and priority differ with locality and their needs. *Cynodon plectostachyus*, *C. citratus*, *C. ciliaris*

and *C. gayana* were identified as the most effective for controlling erosion as well as most productive for livestock feed. Owing to the different perceptions, priorities and need for different communities, this study recommends a site-specific choice of grass species for rehabilitation with the guidance of local community if reversing land degradation and improving the livelihoods of the people is to be achieved. Decision-making is guided by the challenges affecting the local communities' livelihood. Although the results of this study give indications of the potential of the various grass species in controlling soil erosion, a longer study with different ecotypes of the grasses is required to monitor the efficacy of the identified indigenous grasses in combating range degradation.

Keywords: Range grasses, Suitability, Rehabilitation, indigenous knowledge, Suswa

CHAPTER ONE

General Introduction

1.0 Introduction

Land degradation is a global problem that has received a lot of attention given the magnitude of people affected, the vastness of the affected areas and the annual rate at which it encroaches into the non-degraded areas. An estimated 75 billion tons of productive soil has been lost to the processes of degradation and an estimated 5-10 Million ha are prone to land degradation annually (Lal *et al.*, 2012). Over 40% of the earth is degraded (MEA, 2005), with 74% of the earth being the African landmass. Most of these lands are partially to severely degraded in the Arid and Semi-arid Lands (ASALs), however, there is no consensus on the accurate extent and severity of the land degradation in East Africa (Maitima *et al.*, 2009; Tully *et al.*, 2015). In Kenya, more than 80 % of the land is classified as ASALs and is characterised by highly variable and unpredictable climate (Nyangito *et al.*, 2008; Miriti *et al.*, 2012). Pastoralism makes the best livelihood option in these areas compared to other livelihood options like farming.

In Kenya, land is the most strategic natural capital that forms the backbone of the country's subsistence and national economy (Odini *et al.*, 2015). Efforts of production in high potential areas and ASALs has been curtailed by land degradation. Land degradation is a consequence of climate change and variability as well as anthropogenic activities. Human factors include production, unsustainable logging for charcoal poor cultivation methods on marginal and slope cultivation and overgrazing (Sindiga, 1984; Maina, 2013; Kirui and Mirzabav, 2014; Odini *et al.*, 2015). These human factors result from economic, environmental and social pressures, ignorance and increased drought frequencies. The main forms of land degradation are soil erosion, desertification in drylands, waterlogging, and salinisation (Kirui and Mirzabaev, 2014).

Soil erosion as a form of land degradation is globally widespread (Lal, 2014) and a major threat to livelihoods (Pimentel, 2006; Mullan, 2013). In Kenya, soil erosion is the leading form of land degradation (Mganga *et al.*, 2010). The erosion processes involve detachment, transportation, redistribution and disposition of soil (Lal, 2014). The two types of soil erosion most far-flung are wind and water erosion. In Kenya, most studies document soil erosion by water as compared to wind erosion. Soil erosion in Kenya has its roots in high potential areas (Gachene and Mureithi, 2004) and more pronounced in the ASALs (Riginos *et al.*, 2012).

The presence of eroded hillsides, denuded plains, large erosion shelves and deep sided gullies exhibit soil degradation (Sindiga, 1984) as the case in Narok North sub-County in Kenya. There are on-site and off-site impacts of erosion; the former includes a decline in pasture and agronomic yields, reduction in the efficient use of inputs while the latter has impacts like an increase in the emissions of greenhouse gases and siltation of reservoirs and waterways (Lal, 2003). These impacts have greatly resulted in food insecurity in Kenya (Mulinge *et al.*, 2016) as well as in Sub-Saharan Africa (Lobell *et al.*, 2008; Clair and Lynch, 2010; Nkonya *et al.*, 2016).

Soil erosion is a globally acknowledged problem. Therefore, prevention of degradation and rehabilitation efforts are highly recommended given the high direct and indirect costs attributed to its impacts. Rehabilitation interventions are rifully encouraged by international communities, local governments, Non-governmental Organisations (NGO's) as well as the affected communities. These efforts are however curtailed by financial constraints (Stavi and Lal, 2014). Moreover, challenges like communal land tenure systems in most parts of the drylands of Sub-Saharan Africa (SSA) offer the least help in aiding rehabilitation unlike in the private ownership where incentives for rehabilitation and use of tractor driven rippers among other technologies are observed (Riginos *et al.*, 2012). The practicality of using capital intensive and technological

measures in pastoral areas becomes less useful owing to limited financial ability and land tenure systems.

Therefore, there is need to use cheap, labour effective, locally available materials that are adapted to the pastoral lands for rehabilitation efforts (Riginos *et al.*, 2012). The use of indigenous grasses as a vegetative measure to rehabilitate degraded lands has been done and has proved to be affordable, require less labour and relies on locally available species. Successful rehabilitation efforts using grasses has been done in India (Truong *et al.*, 2004), in South Africa (Visser *et al.*, 2007), in Kenya (Mganga *et al.*, 2010; Kinyua *et al.*, 2010). A combination of soil and water physical conservation measures with vegetative measures give quicker results, that is, quicker healing of degraded land (Visser *et al.*, 2007).

Grasses especially those with decumbent growth form protect the soil from scouring and retard the speed of water, which gives the water time to dislodge the sediments. Grasses possess fibrous roots that improve the soil structure especially the macropores which improve hydrological responses like infiltration. There is an increasing need to build to scientific knowledge on potential benefits of using native grasses over exotic in rehabilitation efforts to reduce costs and increase benefits to community giving incentives owing to their adaptability to local climatic conditions like tolerance to moisture stress, salinity, excessive defoliation during grazing and hence best choice for rehabilitation.

1.1 Statement of the problem

The problem of land degradation in the ASALs of Kenya has been in existence since the colonial era and the practices of rehabilitation date then. Soil erosion is a global problem and is widespread in Kenya, resulting in widespread food insecurity (Nkonya *et al.*, 2016; Mulinge *et al.*, 2016). The severity and extent of erosion in Kenya differ from one region to another, and

there is no consensus on the actual extent. In Suswa location, Narok North Sub-County in Narok County, Kenya (study site) land degradation is mainly as a result of soil erosion accelerated by unsustainable land management. Gullies in the area reach up to a depth of over 25m and widths of over 30m and run for kilometers (Odini *et al.*, 2015). This area has been under land use changes with transition taking place from pastoralism to agro-pastoralism further exacerbating the processes of degradation (Odini *et al.*, 2015). The area was previously a predominantly pastoral with livestock being the main livelihood. However, in the recent past, pasture scarcity in both quality and quantity in the area has become severe, which has been made worse by the past and present dependence on the natural pastures and water. The rates and extent of soil erosion have reduced not only the pasturelands but also the area under cropland (Odini *et al.*, 2015). This is worsened by the increasing climate variability coupled with shrinking grazing land from conversion to cropland.

Rehabilitation efforts in Suswa Location by the communities and non-governmental organisations (NGOs) consist of the establishment of physical structures, for example, water retention ditches, terraces, cut-off drains, water pans, semi-circular bands and check dams (Odini *et al.*, 2015). Terracing, a long used and proved technology in reducing the speed of run-off water has recently been tested for optimising moisture in farming (Ruto, 2015), which has helped farmers improve their productivity. However, the pastoralists who are the majority in the study area continue to face the problem of pasture scarcity.

The physical measures for soil and water conservation have shown success (Odini *et al.*, 2015). However, means of stabilising these structures are needed. Grasses have great potential in stabilising the soil conservation physical structures in degraded areas under rehabilitation. This, therefore, calls for the need and attention in selection of the best-suited grasses for the purpose,

with the aim of identifying grass species that will protect the soils and provide quality animal forage.

1.2 Justification of the study

Use of grass species to combat soil erosion/land degradation and pasture deficiency has been promoted widely in Kenya. Grass species suitability studies for fodder production have been done in Kenya, for instance in Northern Kenya (Bulle *et al.*, 2010), Southeastern Kenya (Mganga *et al.*, 2015; Opiyo *et al.*, 2011), coastal region (Koech *et al.*, 2016). However, gaps still exist. For example, the mentioned studies focused on grass species that have been recommended for rangelands but fail to consider the community perceptions, priorities and their needs. In addition, the studies focused on fodder productivity and accorded little or no attention to their ability in reducing soil erosion. There is a need, therefore, to focus on the community needs and priorities in selecting and promoting grasses for communities to adopt. Past studies by Glover (2012), Mganga *et al.* (2015), Assefa, and Hans-Rudolf (2016) have shown that needs and priorities of farmers predominantly influence their decision-making. The needs of communities also vary with respect to beliefs, needs, priorities, attitudes and perceptions. Consequently, to simultaneously control soil erosion/land degradation and provide fodder for the pastoral community, it is necessary to conduct site-specific studies to identify the grass species perceived by the community to resolve the problem.

To bridge the above knowledge gap, this study identified and determined the efficacy of selected grass species for both control of soil erosion/land degradation and provision of pasture for the Maasai community in Suswa. The information generated from by this study will improve the livelihoods of the pastoral community in Suswa and importantly guide other studies and rehabilitation efforts globally.

1.3 Objectives

Broad objective

To promote sustainable land management efforts in Kenya through evaluation of suitable and locally available grass species for rehabilitation of degraded rangelands to increase rangeland productivity, soil conservation and improve pastoral livelihoods.

Specific objectives

1. To identify grass species suitable for rehabilitation of Suswa rangelands as perceived by the community
2. To determine the effect of root parameters of the selected grass species on sediment yield, infiltration and runoff for reduced erosion
3. To quantify the aboveground biomass and selected morphological/morphometric parameters of the selected grasses at different phenological stages

1.4 Research questions

1. What grass species does the community in Suswa perceive suitable for land rehabilitation?
2. What effects do the root parameters have on sediment yield, infiltration and runoff?
3. How do the selected grasses perform at different phenological growth stages?

CHAPTER TWO

Literature review

In Kenya, soil erosion became a national concern back in the 1890s, and around the same time, soil water conservation (SWC) was introduced (Tiffen *et al.*, 1994). It is after the independence that the National Soil Programmes (1974) in the ministry of Agriculture was formed to deal with soil degradation through physical structures and occasionally biological measures. The main physical features implemented were terraces, bench trenching and construction of gabions. Biological measures included grass and tree planting. The main technique or procedure for terracing was *fanya juu* and bench terraces.

Physical measures are common both in the past and at present. However, complaints of the need for communal work or huge capital are rife (Wanjiku, 2015). Large sized farms and high cost in the establishment, maintenance and management of soil physical conservation measures are responsible for the low adoption among the communities in the recent past (Riginos *et al.*, 2012; Wanjiku, 2015). According to Wanjiku, (2015) and Birhanu, (2016) adoption of the physical measures for SWC is positively influenced by the age and sex of the farmer or household head, available extension and training, education, and membership of the farmer or household head to a group or organisation. However, farm size, access to credits, off-farm activities negatively influence adoption of SWC measures. Technically and economically feasible SWC interventions that can suit the needs of small-scale farmers are needed.

Biological SWC measures include the use of trees and grasses. Trees take a long time to mature and effectively execute the role of soil erosion control and eventually rehabilitate the land. On the contrary, grasses establish fast requiring less management. They are also able to accomplish a high ground cover within a short period given their growth form (Burger *et al.*, 2009). Many

degraded areas in the drylands, require urgent rehabilitation to curb the menace. Regardless of the grasses being fast growers, in the past, their role in soil erosion control was not recognised. Presently, with the increase in knowledge and dissemination, there has been an increase in the use of grasses both in the drylands and non-drylands areas to control soil erosion (Gachene and Mureithi, 2004; Riginos *et al.*, 2012). Grasses tend to be readily available, simple to plant and establish, maintain and manage while still providing livestock feed.

Different areas differ in soil quality, uses for grasses, community priorities and perceptions and therefore grasses establishment should be meticulously selected to register faster adoption and increase establishment for land rehabilitation.

2.1 Selection of grass species for range rehabilitation

The choice of appropriate grass for reseeded is dependent on two main principles: proper adaptation to the local environmental conditions and its ability to meet the aims of production and or conservation (Suarez *et al.*, 2012). The common approach in making decisions of species choice by the researchers, technicians and experts has been based on projects; programs and published information and their own experience, which has often ignored the indigenous knowledge and the community's needs and priorities. The consequence of this decision-making process is that farmers fail to adopt the technologies, or the ideas brought forward for lack of interest (Mekoye *et al.*, 2008). Communities in the ASALs often select plants that can survive during the dry seasons and whose ability to coppice and re-grow is high following defoliation and or survive the extremely adverse weather conditions (Mganga, 2009).

Indigenous knowledge has emphasised on plant species that can provide feed during the dry seasons. For example, the people of Veracruz choose fodder trees because grasses are limited in the dry seasons, and they can supplement the animal's diet (Suarez *et al.*, 2012). Similarly, in

Ethiopia and Kenya, they select fodder plants to use for rehabilitation to provide for fodder (Mekoye *et al.*, 2008; Glover, 2012). This case is no different from that of grass species. In Kenya, indigenous perennial grasses and their productivities are much studied (Opiyo *et al.*, 2011; Mganga *et al.*, 2011; Koech *et al.*, 2016). Needs and priorities of communities differ with respect to their location and perceptions. Different communities will use same grass species for different uses. For example, in West Pokot (Kenya) *Themeda triandra* is used for thatching (Kitalyi *et al.*, 2002), while a pastoral community in South Africa uses it as a broom (Makhado *et al.*, 2009) and the people of Metu in Ethiopia use vetiver for thatching.

Van den Berg and Kellner (2005) reported that the people of Karoo in South Africa preferred *Chloris gayana*, *Digitaria eriantha*, *Eragrostis curvula* and *Themeda triandra* for rehabilitation due to their perennial characteristics, their large tufts and palatability. In Venezuela, the farmers use vegetation as filters, for example, *Paspalum fasciculatum* in floodplains. The farmers also primarily use grass for conservation purposes (Barrios and Trejo, 2003).

Unlike modern scientists and experts who will look at the self-seeding ability and viability of the seeds (Mnene, 2005; Opiyo, 2007), good cover and root depth as features for good grass in soil conservation, indigenous knowledge will focus on the community needs and prioritise them. For example, the study community is predominately a pastoral community, and therefore their needs equate to livestock feed. Selection of grass species for the study will tend towards species that can provide sufficient aboveground biomass for the livestock throughout the year with greater concern for the dry season. While Mganga *et al.* (2013) was working with the Akamba community in Kenya, they found that the communities' grass species preference for combating desertification were those that surmounted to livestock feed.

Needs and priorities of farmers predominately drive the decisions they make (Glover, 2012; Mganga *et al.*, 2013; Assefa and Hans-Rudolf, 2016). The decisions are not limited to grass species but also to tree species. The aimed achievement of the species supersedes their immediate needs (Mganga, 2009). Although there is high relevance in indigenous knowledge in matters of local climatic conditions, there is need to bridge the local input with the scientific knowledge in selection of best-suited indigenous grass species for rehabilitation of degraded lands because of it can be inaccurate and biased towards a specific criterion (Barrios and Trejo, 2003).

2.2 Role of range grassroots in soil conservation

Despite the role of grassroots in soil conservation, the attention given to the aboveground biomass supersedes that of the roots. The bias exists largely because the roots are invisible and methodological challenges (Gyssels and Poesen, 2003; Gyssels *et al.*, 2005). The architectural organisation of the grassroots is fibrous that forms a mat-like structure. Roots change the soil properties both mechanically and subsequent effects on hydrological properties. Mat-like structure increases the stability of the soil through the roots exudates that bind the soil eventually increasing the soil resilience (Gyssels *et al.*, 2005; Vannoppen *et al.*, 2015). Grasses are characterised by fine roots (<1 mm diameter). Fine roots have been found to increase the soil roughness and permeability (De Baets *et al.*, 2006). Hydrologically, increase in the number of roots increases the allocation of nutrients and water to the aboveground biomass, which in turn increases the shear strength and a decrease in soil water, consequently improves the soil aggregate stability (Gregory, 2006; Nyangito *et al.*, 2009).

Perennial grasses have been shown to improve infiltration (Broersma *et al.*, 1995), which is a major characteristic of good quality soils. This is because of their ability to penetrate deep even

in compacted soil, unlike the annuals that have less ability to penetrate deep into the strong layers. Infiltration can vary during a crop growth. For instance, Gish and Jury (1981) hypothesised that the initial growth of plant roots would reduce infiltration because of compaction and obstruction of the existing soil macropores by the roots. The roots tend to grow on low tensile strength and better on pores. Bharati *et al.* (2002) also observed that this phenomenon changes when the plant roots die which opens up the macropores increasing infiltration later in the growing season. The grasses possess fibrous roots that have numerous fine roots, the fine roots dry the soil in many sites forming non-oriented cracks that give rise to numerous bio pores aiding in infiltration.

Grasses can be used to stabilise the physical soil water conservation structures like terraces both bench and *Fanya juu*. In Tanzania for example, Guatemala grass (*Tripsacum andersonii*) and Napier grass (*Pennisetum purpureum*) have been used to stabilise and control erosion during concentrated flow (Mwango *et al.*, 2014). Soil resistance to detachment is greatly influenced by the root density (Gyssels *et al.*, 2005; Mwango *et al.*, 2014). In Tanzania, Mwango *et al.* (2014) found Guatemala grass to have a higher root density that lowered the erosive potential of the soil. In Beijing, Zhang *et al.* (2013) found that increase in the root density of switchgrass (*Panicum virgatum*) reduced the detachment rate. Elsewhere in Belgium, Katuwal *et al.* (2013) found similar results while working with ryegrass (*Lolium perenne* L. Hugo) that as the root density increased erosion by wash and splash decreased.

Root length density has also been found to increase soil's resistance to erosion. Roots reinforce and increase the shear strength of the soil as they penetrate deep (Styczen and Morgan, 1995). De Baets *et al.* (2006) found that increasing the root length density (Km m^{-3}) reduced the rate of sediment detachment significantly. Similarly, (Mamo and Bubenzer, 2001a; 2001b) found that

increasing the root length density in the laboratory and field reduced the detachment rate of the soil.

2.3 Productivity of range grasses

Grasses constitute the largest proportion of animal feed. Regardless of the grasses' role in animal diet, over the years, primary production has dwindled posing a major threat to livestock production in Kenya (Gitunu *et al.*, 2003; Mnene 2005; Kibet *et al.*, 2006; Mganga 2009; Koech 2014; Lugusa 2015). Reduced primary production is attributed to the decreasing grasslands as a result of increased conversion of grazing fields to arable lands, overgrazing, soil degradation and nutrient depletion as well as a decrease in soil seed bank (Lal, 2013; Kimble *et al.*, 2016). There exists considerable high feed deficit that needs to be addressed to meet the high animal feed demand. The future interventions should increase quantities and qualities of the grasses available in the rangelands regardless of the vagaries of nature and other environmental factors.

Many factors influence the productivity of grasses, but most important ones are environmental factors and specific grass characteristics. Water/soil moisture is the most significant factor because excess and inadequate supply of the same affects productivity (Ram and Trivedi, 2014; Koech *et al.*, 2016). In the ASALs, the major problem is the inadequacy of water which has been found to result in reduced leaf size and internode length and suppression of root growth in perennial grasses (Slatyer, 1974). Regardless of the water deficits, range grasses have evolved in adaptive capacities to tolerate water stress. In a study conducted by Koech *et al.* (2016) on irrigated and rainfed pasture growth quantified the importance of water in pasture production in the arid and environments where irrigated pastures produced more biomass in comparison to the rainfed. Tolerance to water stress and recovery of grasses was also tested on a field study in Tana, Kenya and results showed that *Cenchrus ciliaris* and *Sorghum sudanense* are best adapted

to water stress while *Sorghum sudanense*, *Cenchrus ciliaris* and *Chloris gayana* have faster recovery from water stress (Koech *et al.*, 2015)

A decline in gene pool reservoirs (Lal, 2013), reduced soil depth due to erosion and reduced organic matter characterise degraded soils (Pimentel and Burgess, 2013). Soils with depleted organic matter have fewer nutrients resulting in the reduction of plant biomass. Herbivory also influences the productivity of grasses. High stocking densities can severely reduce the grass cover while moderate densities can simulate grass productivity (Pe'rez-Prieto and Delagarde, 2013). In a study by Zheng-Chao and Zhou-ping (2008), intense defoliation (80 % of the plant) at high frequencies was found to decrease productivity. Additionally, shoot internode decreased as clipping intensity increased from 60 % while light (20%) and moderate (40%) clipping induced rhizomatic tillers. Competition by other plants especially the weeds for resources influence the productivity of the grasses resulting in reduced biomass.

Intrinsic seed characteristics also affect the productivity of range grasses. Seed dormancy is both a pro and a con. Seed dormancy is a positive adaptation to conserving the soil gene bank in the highly unpredictable climatic conditions in the ASALs. It avoids germination when the favourable climatic conditions are ephemeral (Willis *et al.*, 2014). On the other hand, it contributes significantly to reduced grass productivity because of patchiness as a result of reduced germination of the seeds. In studies by Koech *et al.* (2016) and Mganga *et al.* (2010) faster germination rates of *Enteropogon macrostachyus* gave it a head start and a competitive advantage because of its seed dormancy form (integumental) resulting in higher biomass yield in comparison to other grass species like *Eragrostis superba* and *Cenchrus ciliaris* with slower germination rates.

Above-ground biomass production of grasses is also dependent on their morphometric characteristics. These characteristics include the tiller heights, tiller numbers, density and shoot:stem ratio. Genetic makeup is responsible for differences in tiller heights and numbers of different grass species (Ahmad *et al.*, 2016). Adequate water supply, soil nutrients and favourable climatic conditions enhance more tillering that increases the biomass yield potential (Thiry *et al.*, 2002; Koech, 2014). Opiyo *et al.* (2011) and Kinyua *et al.* (2010) found that land preparations like ripping equally influences the tillering, plant height and ultimately the yield of the grasses.

Production of viable seeds is essential for the creation of a rich soil seed bank and the stored seeds if harvested properly, there is great market given that there is high demand for seeds for rehabilitation and the pasture establishment for increased production of adequate feed for the animals in Kenya (Koech *et al.*, 2014). Poor quality seeds as a result of false seed formation also referred to as empty seeds largely attribute to patchy fields and unproductivity of rangelands (Malaviya *et al.*, 2013).

CHAPTER THREE

General materials and methods

3.1 Description of the study site

The study was carried out in Keekonyokie ward, Narok County located in the Southwest of Kenya. The County lies between longitude 34⁰45' E and 36⁰00' E and between latitudes 0⁰45' S and 2⁰00' S. The topography ranges from plateau (1000-2350m above sea level at the southern parts) to mountainous landscape (3098m above sea level at the highest peak of Mau escarpments in the north) (Serneels and Lambin, 2001; Jaetzold *et al.*, 2010).

The rainfall pattern in Narok County is bimodal. Long rains start in mid- March to June while the short rains start in September to November. Highlands receive up to a maximum of 2000 mm/year while the lower and drier areas receive less than 500mm/year mainly due to the local variation in topography (Ojwang *et al.*, 2010). The temperatures vary from 10⁰C in the Mau escarpments to about 20⁰C in the lower areas (NEMA 2009; Jaetzold *et al.*, 2010).

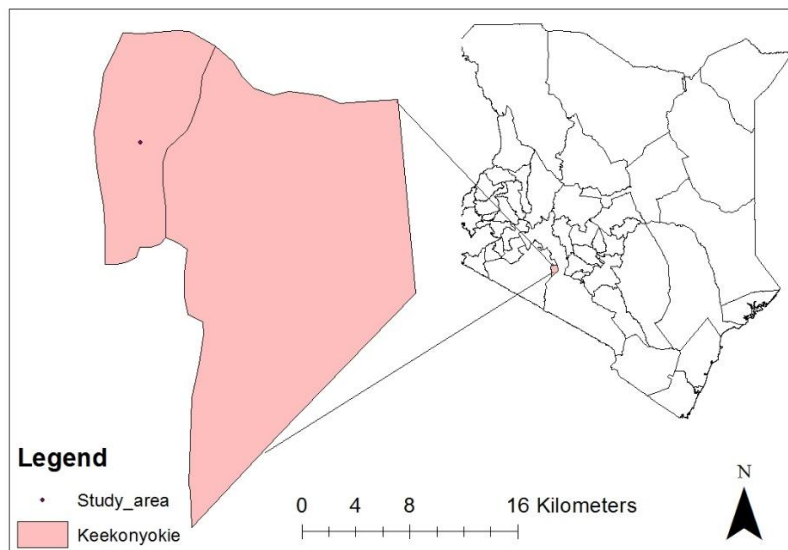


Figure 3.1: A map showing Keekonyokie ward in Narok County in relation to Kenya

3.1.1 Soil types

Keekonyokie ward area is characterised by volcanic soils and sharp gradient liable to soil erosion. Suswa soils are humic Andosols, dark brown, friable and smeary, sand clay to clay with acidic humic topsoil (Sombroek *et al.*, 1982; Jaetzold *et al.*, 2010). The humic andosols comprised sand (64.01%), clay (11.63%) and silt (24.36%) (Sainepo, 2017) and the slope average is 10°. Most of the area is bare due to overgrazing and loss of cover (Ruto, 2015). The soils are stratified with hardpan underlain by soft clayish strata that are easily washed away by water (Maina, 2013).

3.1.2 Vegetation of the study area

Tarchonanthus camphoratus trees densely dominate the area (Odini *et al.*, 2015). Other tree species in the area include *Acacia drepanolobium*. *Aristida keniensis* and *Eragrostis tuncifolia* are the common annual grasses that are found within the area. Perennial grasses present include *Hyparrhania lintoii*, *Harpache schimperi*, *Aristida adoensis*, *Sporobolus fimbriatus*, *Cymbopogon citratus*, *Cynodon plectostachyus* and *Themeda triandra* among others. Forbs found in the area include *Euphorbia inequilatera*, *Satureia biflora*, *Borreria stricta* and *Fuerstia africana* among others (Ombega, 2018).

3.1.3 Economic activities

Narok County has multiple land uses. In the highlands, the people are dominantly large-scale crop farming of wheat. In the mid-elevation, there are more of small-scale farmers. In the lower and drier areas, there is a combination of these activities taking place. Livestock production is the main activity in which sheep, goats and cattle are the main kinds of animals reared. Indigenous breeds are the main breeds kept but have recently crossbred with exotic breeds

(Maina, 2013). Beekeeping is also practiced (Jaetzold *et al.*, 2010). Keekonyokie is predominantly agro-pastoral regardless of the land being held communally. Charcoal production is also a major activity in Suswa flagging it for environmental concern (Odini *et al.*, 2015). The area has vast wildlife, which is harnessed for ecotourism and tourism (Ruto, 2015).

3.2 Research Design

Survey study approach

The Keekonyokie ward was purposively selected because of the gullies and the past rehabilitation interventions under “mainstreaming sustainable land management (SLM) in agropastoral systems of Kenya” project. The target population included households living close to the gulleys in four (Olepolos, Enkiloriti, Eluai and Olesharo) villages within the ward, state and non-state experts on livestock production, pasture management and soil conservation, and early adopters of SWC measures in the study area. Purposive sampling was employed to select participants for focus group discussion (FGD), key informant interviews (KII) and individual interviews.

Field experiment approach

For the determination of aboveground biomass, morphometric characteristics and the erosivity of the soil, a field experiment was set up on the slopes of Suswa-Ole Sharo Catchment. A plot measuring 45 X 20 m was identified cleared off all vegetation and ploughed using hoe and fork. The ploughed area was then subdivided into 21 subplots of 5 X 5 m. The buffers were 2m and 3m off boundary and 1m wide pathways separating the plots as shown in figure 3.2.

21 micro plots measuring 0.97 m X 0.29 m X 0.32 m were buried in the centroid of the 5 m X 5 m plots. Micro plots consisted of three movable basket-like sub-micro plots measuring 0.25 m X

0.25 m X 0.3m made of wire mesh on the sides to allow free movement of water and nutrients in the soil. The micro plots were used for ease of extraction of soil blocks for simulation of the soil erosion.

In completely randomized design, treatments (grass species) were randomly assigned to the plots as in table 3.1 in 3 replications. The grasses tested were *Chloris gayana* (Tt1), *Cymbopogon citratus* (Tt2), *Cynodon plectostachyus* (Tt3), *Cenchrus ciliaris* (Tt4), *Enteropogon macrostachyus* (Tt5) and *Eragrostis superba* (Tt6) and Control (Tt7). The local community identified Tt1, Tt2 and Tt3 as best suited for rehabilitation (chapter 4) while Tt4, Tt5 and Tt6 were selected because they have been previously used to rehabilitate land in other areas with success.

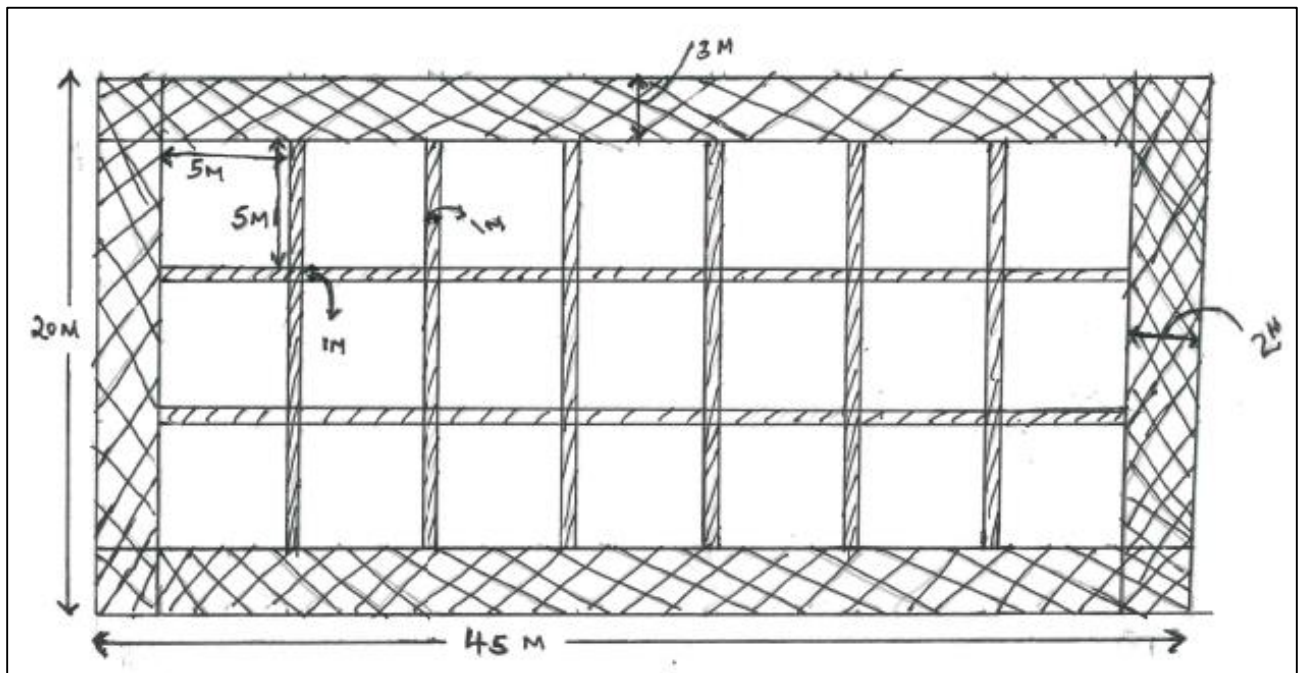


Figure 3.2: Field experiment layout in Keekonyoie ward, Narok County

Table 3.1: Treatment placement in the field layout

Tt2	Tt6	Tt4	Tt1	Tt7	Tt3	Tt5
Tt4	Tt7	Tt2	Tt5	Tt3	Tt6	Tt1
Tt6	Tt4	Tt1	Tt5	Tt2	Tt3	Tt7

Grass seeds for *Chloris gayana*, *Cenchrus ciliaris*, *Enteropogon macrostachyus* and *Eragrostis superba* used were sourced from International Livestock Research Institute (ILRI) Adis Ababa, Ethiopia primarily because the germination rates of those in Kenya was very low. *Cynodon plectostachyus* splits and *C. citratus* clumps were obtained locally and used for propagation. In control, plots were left bare, and vegetation growth occurred naturally from the soil's gene bank. Seeds from the other grass species were sowed manually by broadcasting. All the other pasture husbandry practices like weeding were done at the same time for all the treatments after standarization of the grasses one week after germination. Due to inconsistent and unreliable rainfall (137mm in 20 days) during the experiment period, supplemental irrigation of a total of 100 liters of water per plot was applied weekly within two days of 50 litres for each of two days irrigation was done using basins.

3.3 Data collection

3.3.1 Social data collection

Primary data on grass species locally found in the study area and selection of the best-perceived grass species for range rehabilitation was collected using focus group discussions (FGDs), household surveys, key informant interviews (KII) and direct observations from May to August 2016. A semi-structured questionnaire was administered to 33 selected respondents who live

close (1 kilometer away from both sides of the gully) to the gullies. Five FGDs each with 8-10 participants not previously interviewed (Gill *et al.*, 2008) were held in the villages at different locations as chosen by the village elders to complement data obtained from personal interviews. Discussions with the same group were held twice on different days complete the round of questions and for identification of the grass species. The FGDs provided information on the communities' perceptions towards the use of grass to control soil erosion, previous rehabilitation efforts, grass species found in the area during the wet and dry seasons and preferred grass species for rehabilitation of the degraded land. Further, 8 key informant interviews comprising of experts working with the state in the field of pasture management, livestock production, soil and water conservation, state and non-state actors operating in the areas and early adopters of biological SWC measures were conducted to validate data collected from FGDs and personal interviews. Comprehensive literature reviews on community attitudes, perceptions, priority, needs and land degradation and rehabilitation before and after data collection were done to contextualise the study and provide the needed secondary data. Field visits and direct ecological observations were conducted to identify the grass species mentioned by the community.

3.3.2 Erosion simulation experiment

For the determination of the erosivity of the soils, the buried micro plots were harvested at 3 different times after 8,12 and 16 weeks after germination of the grasses. Once excavated the sub micro plots were taken to the laboratory (University of Nairobi) where the above ground biomass was cut to ground surface and the plots watered with 3l of water a day before the simulation to reduce soil water variability. Rainfall simulations were conducted using a Kamphorst simulator (Kamphorst,1987) that was slightly modified (see figure 3.3). The slope was set at 10^0 mimicking the field conditions. Rainfall was supplied at a high intensity of 116mm hr^{-1} for 5

minutes in each plot to simulate erosion. Runoff and sediments produced was collected in a bucket and volume recorded. Sediment loaded runoff was then left for 4 hours to decant after which, the supernatant was drained, and the soil oven dried at 105⁰C for 8 hours.



Figure 3.3: Erosion simulation setup using a modified Kamphorst simulator

3.3.3 Grassroots sampling

After erosion simulation, the sub micro plots were immersed in water to soften the soil for 1 hour. Soil was then washed on a 0.5 mm sieve by spraying water aided by hand manipulation (Bohn, 1979). The washed roots were then scanned using a v700 Epson photo perfection roots scanner. Image analysis of the scans using WinRHIZO software (Regent Instruments INC, Quebec, Canada) were done to obtain total root length (cm), fine root length (cm), and average root diameter (cm). After scanning the roots were oven dried for 48 hours at 60⁰ C for the determination of root density (Kg m⁻³).

3.3.4 Aboveground and morphometric characteristics determination

Three plants were randomly selected from each plot and tagged for observation and data collection on plant height, tiller numbers, number of leaves per tiller and on the primary shoot. On the 8th, 10th and 12th WAP of the grasses above-mentioned parameters were measured and recorded. Plant height was measured from the base of the plant to the longest tiller leaf.

Above ground biomass was harvested after 16 WAP using the destructive clipping method. A total of 0.25m² area was harvested and a stubble height of 2.5cm was left to avoid soil contamination.

CHAPTER FOUR

Selecting suitable grass species for range rehabilitation: Perceptions of the pastoral community in Suswa, Narok County

Abstract

Land degradation is a major problem facing rangelands globally leading to diminished production capacity of these fragile ecosystems. This reduces their potential to provide ecosystem services such as provision of feed and food increasing communities' vulnerability to droughts and other effects of climate change. Land degradation can be reversed by planting and protecting grasses to provide soil cover and enhance soil physical and chemical properties aimed at controlling soil erosion. Different grass species are used for land rehabilitation for varied reasons among communities. These vary with location, communities' needs and priorities, preferences and type of livestock species reared. There is a need therefore for site-specific studies, to take into account the unique indigenous knowledge pool and livelihood preferences to inform rehabilitation efforts using grasses among rangeland communities. This study investigated grass species preferences for rangeland rehabilitation among pastoral community in Suswa, southern Kenya and the reasons underlying these preferences. Household surveys, focus group discussions and key informant interviews were used to assess community's perceptions of the existing grass species and their suitability for range rehabilitation. Descriptive analysis revealed that *Cynodon plectostachyus* (76%), *Chloris gayana* (73%), *Pennisetum clandestinum* (69%), *Cymbopogon citratus* (46%) and *Themeda triandra* (42%) were the most preferred species for range rehabilitation. Additionally, grasses perceived to be suitable for range rehabilitation were those with high grazing value to the livestock. This study shows that the

grazing value influences choice of grasses for range rehabilitation among the Maasai community in the study area. The study recommends consideration of community knowledge in selection of grasses to rehabilitate land owing to their vast indigenous knowledge on local grasses.

Keywords: Indigenous knowledge, range grasses, rehabilitation, land degradation, Suswa

4.1 Introduction

Soil erosion is the most widespread form of land degradation in the world (Lal, 2001; 2003; 2014; Pimentel and Burgess, 2013) and in Kenya (Mganga *et al.*, 2010). Wind and water erosion are the major forms of soil erosion resulting in degraded soils (Lal, 2014). Degraded soils are characterised by limited ability to sink atmospheric carbon, decline in plant nutrient reservoir as well as gene pool (Kimble *et al.*, 2016). Degraded soils directly reduce vegetation cover resulting in bare land and hence risking a range of ecosystem services and livelihoods in the arid and semi-arid rangelands. Human, natural factors and conditions and the physical features and conditions of the land aggravate the erosion process in the rangelands. The resultant is eroded hillsides, denuded plains, massive erosion shelves and deep sheer sided gullies (Sindiga, 1984; Odingi *et al.*, 2015).

Many measures have been used to control land degradation in different parts of the world. This include the use of soil water conservation (SWC) methods like terraces, cut-off drains, semi-circular bands, ditches, water pans and stone bunds. However, these measures are often expensive to implement and are labour intensive, making them only available and relevant to large-scale commercial entities (Riginos *et al.*, 2012), or donor-funded rehabilitation support projects on community land. Despite the physical SWC measures being expensive, the successful slowdown of runoff and control of soil erosion has been reported (Wolka, 2014; Ruto, 2015; Saiz

et al., 2016). A biological/ vegetative tool is another SWC measure that can control soil erosion and rehabilitate degraded land. It is a technique whose use has increased in the recent past due to its availability, affordability, ease of establishment and management, low labour requirement, and its ability to provide livestock feed in the arid and semi-arid rangelands (Gachene and Mureithi, 2004; Riginos *et al.*, 2012). Trees require a longer time to establish compared to grasses and take a long period before firmly executing the role of soil erosion control. Grasses are therefore the first choice for range rehabilitation because they are easy to establish and grow rapidly and colonise a large area due to their prolific growth nature. However, selection of best grass species for rehabilitation of degraded rangelands is key to successful restoration. The grasses vary in ecological adaptability, growth characteristics, as well as preferences by the community. As indicated by Mekonnen *et al.* (2016) the choice of grass species for rehabilitation should consider the availability of the target species, as well as their adaptability to the local environment. Also, they should be drought tolerant, establish within a short time, have a good seedling ability, high seedling survival and provide viable seeds (Mnene, 2005; Opiyo, 2007). The grasses should also be able to stabilise soil conservation physical structures and improve hydrological properties of the soil (Nyangito *et al.*, 2009) while producing adequate biomass for livestock feed.

Successful range rehabilitation and erosion control using grass species has been done in many countries (Truong *et al.*, 2004; Visser *et al.*, 2007; Mganga *et al.*, 2010; Terefe, 2011; Wanyama *et al.*, 2012; Mganga *et al.*, 2015; Ogwa and Ogu, 2014; Amare *et al.*, 2014; Manyeki *et al.*, 2015; Mekonnen *et al.*, 2016). Whereas some productivity and rehabilitation suitability studies of grass species for arid and semi-arid environments is already done in Kenya (Mganga *et al.*, 2010; Opiyo *et al.*, 2011), little attention has been given to community views on suitable grass

species that best fits their needs. Besides, variations on communities' views exist with respect to location, species performance, grass uses and preference. According to Kangalawe (2012) local perceptions, attitudes and knowledge have far greater implications to their environment including resource management and control of land degradation. Local communities know what plants are available in the wet and dry seasons, species that are more persistent and drought tolerant, and this information complements the modern scientific knowledge in selecting species for rehabilitation (Wasonga *et al.*, 2003; Wekesa *et al.*, 2015). Understanding the community perceptions, needs and priority grass species that address existing environmental and livelihood challenges enhances the selection of appropriate grass species for adoption by communities for Sustainable Land Management (SLM). This study was therefore conducted to 1) determine the community's perceptions on soil erosion and degradation 2) identify suitable grass species suitable for rehabilitation of degraded rangelands.

4.2.2 Data collection

Primary data was collected through household surveys, focus group discussions (FGDs), key informant interviews and direct observation from May to August 2016. A semi-structured questionnaire was administered to 33 selected households who live close (1 kilometer away from the gulley) to the gullies. Five FGDs each involving 8-10 participants (Gill *et al.*, 2008) were held in the villages at different locations as chosen by the village elders to complement data obtained from personal interviews. Discussions with the same group were held twice on different days to complete the questions and field tour in identification of the grass species. The FGDs provided information on the communities' perceptions towards the use of grass in controlling soil erosion, previous rehabilitation efforts, grass species found in the area during the wet and dry seasons and preferred grass species for rehabilitation of the degraded land. Further, eight key

informant interviews were conducted to validate data collated from FGDs and personal interviews. Key informants comprised of experts working with the government in the field of pasture management, livestock production, soil and water conservation among others, state and non-state actors operating in the area and early adopters of biological SWC measures. Comprehensive literature reviews were done to contextualise the study and provide the secondary data on community perceptions on grass species for rehabilitation. Field visits and direct ecological observations were conducted to identify the grass species mentioned by the community.

4.2.3 Data analysis

Quantitative data from surveys were analysed to generate descriptive statistics using Microsoft Excel 2010 after organisation into thematic areas. Field notes were collated and consolidated into different topics to validate and complement the individual interviews.

4.3 Results

4.3.1 Socio-demographic and economic characteristics

Majority (85%) of the surveyed households were male-headed. The average family size was seven persons. The age of the respondents ranged from 20 to 80 years. The average tropical livestock unit (TLU) kept by the households was 20.1 (Table 4.1).

Table 4.1: Descriptive statistics of the respondents of Suswa, Narok County

Variables	Respondents (n=33)	Percentage
Household characteristics		
Male household head in percentage (dummy)	28	61
Age of household head		
20-35	5	15
36-49	11	33
50-70	8	24
>70	9	27
Education of household head		
Formal	11	33
Informal	22	67
Average Household size	7± 2	
Average TLU	20.1± 11.786	
Land and pasture production characteristics		
Severe level of land degradation	33	100
Causes of land degradation		
Climatic	16	48
Anthropogenic	17	52
Proportion of respondents that planted grasses (dummy)	9	27
Rehabilitation challenges using grasses		
Insufficient rainfall	33	100
Seedling mortality	26	79
Recurrent dry spells	33	100
Defoliation by animals	20	61
Destruction by flash floods	28	85

4.3.2 Community local knowledge on land degradation

All the respondents (100%) strongly agreed that the study area is severely degraded resulting in large gullies, loss and change of vegetation cover and huge soil deposits in the lowlands (Table 4.1). The community reported that presence of the gullies, depth of the gulley and presence of

undesirable and decrease of desirable plants were the signs of a degraded land. Over 50% of those interviewed attributed land degradation to anthropogenic factors, while 48% attributed climatic factors for the observed trends (Table 4.1). Human population, overgrazing and bush clearing for charcoal, fences, and shelter (locally referred to as *manyatta*) building were cited as the main anthropogenic factors that aggravate degradation in the study area. The respondents reported frequent and prolonged dry spells that culminated to droughts and low and poorly distributed rainfall as proof to the state of degradation. The communities indicated that they had been affected by the soil erosion processes at two levels; individually and communally. In the former, the respondents faced problems of crop failure, land fragmentation and death of animals from falling off the gully cliffs. Communally, communities are faced by new boundaries caused by gullies that separate them and restrict people and animal movements. Formations of ballast for construction, sand deposits in the lowlands and dry season feed reserves in the gullies were the benefits associated with soil erosion in the area.

4.3.3 Common grass species and their uses by Maasai community in Suswa

Twenty (20) grass species were identified during the FGDs (Table 4.2). Nine of these grasses were identified as dry season livestock forages namely: *Cymbopogon citratus*, *Cynodon plectostachyus*, *Sporobolus fimbriatus*, *Chloris gayana*, *Eragrostis superba*, *Pennisetum mezianum*, *Cenchrus ciliaris*, *Hyparrhenia lintonii* and *Aristida adoensis*. Out of the 9 species, *Cenchrus ciliaris*, *Cynodon plectostachyus*, *Chloris gayana*, and *Cymbopogon citratus* were reported to be highly preferred by the livestock. During the wet season, livestock was reported to utilise mostly annuals including *Setaria verticillata*, “Mutanduro” (in Maa language) and *Sporobolus fimbriatus*. Farmers highly preferred Mutanduro to the other annual grasses citing its distinctive taste in the milk. The respondents indicated that *C. citratus*, *C. plectostachyus*, and *S.*

fimbriatus were the fastest growing grasses following the rains. Farmers felt that *T. triandra* had declined in abundance and was no longer available in abundance.

Livestock feed is the major use of grasses in the study area. Other uses of grasses include thatching, plastering, and land rehabilitation. *C. citratus* is considered more durable to *T. triandra* by the community hence used for thatching. *Themeda triandra*, on the other hand, is cut into small pieces, mixed with mud and used for plastering their traditional huts.

Aver a quarter (27%) of the respondents had planted grasses out of which 11% had planted *C. citratus* for rehabilitation purposes. Most (89%) planted *C. gayana* and *P. clandestinum* to provide forage for the livestock. *Pennisetum clandestinum* was mainly planted around the homesteads and water pans due to the species high water demand. *Chloris gayana*, which was established by beneficiaries of SLM project, was reported to have good biomass yield where the establishment was successful. The main pasture production challenges reported were insufficient rainfall, seedling mortality, recurrent dry spells, animals grazing when plants are still young leading to uprooting and destruction of the seedlings by flash floods (Table 4.1).

4.3.4 Suitable grass species for range rehabilitation and reasons for their choice

From the 20 species identified by the communities, five were perceived and selected to be the best suited for soil erosion control and range rehabilitation, namely, *C. plectostachyus*, *C. gayana*, *P. clandestinum*, *C. citratus* and *T. triandra* (Table 4.2). Provision of livestock feed was the primary reason for the choices (Table 4.3). Land rehabilitation was considered secondary to use of the selected grasses for forage while land rehabilitation came second. Stabilizing the soil and water conservation physical measures like terraces was a concern for the community.

Table 4.2: Common grass species in Keekonyokie Ward, Narok County, Kenya and their uses

Grass Species	Preference by Livestock species	Other grass uses
Scientific name	Local names (Maa language)	
<i>Cynodon Plectostachyus</i> **	<i>Emurua</i>	All livestock (cattle, sheep, goat, donkey)
<i>Digitaria macroblephara</i>	<i>Erikaru</i>	Cattle and sheep
<i>Chloris gayana</i>	<i>Olekiramatian</i>	All livestock (cattle, sheep, goat, donkey)
<i>Cymbopogon citratus</i> **	<i>Olung'u</i>	Cattle and sheep (dry season only)
<i>Aristida adoensis</i> **	<i>Onkosos</i>	
<i>Sporobolus fimbriatus</i>	<i>Olperesi</i>	Sheep, goats (feed on inflorescence)
<i>Hyparrhenia lintonii</i>	<i>Ologorroing'ok</i>	All livestock (cattle, sheep, goat, donkey) (cattle consume more)
<i>Pennisetum clandestinum</i>	<i>Olobobo</i>	Donkeys and sheep
<i>Themeda triandra</i>	<i>Olperesi Orasha/Orkijitaonyokie</i>	Preferred by goats
<i>Setaria verticillata</i>	<i>Olorepirepi</i>	All livestock (cattle, sheep, goat, donkey)but more preferred by sheep
<i>Tragus barteronianus</i> **	<i>Onkosos</i>	
<i>Cyperus spp</i>	<i>Oseyia</i>	All livestock (cattle, sheep, goat, donkey)but more preferred by goats
<i>Pennisetum mezianum</i>	<i>Not specified</i>	
<i>Cenchrus ciliaris</i>	<i>Oshankash</i>	All livestock (cattle, sheep, goat, donkey) but more preferred by cattle
<i>Brachiaria brizantha</i>	<i>Ormagutian</i>	All livestock (cattle, sheep, goat, donkey)
<i>Harpachne schimperi</i> **	<i>Onkosos</i>	
Not specified	<i>Mutanduro</i>	Cattle and sheep
Not specified	<i>Ngonyoro</i>	Sheep and goats
Not specified	<i>Oltiol (found in the forest)</i>	Cattle
Not specified	<i>Olparakae</i>	Cattle and sheep

Source: Focus Group Discussions (n=5): Survey data 2016

** Represents dominant grasses as identified by the community in the study site

Table 4.3: Grasses perceived to be suitable for rehabilitation and reasons as perceived by the community

Scientific name	Respondents		Reasons for selection						
	Frequency	Percentage	Livestock feed	Rapid growth	High biomass	Perennial	Drought tolerance	Continuous grass cover	Stabilize SWC
<i>Cynodon plectostachyus</i>	25	76	x	x	x	x	x	x	
<i>Chloris gayana</i>	24	73	x		x	x	x		x
<i>Pennisetum clandestinum</i>	23	69	x			x	x	x	
<i>Cymbopogon citratus</i>	15	45		x		x	x		x
<i>Themeda triandra</i>	14	42	x			x	x		x

Source: Focus group Discussions (n=5), Survey data 2016 (n=33)

Key: SWC= Soil water conservation

4.4 Discussion

The Maasai's inhabiting Narok County are aware of their surrounding environment and possesses a great pool of knowledge about the environment. The knowledge possessed by the community forms their decision-making tool on key issues of degradation, pastoralism and alternative livelihoods. The indicators used by the communities to describe the extent of degradation were close to what the modern scientists use. The Maasai community of Narok County considers the presence of gullies, gully depth and presence of desirable and undesirable species for their livestock when making their rehabilitation decisions. Based on the indicators, the pastoral communities know where to take their animals during wet or dry seasons to control erosion. Jandreau and Berkes (2016) observed a similar phenomenon at the Maasai Mara where the community uses forage characteristics like grass height, keystone species and grass colour in making rehabilitation and use decisions. It was equally evident that anthropogenic induced land degradation is rife in the study area arising from agricultural activities like unsustainable cultivation methods on hillsides and indiscriminate bush clearing (*personal observation*). Diversification of livelihoods has increased with many starting poultry farming and bush clearing for charcoal. Mganga *et al.* (2015) observed a similar scenario of increased charcoal production from indigenous trees while working with the Akamba agropastoral community in South Eastern Kenya. This is so because land and forage condition has reduced because of degradation. Besides, the increase in human population within the area and fragmentation of land influence the lifestyle of the community by increasing rearing of small ruminants because of their tolerance to undesirable species and their ability to utilise the rough terrain created by degradation (Odini *et al.*, 2015). It is evident that different grass species are perceived differently with respect to location, community perceptions, and priorities. The pastoral community in the study area use

grasses as livestock feed, thatching, plastering, and rehabilitation. The grass species considered suitable for rehabilitation are the ones that provide adequate livestock feed. As opposed to modern scientists who link the plant characteristics like root length, root biomass and diameter, cover and plant density as good for rehabilitation, the community acknowledges the amount of biomass produced by the grass species for livestock as another most desirable consideration for rehabilitation. These findings agree with those of Mganga *et al.* (2015) who found that provision of livestock feed by grass species influenced its choice as good for rehabilitation of degraded lands among the Akamba community in South Eastern Kenya.

Cynodon plectostachyus's higher preference compared to *C. gayana*, *P. clandestinum*, *C. citratus* and *T. triandra* demonstrates their need for yearlong livestock feed. *Cynodon plectostachyus* is also available in many areas and establishes rapidly from splits or seeds (Harlan *et al.*, 1969). Additionally, the grass species is also preferred by all kinds and classes of livestock in the area. Geissen *et al.* (2007) found that grass species was important in slowing the speed of runoff thereby controlling erosion while working in Mexico. *Chloris gayana* preference for rangeland rehabilitation was attributed to its high biomass and palatability to all livestock in the study area. Koech *et al.* (2016) found that the species produces high biomass even under limited water conditions. *Pennisetum clandestinum* was preferred for its growth form and its ability to spread and cover the land. The lower preference accorded to *C. citratus* can be attributed to the citral content that lowers its palatability (Thomas *et al.*, 2012). *Themeda triandra* was least preferred species because of its rapid decline in abundance after establishment. This can be attributed to the grazing and trampling because it is highly sensitive to poor management (Snyman *et al.*, 2013)

Wasonga *et al.* (2003) and Mutu (2017) observed that calamities and lack of resources make the pastoralists flexible in decision-making and utilisation of resources. The chosen grasses by the Maasai community as best for rehabilitation demonstrate the flexibility in decision-making depending on their needs and way of life. Indigenous knowledge among the pastoral community is increasingly evolving to suit the needs of the community and cushion them from future calamities.

4.5 Conclusions

The study shows that the pastoral communities possess a wealth of knowledge on grasses and their uses. They are conscious of the trends in range degradation and their causes and can identify grass species suitable for range rehabilitation. Maasai's inhabiting Narok County perceives *C. plectostachyus*, *C. gayana*, *P. clandestinum*, *C. citratus* and *T. triandra* as the most suitable grass species for range rehabilitation and soil erosion control. This study demonstrates that recurrent and frequent drought influence the communities' decision-making in the choice of species for range rehabilitation. Provision of forage is the primary reason considered in the choice of grass species for rehabilitation. These findings show the importance of local knowledge in the selection of grasses for rehabilitation which should be considered in future interventions for sustainable range management. However, we recommend further study to assess the efficacy of the five identified grasses in the control of runoff and of soil erosion. Furthermore, communities should be involved in the choice/selection of species for rehabilitation to address their livelihood challenges.

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CHAPTER FIVE

Effects of root parameters of selected tropical perennial grasses on erosion control in humic Andosols in Suswa, Narok County, Kenya

Abstract

Plant roots are important in controlling runoff and soil detachment, especially in sloppy land. However, few studies have been conducted to establish the potential of indigenous tropical grasses to control soil erosion. This study, therefore, evaluated the efficacy of six tropical range grasses - *Cymbopogon citratus*, *Cynodon plectostachyus*, *Chloris gayana*, *Cenchrus ciliaris*, *Enteropogon macrostachyus* and *Eragrostis superba* and naturally regenerated vegetation (control) in reducing sediment production. The sediment production, root density (RD), root length density (RLD) and sediment detachment rates (SDR) were measured after laboratory rainfall simulations of undisturbed soil samples. The plots of grasses demonstrated varied sediment yields of 1.01t ha⁻¹ to 27.5 t ha⁻¹ at different phenological (vegetative, flowering and maturity) growth stages. *Cymbopogon citratus*, *C. plectostachyus* and *C. ciliaris* reduced sediment yield significantly ($p < 0.05$) compared to the control. Sediment yield and SDR reduced as grasses advanced in maturity while RD and RLD increased with the maturity of grasses. This study recommends the 3 species for rehabilitation of degraded areas to reduce sediment yield in semi-arid lands where they can grow.

Keywords: sediment detachment rate; range grasses, soil erosion, root length density, root density

5.1 Introduction

Previous studies have indicated that belowground biomass could be as important as the above-ground biomass in controlling soil erosion (Gyssels and Poesen, 2003; De Baets *et al.*, 2006; Zhang *et al.*, 2013; Mwango *et al.*, 2014). Plant roots reinforce the soil increasing their shear strength through the roots binding agents (exudates). The reinforcement increases the surface roughness which consequently reduces the scouring of the soil (Zhou and Shanguan, 2008). Root parameters such as root density (RD), root length density (RLD), average root diameter (D), root architecture and root area ratio (RAR) have been found to influence the ability of roots to control erosion (Gyssels and Poesen, 2003; Mwango *et al.*, 2014).

Tropical range grasses such as *C. ciliaris*, *E. macrostachyus*, *E. superba*, *C. plectostachyus* and *C. gayana* have been recommended for use in rangeland rehabilitation because of their good biomass production that provide livestock feed (Ndathi *et al.*, 2012; Koech *et al.*, 2016), and have become important feed resources even in areas with water stress conditions. These grasses have been studied widely for their drought tolerance as well as productivity (Mganga *et al.*, 2010; Opiyo *et al.*, 2011). However, their ability and contribution of their roots in controlling soil erosion remain unknown. Grasses have been found to rehabilitate land quickly because of their faster germination rates and ability to cover the ground within a short time. However, few studies have been conducted to establish the contribution of grassroots to soil erosion control. Grasses that have been studied in controlling soil erosion in other parts of the world include; *Avena sativa* (oats) in Japan (Shinora *et al.*, 2016), *Lolium perenne* (ryegrass) in Denmark (Katuwal *et al.*, 2013) and China (Zheng-Chao and Zhou-ping, 2008) and *Tripsacum anderssonii* (guatemala) and *Pennisetum purpureum* (nappier) grasses in Tanzania (Mwango *et al.*, 2014). Despite roots having great effects in soil stability and increase in infiltration rates while reducing

soil erosion, there are limited studies to compare the most roles played by roots of the most promoted grass species at different phenological stages. This study was therefore conducted to determine the impact of six range grass species used for rangeland rehabilitation on a concentrated flow erosion. Three of the six grass species were selected by the study area community as best perceived for rehabilitation -*C. plectostachyus*, *C. citratus* and *C. gayana*. The study also introduced other three grasses commonly used for rangeland rehabilitation for comparison purpose, which included *C. ciliaris*, *E. macrostachyus* and *E. superba*. The study's specific objectives were to determine 1) the runoff, percolate and sediment yield at different growth stages of the grasses, 2) the sediment detachment rate of the selected grasses, and 3) the effect of root parameters (root density (RD), root length density (RLD) and average root diameter (D)) on runoff.

5.2 Data collection

Detailed experimental design is presented in chapter 3. Within the experiment main plots, sub-micro plots sampling was done at three phenological growth stages of vegetative, flowering and maturity with seeds ripened represented by weeks -8th, 12th and 16th. At every phenological growth stage, one sub-micro plot in each of the 5 X 5 m plot was extracted (in total 21 sub-micro plots) and transported to the laboratory (University of Nairobi) for erosion simulation.

5.2.1 Rainfall simulation tests

Once the sub-micro plots were brought to the laboratory, the aboveground biomass was clipped to the ground level to solely investigate the grassroots effects on soil erosion. All the subplots were watered with exact (3 litres) of water a day before rainfall simulations to reduce moisture variability that may be caused by different soil-water contents. Rainfall simulations were done on

the sub-micro plots using a portable Kamphorst simulator (Kamphorst, 1987) after minimal modifications (Figure 3.3). The slope was set at 10^0 mimicking the field conditions. Each simulation consisted of a shower of 5 minutes at a high intensity of 116 mm hr^{-1} . Volumes of the runoff with sediments were measured and recorded. The sediment-loaded runoff was then left to decant for 4 hours after which, the supernatant was poured out and the sediments oven dried at 105^0 C for 8 hours to calculate the sediment yielded (kg ha^{-1}) and sediment detachment rate (SDR).

5.2.2 Roots sampling

After simulation, the sub-micro-plots were immersed in water to soften the soil for one hour and then the soil was washed on a sieve of 0.5 mm by spraying water aided by hand manipulation (Bohm, 1979). The washed roots were scanned as images by a scanner (V700 Epson Photo perfection). From the scans, total root length (cm), fine root length (cm), thick root length (cm) and average root diameter (mm) were obtained from image analysis using Win RHIZO software (Regent Instruments INC, Quebec, Canada) (Figure 5.1). The roots were then oven dried for 48 hours at 60^0C to determine the root density (kg m^{-3}).

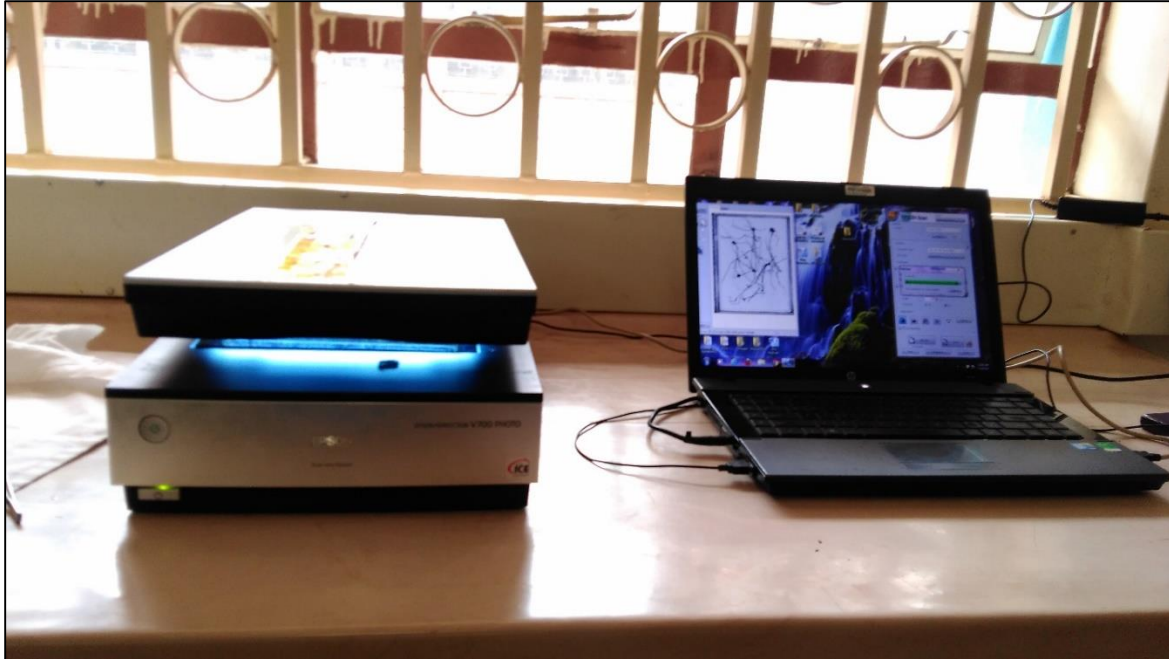


Figure 5.1: Root scanning and root image analysis for root length

5.3 Data computations and analysis

The following equations were used for the calculation of sediment detachment rate (SDR), root density (RD) and root length density (RLD):

$$SDR = SC \frac{Q}{A} \dots\dots\dots Equation 1$$

Where SC is sediment concentration (Kg L⁻¹), Q is the flow discharge (LS⁻¹), and A is the surface area of the sample box (m²). Root density (RD) and root length density (RLD) were calculated as:

$$RD = \frac{M}{V} \dots\dots\dots Equation 2$$

$$RLD = \frac{L}{V} \dots\dots\dots Equation 3$$

Where M is dry living root (kg), L is the length of the living root (km), and V is the volume of the sample box (m³).

Analyses of Variance (ANOVA) for SDR, RD and RLD were conducted using R statistical package version 1.0.153 (R Core Team, 2017) and Genstat 15th Edition (Payne *et al.*, 2009). Statistical differences of the means of SDR, RD and RLD were determined at $p < 0.05$ and means separated by Duncan's multiple range test.

5.4 Results

5.4.1 Runoff, percolate and sediment yield

Figure 5.3 shows the runoff volumes from the plots planted with different grass species at the three different phenological stages of the grass growth and development. Runoff from the plots increased as the grasses advanced to maturity except for *E. superba*. At 8th week, *E. superba* had the highest runoff (6.965L) while *C. plectostachyus* had the lowest runoff (2.309L). Plots planted with *C. plectostachyus* had the highest runoff (7.125L), while *E. macrostachyus* had the lowest runoff (5.45L) at 12th week. At 16th week, the plots with *C. plectostachyus* still had the highest runoff (7.316L) and the lowest was control plot (5.125L) (Figure 5.2). The average runoff increased from 4.04L at 8th week to 6.27L during the 12th week and to 6.47L at 16th week. The grass species had a significant influence on runoff at $p < 0.001$, $p < 0.01$ and $p < 0.001$ at 8, 12 and 16 weeks respectively. Interaction of the RLD and RD was not statistically significant to the runoff at any week.

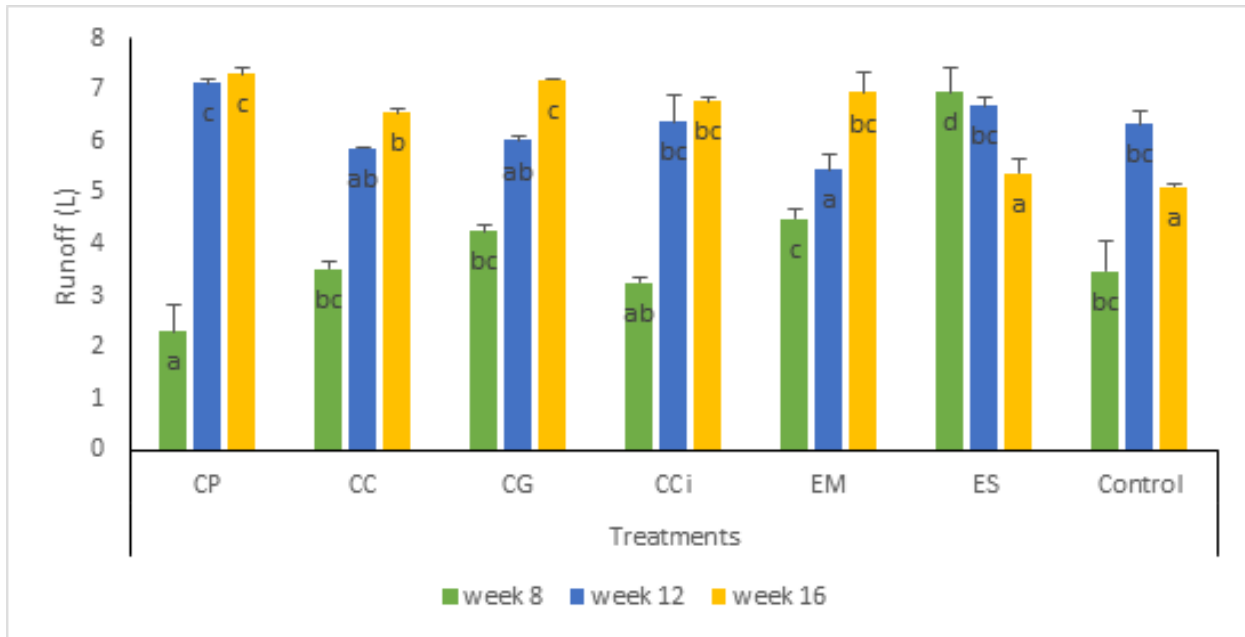


Figure 5.2: Runoff of grasses at different stages of growth

Notes: Different letters on bars with the same colour are significantly different at $p < 0.05$

CP= *Cynodon plectostachyus*, CC= *Cymbopogon citratus*, CG= *Chloris gayana*, CCI= *Cenchrus ciliaris*
 EM= *Enteropogon mactostachyus*, ES= *Eragrostis superba*

Percolate levels significantly declined with maturity of the grasses where the volumes were relatively high at 8th week as compared to 12th and 16th weeks. Similar to the runoff, grass species significantly influenced the percolate at $p < 0.001$, $p < 0.001$ and $p < 0.01$ at 8th, 12th and 16th weeks respectively. At 8th week, the highest percolate was 4.575L and lowest (2.82L) percolate levels in plots with *C. plectostachyus* and *C. gayana* respectively. At 12th week, plots with *C. ciliaris* had the highest percolate (2.909L) while *C. plectostachyus* had the lowest (1.915L) percolate levels. At 16th week, plots with *E. macrostachyus* and *C. citratus* had the highest percolate (2.423L), and lowest (1.725L) percolate levels respectively (Figure 5.3). The average percolate for all the species was 3.53L, 2.39L and 2L at 8, 12 and 16 weeks respectively. The interaction of RD and RLD influenced the percolate levels at the maturity stage at $P < 0.001$.

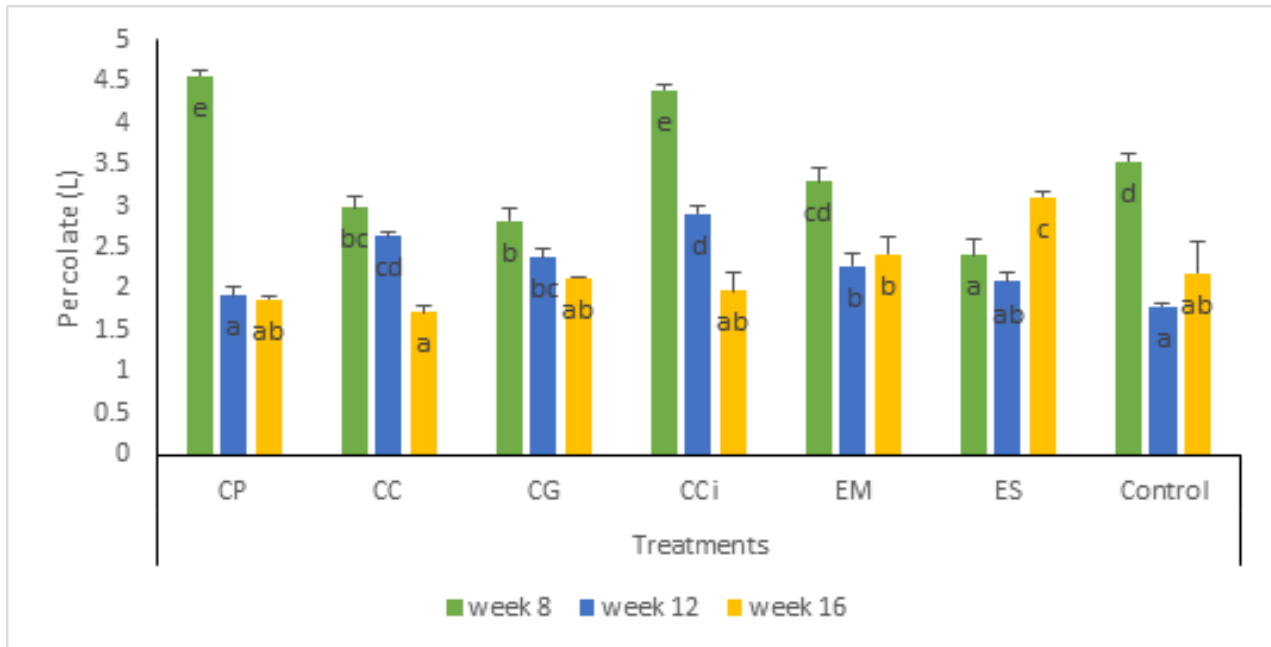


Figure 5.3: Percolate of different grass species at different stages of growth

Notes: Different letters on bar with same color are significantly different at $p \leq 0.05$

CP= *Cynodon plectostachyus*, CC= *Cymbopogon citratus*, CG= *Chloris gayana*, CCI= *Cenchrus ciliaris*
 EM= *Enteropogon macrostachyus*, ES= *Eragrostis superba*

Sediment yield was significant ($p < 0.05$) at different observed weeks of the grasses growth. Plots with *E. macrostachyus* recorded the highest sediment yield (27.524 t ha^{-1}) while *C. plectostachyus* recorded the lowest (10.65 t ha^{-1}) sediment yield at 8th week. At 12th week, plots with *E. superba* had the highest sediment yield (27.189 t ha^{-1}) while *C. plectostachyus* had the lowest (14.33 t ha^{-1}). Plots with *E. macrostachyus* had the highest yield on 16th week (2.697 t ha^{-1}) while *C. citratus* had the lowest (1.011 t ha^{-1}). Average sediment yield across the treatments reduced with advancement of the grasses (Table 5.1).

5.4.2 Sediment Detachment Rate (SDR)

Sediment detachment rate (SDR) at the different growth weeks of the grasses was statistically significant ($p < 0.05$). Sediment detachment rate was highest in control plots ($0.02092 \text{ Kg s}^{-1} \text{ m}^{-2}$)

and lowest in plots with *E. superba* ($0.00873 \text{ Kg s}^{-1} \text{ m}^{-2}$) at 8th week. At 12th week, plots with *E. superba* ($0.01283 \text{ Kg s}^{-1} \text{ m}^{-2}$) SDR was the highest while *C. plectostachyus* ($0.006206 \text{ Kg s}^{-1} \text{ m}^{-2}$) was the lowest. At 16th week, SDR was lowest on plots with *C. citratus* ($0.008439 \text{ Kg s}^{-1} \text{ m}^{-2}$) treatment while *E. macrostachyus* ($0.01256 \text{ Kg s}^{-1} \text{ m}^{-2}$) was highest (Figure 5.4).

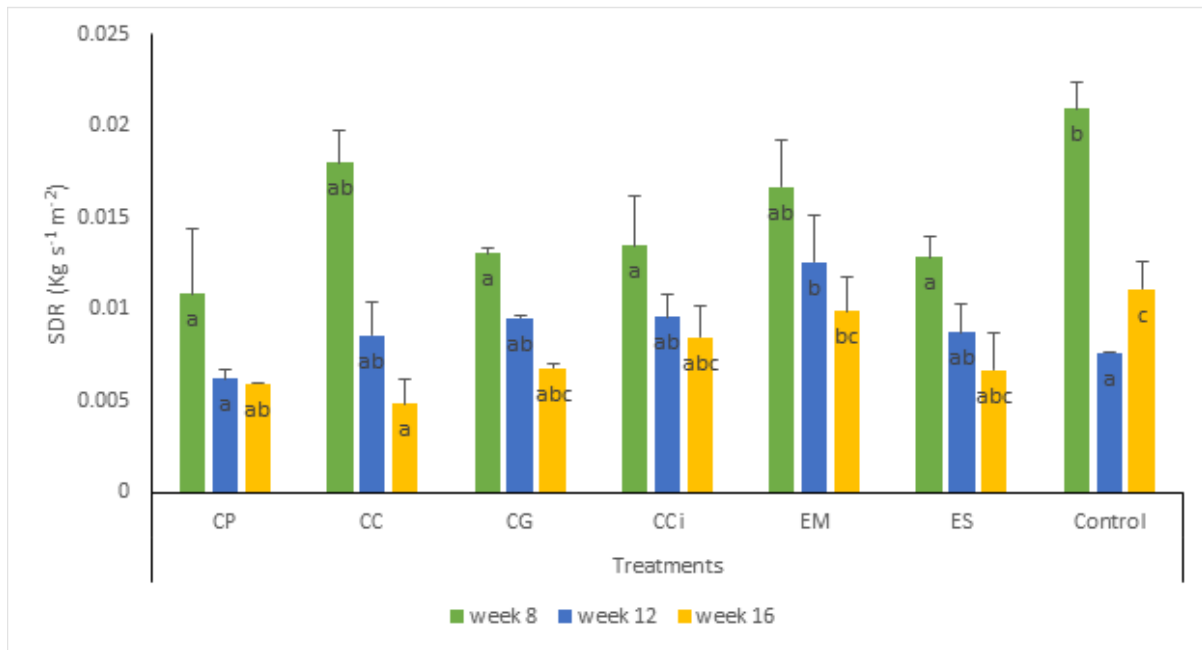


Figure 5.4: SDR of different grasses at different phenological plant stages

Notes: Different letters on bar with same colour are significantly different at $p \leq 0.05$

CP= *Cynodon plectostachyus*, CC= *Cymbopogon citratus*, CG= *Chloris gayana*, CCI= *Cenchrus ciliaris*
 EM= *Enteropogon mactostachyus*, ES= *Eragrostis superba*

Pearson correlations at $\alpha=0.05$ showed moderate negative relationships between runoff and root parameters as well as that of sediment yield and RD and RLD. However, a positive relation on percolate and root parameters was observed though it was weak.

5.4.3 Root density, root length density and fine roots

Table 5.1 shows the RD and RLD. The RLD increased up to the 12th week and reduced at the 16th week. *Cynodon plectostachyus* consistently had longer RLD except at the 12th week (43.494 km m^{-3}) where control had a higher (94.9 km m^{-3}) RLD. *Chloris gayana* and *E. superba* had

relatively low RLD throughout the stages. The fine roots increased with maturity in all species. *Cynodon plectostachyus* had the longest fine roots (1119 cm) at maturity. *Cenchrus ciliaris* increased with maturity, but increment margins were the lowest. Long fine roots were recorded in the control plots because of the mix of vegetation types. However, the length reduced significantly at the 16th week (1016 cm) because of the death of most of the ephemeral weeds that had grown.

Table 5.1: Means of RD, RLD and sediment yields of six grass species at different phenological growth stages

	CP	CC	CG	CCi	EM	ES	Control
Root density (Kgm⁻³)							
Week 8	0.0839 ^a ± 0.07	0.0412 ^a ± 0.01	0.00853 ^a ± 0.00	0.0254 ^a ± 0.02	0.00462 ^a ± 0.00	0.0148 ^a ± 0.01	0.1621 ^b ± 0.08
Week 12	4.475 ^b ± 3.85	2.133 ^{ab} ± 0.39	0.209 ^a ± 0.19	1.356 ^a ± 1.25	0.247 ^a ± 0.26	0.711 ^a ± 0.92	14.127 ^c ± 1.48
Week 16	7.765 ^a ± 8.97	2.2 ^a ± 0.76	0.455 ^a ± 0.11	2.247 ^a ± 3.72	0.597 ^a ± 0.47	0.787 ^a ± 0.45	8.220 ^a ± 3.90
Root length density (Kmm⁻³)							
Week 8	4.42 ^{ab} ± 3.09	6.732 ^b ± .087	0.161 ^a ± 0.12	1.242 ^a ± 1.45	1.176 ^a ± 1.05	0.294 ^a ± 0.30	3.925 ^{ab} ± 6.60
Week 12	43.492 ^a ± 47.26	16.7 ^a ± 15.67	13.02 ^a ± 7.64	26.52 ^a ± 35.60	10.51 ^a ± 9.81	10.25 ^a ± 3.49	94.9 ^b ± 25.94
Week 16	0.3924 ^b ± 0.25	0.1067 ^a ± 0.02	0.1782 ^{ab} ± 0.07	0.261 ^{ab} ± 0.14	0.0677 ^a ± 0.08	0.201 ^{ab} ± 0.08	0.3553 ^b ± 0.12
Sediment yield (Kgha⁻¹)							
Week 8	14331 ^a ± 2232	21309 ^{abc} ± 3767	18593 ^{ab} ± 922.8	19939 ^{abc} ± 7209	27525 ^c ± 5072	27190 ^c ± 3643	24063 ^{bc} ± 4746
Week 12	10650 ^a ± 9989	16839 ^a ± 6798	18575 ^a ± 599.2	14648 ^a ± 5518	17641 ^a ± 7014	19551 ^a ± 4676	15542 ^a ± 716.8
Week 16	1363 ^a ± 68.32	1011 ^a ± 535	1494 ^a ± 91.52	1789 ^{abc} ± 640.6	2697 ^b ± 995.5	1124 ^a ± 584.3	1749 ^{ab} ± 423.4

Notes: Row means with different superscripts are significantly different at p≤0.05 ± SD, significant level p≤0.05

CP= *Cynodon plectostachyus*, CC= *Cymbopogon citratus*, CG= *Chloris gayana*, CCi= *Cenchrus ciliaris* EM=*Enteropogon mactostachyus*, ES= *Eragrostis superba*

Table 5.2: Length of fine roots (<1 mm) in cm as the grasses advanced to maturity

Grass species	Week 8	Week 12	Week 16
<i>Cynodon plectostachyus</i>	477.8 ^a ± 394.1	1116.9 ^a ± 1152	1119.3 ^a ± 804.7
<i>Cymbopogon citratus</i>	351.7 ^a ± 71.63	498.8 ^a ± 456.4	721.1 ^a ± 277
<i>Chloris gayana</i>	289.5 ^a ± 156.7	433.2 ^a ± 247.5	576.5 ^a ± 207.9
<i>Cenchrus ciliaris</i>	807.1 ^a ± 463.8	811.1 ^a ± 1062	820.4 ^a ± 386.5
<i>Enteropogon macrostachyus</i>	220.9 ^a ± 227.7	327.7 ^a ± 314.5	664.8 ^a ± 180.
<i>Eragrostis superba</i>	169.6 ^a ± 123.1	311.5 ^a ± 88.3	646.2 ^a ± 253.1
Control	866.1 ^a ± 1310	2760 ^b ± 844.7	1016.3 ^a ± 373

Notes: Means with different superscripts within a column are significantly different at $p \leq 0.05$
± SD, significant level $p < 0.05$

Below ground biomass per cubic meter increased with maturity. The belowground biomass increment across the weeks was relatively low with control plots reducing significantly after the 12th week. Control plots had a heavier (8.22 kg m⁻³) biomass followed by plots with *C. plectostachyus* (7.77 Kg m⁻³). The lowest biomass obtained was from plots with *C. gayana* (0.455Kg m⁻³) and *E. macrostachyus* (0.597 Kg m⁻³) respectively (Table 5.1).

5.5 Discussion

Soil disturbance before planting affects hydrological characteristics of the soil. A higher runoff and higher percolation were observed in the early developmental stages of the grasses in this study in comparison to the other stages. The higher percolation could be attributed to the surface crust breaking by the tillage practice and creation of macropores. Mganga *et al.* (2010) working in Kibwezi observed a higher increase in infiltration capacity at the elongation stage of the grasses as compared to the flowering and maturity stages even though the author focused on

standing biomass. Schmidt (2010) found similar results working with silty soils that after land ploughing the infiltration increases but reduces after a period of time because the bulk density goes back to normal and processes of surface sealing influence the infiltration. Meek *et al.* (1992) argued that tillage can either decrease or increase the infiltration rate depending on the extent of soil compaction. The initial increase in percolate can also be attributed to the changes in surface sealing (Burch *et al.*, 1986). At the vegetative stage, the amount of sediment yielded was high which can be attributed to the highly pulverised soil after the tillage that was susceptible to the raindrop impact. The findings were consistent with Engel *et al.* (2007) who found that soil preparation resulted into fine fragmented soil which was consequently easy to detach and transport by the rainfall and the runoff. High sediment yields of $0.187 \text{ kg m}^{-2} \text{ min}^{-1}$ on 12° slope were also recorded in the Loess Plateau of China by Zhou *et al.* (2017) at 90 mm hr^{-1} . The increased sediment load could also be attributed to the interaction between the runoff and rainfall erosivity and the soil resistance. In the subsequent stages, runoff increased and percolate decreased which could be attributed to the reconsolidation of the soil causing the formation of a crust. Meek *et al.* (1992) also observed that the settling back of soil following tillage reduced the infiltration. Small soil particles and living roots can also cause the closing of micropores which reduces infiltration (Schmidt, 2010).

Zhou and Shangguan (2006) working with *L. perenne* in China found that shoots contributed more to runoff reduction while roots contributed above 50% more in reducing sediment yield. Absence of shoots in this study could explain why the runoff amounts were relatively high. The role of shoots in reducing runoff has been discussed. The shoot intercepts the rainfall, lowering the velocity of the raindrops which increases the infiltration and consequently reducing the runoff (Styczen and Morgan 1995; Gyssels *et al.*, 2005; Katuwal *et al.*, 2013).

Sediment detachment rates reduced as the grasses advanced to maturity while the fine roots increased. A negative relationship between the fine roots and soil loss was observed. Similar results were observed by (Gyssels, 2005) while working in Belgium. Mwangi *et al.* (2014) found that the massive fine roots possessed erosion reducing potential by increasing the resistance of the topsoil to the concentrated flow. In this study increase in the number of fine roots reduced the rate of sediments detaching. Bubenzer (2001) similarly reported that increased root length density reduced the erodability of the soil while Gyssels *et al.* (2002) reported that increase in root biomass density reduced erosion.

Cynodon plectostachyus and *C. citratus* showed longer root length development as compared to other grasses indicating their higher competitive ability. *C. plectostachyus*'s competitive ability is attributed to its quick development, prostrate and decumbent nature which covers much ground surface (Georgiadis and McNaughton, 1988) preventing direct sunlight to the soil. In addition, *C. plectostachyus* forms roots at every node that is in contact with the soil (Gobilik *et al.*, 2013). The competitive ability of *C. citratus* is attributed to its hardiness and resistance to drought (Joy *et al.*, 2006). The initial high root length density in *E. macrostachyus* is attributed to its faster germination because of the seed dormancy type (integument) as compared to *E. superba* (Koech *et al.*, 2014). The RD and RLD increased as the grasses advanced to maturity which can be attributed to the grasses response to water stress (Hsiao and Xu, 2000). Extreme water stress can further lead to a reduction in root length (Comas *et al.*, 2013), which could explain the small increment margins.

5.6 Conclusion and recommendations

Cymbopogon citratus, *C. plectostachyus* and *C. ciliaris* could significantly control soil erosion in Suswa. In this study, these grasses had more below ground biomass, extensive root length and

lesser sediment detachment rates. The root role investigated in this study show that grasses can effectively reduce sediment yield as compared to runoff in a high-intensity rainfall. This study recommends that the land managers should plant the aforementioned grasses for control of sediment detachments as well as stabilising of the slopes and water conservation physical structures in Suswa. Further, the study recommends a quantification of erosion control contribution by both roots and shoots separately and combined in a longer observation period.

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CHAPTER 6

Above ground biomass and morphometric characteristics at different phenological stages of six range grasses used for rehabilitation

Abstract

Inadequate livestock feed both in quantity and quality is a major threat to livestock production in the arid and semi-arid rangelands in Kenya. Consequently, drastic measures are required to maintain the pastoralists' livelihood. A completely randomized design experiment with three replications was conducted to obtain data on morphometric characteristics and aboveground biomass of six grasses (*Eragrostis superba*, *Cynodon plectostachyus*, *Cenchrus ciliaris*, *Enteropogon macrostachyus*, *Chloris gayana* and *Cymbopogon citratus*) in Suswa, Narok County. Plant height, tiller numbers and leaves per tiller increased with maturity. Statistical analysis of LSD 5 % showed that the aboveground biomass was significantly different ($p < 0.001$) between species and *C. plectostachyus* produced the highest (0.9 t ha^{-1}) biomass, while *E. superba* produced the lowest (0.424 t ha^{-1}). Plant height varied among the grass species with the highest being *C. plectostachyus* (36.6 cm) and the least *E. superba* (2.47 cm). Tiller numbers increased with maturity where *C. plectostachyus*, *C. ciliaris* and *E. macrostachyus* had a higher number of tillers compared to the other grasses. Correlation of morphometric characteristics and above ground biomass was significantly positive. The identified high yielding species under the rainfed conditions in the study area were *C. plectostachyus*, *E. macrostachyus*, *C. gayana* and *C. ciliaris* (0.9 , 0.818 , 0.8 and 0.79 t ha^{-1}) respectively. These species are well adapted to the semi-arid areas of Southern Kenya as shown by their productivity under rainfed conditions.

Keywords: Biomass yields, morphometric characteristics, indigenous grass species, semi-arid lands

6.1 Introduction

Grasses constitute the largest and most important proportion of grazing livestock animal diet, yet their availability remains impeded by land degradation and rainfall (Reichenberger and Pyke, 1990; Kimble *et al.*, 2016). Feed deficit is a major problem facing livestock keepers in Africa's semi-arid lands (Lugusa, 2015; Koech *et al.*, 2016) especially during extended periods of dry season and drought. There is an increasing need to produce more grasses notwithstanding the unpredictable environmental conditions. The ASALs of Kenya occupies the largest percentage of land mass (>80%) (Nyangito *et al.*, 2008; Miriti *et al.*, 2012). The most viable livelihood in these areas is pastoralism and presently faces feed availability seasonalities jeopardizing the livelihood.

Studies on the suitability of the grasses for increased biomass yields have been conducted and drought tolerant grasses have been advocated for in most ASALs. For example, suitability for their production under different land preparations (Opiyo *et al.*, 2011) on varied water regimes (Koech *et al.*, 2016), and on reseeding technologies (Mganga *et al.*, 2015). Grasses like *C. ciliaris*, *C. gayana*, *E. macrostachyus* and *E. superba* have been researched and proven viable under both irrigated and rain-fed regimes.

Communities are rich in indigenous knowledge and have first-hand information in feeding characteristics of livestock both in wet and dry seasons. Different livestock keepers have shown to prefer different grass species for fodder production for their animals (Ndathi *et al.*, 2012). Owing to the time spent by the farmer with the animal, they are bound to know what the animal

prefers and what they averse. The need to produce more palatable grasses has been the drive of many researchers and producers. There is need to use communities indigenous knowledge and experience in selecting suitable pastures for production for higher yields and good feed quality. This study was therefore conducted to compare the productivity of grasses preferred by the pastoral communities in Suswa with those that have been recommended in previous studies.

6.2.2 Data collection

6.2.2.1 Plant height, number of leaves on primary shoot, tillers and tiller numbers

Three plants were randomly selected from each 5 x 5m plot and tagged for observation and data on plant height, number of leaves on primary shoot and tillers and the tiller numbers collected. Data were collected at three phenological growth stages of represented by weeks after planting (8, 10 and 12), representing vegetative, anthesis and maturity. Plant height was measured from the base of the plant to the longest tiller leaf.

6.2.2.2 Above ground biomass

At the 16th week after sowing, biomass was harvested in each plot by destructive method by clipping within a 0.25m² quadrant at a stubble height of 2.5 cm to avoid contamination with soil. The grasses were then put in a labelled brown sample bags, transported to the University of Nairobi laboratory and oven dried at 80⁰ C for 96 hours before weighing to determine dry matter yields (kg ha⁻¹).

6.2.3 Data analysis

Data on aboveground biomass, number of tillers, plant heights, leaves per tiller and leaves on primary shoot were statistically evaluated using ANOVA. Pearson correlation analysis was

performed between morphometric characteristics and above ground biomass. The ANOVA and correlation analyses were performed on R statistical package (R Core Team, 2017). Means of morphometric characteristics and aboveground biomass were separated Duncan's Multiple Range Test.

6.3 Results

6.3.1 Morphometric characteristics of the grass species

6.3.1.1 Plant height

The heights of the grasses at vegetative and anthesis stages were not significantly different ($P>0.05$). However, at maturity stage, the means of the plant heights were significant different ($p<0.1$). Plant height increased with maturity, however, *C. gayana*, *E. macrostachyus*, *C. ciliaris* and *E. superba* heights reduced after anthesis. *Cynodon plectostachyus* and *C. citratus* were the tallest at maturity stage with 36.33cm and 26.73 cm respectively (Table 6.1).

Table 6.1: Means of plant height (cm) of six grass species at different growth stages

Grass species	Phenological Growth stages		
	week 8	week 10	week 12
<i>Cynodon plectostachyus</i>	17.8 ^{ab} ± 15.34	17.8 ^{ab} ± 15.34	36.6 ^a ± 28.57
<i>Cymbopogon citratus</i>	21.57 ^a ± 15.81	24.63 ^a ± 16.97	26.73 ^{ab} ± 23.05
<i>Chloris gayana</i>	8.63 ^{ab} ± 0.982	7.9 ^{abc} ± 3.44	4.4 ^b ± 4.06
<i>Cenchrus ciliaris</i>	5.6 ^b ± 1.08	7.13 ^{bc} ± 0.451	4.43 ^b ± 0.569
<i>Enteropogon macrostachyus</i>	9.47 ^{ab} ± 0.929	11.8 ^{abc} ± 0.361	9.37 ^b ± 1.87
<i>Eragrostis superba</i>	6.2 ^{ab} ± 1.95	6.8 ^{bc} ± 2.262	2.47 ^b ± 4.27

Means in the same column with different superscripts are significantly different at $p<0.05$

± Standard deviation

6.3.1.2 Number of tillers

The tiller numbers at week 8 and 10 were significantly different at $p < 0.05$ among all the grasses while at week 12 the grass species tiller numbers were significantly different at $p < 0.01$. *C. plectostachyus* and *C. ciliaris* had the highest number of tillers at all the phenological stages. *C. gayana* and *E. superba* had the lowest number of tillers (Table 6.2). In the control plots, the main plant was nutsedges (*Cyperus rotundus* L.) which did not produce tillers.

Table 6.2: Means of tiller numbers of six range grass species at different growth stages

Grass species	Growth stages		
	week 8	week 10	week 12
<i>Cynodon plectostachyus</i>	4.33 ^a ± 2.08	5.00 ^a ± 1.73	7.00 ^a ± 1
<i>Cymbopogon citratus</i>	0 ^c ± 0	2.33 ^{bc} ± 1.53	3.67 ^{bc} ± 2.52
<i>Chloris gayana</i>	0.33 ^{bc} ± 0.58	2.33 ^{bc} ± 0.58	1.67 ^{cd} ± 1.53
<i>Cenchrus ciliaris</i>	3.00 ^a ± 1	4.67 ^a ± 0.58	5.00 ^{ab} ± 2.65
<i>Enteropogon macrostachyus</i>	2.67 ^{ab} ± 2.31	4.00 ^{ab} ± 1	4.67 ^{abc} ± 1.15
<i>Eragrostis superba</i>	2.33 ^{abc} ± 0.58	1.67 ^{cd} ± 1.53	0.33 ^d ± 0.58

Means in the same rows with different superscripts are significantly different at $p < 0.05$

± Standard deviation

6.3.1.3 Leaves on the primary shoot and tillers

Primary shoot leaves in week 8, 10 and 12 were significantly ($p < 0.01$) different among the grass species. At week eight, the average leaf number was four in all the grass species except for *C. plectostachyus* with an average of seven leaves. At week 12, leaves on the primary shoot in all the grasses reduced, while the number of leaves per tillers increased. *C. plectostachyus* and *C. ciliaris* had the highest number of leaves per tiller at all the weeks. A positive relationship between the number of leaves per tiller and advancement in growth for the three measurement periods was observed in the three grasses (Table 6.3).

Table 6.3: Mean number of leaves per tiller of six grass species at different growth stages

Grass species	Growth stages		
	week 8	week 10	week 12
<i>Cynodon plectostachyus</i>	17.7 ^a ± 11.06	23.3 ^a ± 2.52	28.0 ^a ± 3
<i>Cymbopogon citratus</i>	0 ^c ± 0	7.0 ^b ± 5.57	12.3 ^b ± 7.23
<i>Chloris gayana</i>	1.3 ^c ± 2.31	5.0 ^{bc} ± 0	4.67 ^{bc} ± 1.53
<i>Cenchrus ciliaris</i>	11.7 ^{ab} ± 3.51	17.67 ^a ± 1.53	14.0 ^b ± 14.8
<i>Enteropogon macrostachyus</i>	7 ^{bc} ± 6.08	9.3 ^b ± 3.51	11.33 ^{bc} ± 1.53
<i>Eragrostis superba</i>	7.3 ^{bc} ± 2.89	4.67 ^{bc} ± 4.51	2.33 ^{bc} ± 2.08

Means in the same column with different superscripts are significantly different at $\alpha < 0.05$

± Standard deviation

6.3.2 Above-ground biomass

The biomass production of the grasses was significantly different ($p < 0.001$). The highest biomass was observed in *C. plectostachyus* (0.9 t ha⁻¹) followed by *E. macrostachyus*, *C. gayana* and *C. ciliaris* 818.7 kg ha⁻¹, 801.33kg ha⁻¹ and 790.8kg ha⁻¹ respectively. The lowest biomass production was observed in *E. superba* with 424.67 kg ha⁻¹ (Table 6.4).

Table 6.4: Mean aboveground biomass yields (kg ha-1) of the six-grass species

Grass species	Above ground biomass at week 16 from sowing
<i>Cynodon plectostachyus</i>	906.7 ^a ± 76.1
<i>Cymbopogon citratus</i>	714.7 ^b ± 14.1
<i>Chloris gayana</i>	801.3 ^{ab} ± 24.1
<i>Cenchrus ciliaris</i>	790.8 ^{ab} ± 132.1
<i>Enteropogon macrostachyus</i>	818.7 ^{ab} ± 86.9
<i>Eragrostis superba</i>	424.7 ^c ± 56.3

Means with different superscripts are significantly different at $\alpha < 0.05$

± Standard deviation

Correlation analysis (Table 6.5) showed tillers and number of leaves per tillers have greater and positive influence on the aboveground biomass as compared to leaves on primary shoot and plant height at week 12.

Table 6.5: Pearson correlation coefficients of aboveground biomass and morphometric characteristics at maturity

Characters	Plant height (12)	Leaves on primary shoot (12)	Tillers (12)	Leaves/tiller (12)	Abgm
Plant height (12)		0.4029*	0.5511**	0.5605**	0.3954*
Leaves on primary shoot (12)			0.6139**	0.6267**	0.3239
Tillers (12)				0.8819***	0.7348***
Leaves/tiller (12)					0.7365***
Abgm					

***, ** and * indicate significant difference at the $p < 0.001$, $p < 0.05$ and $p < 0.1$ levels, respectively, using the least significant difference (LSD) method

Abgm = Aboveground biomass

6.4 Discussion

Increase in plant height over time is a natural occurrence due to growth and development and has been documented in other studies. Opiyo *et al.* (2011) and Koech *et al.* (2016) found similar results where range grasses increased in height with maturity. This is a result of the growth process that the plants undergo. They, however, indicated that the grasses are influenced by climatic conditions and soil type. Under rainfed conditions, different grass heights have been relatively low in comparison to the grasses grown under irrigation. Stagnated growth can be attributed to change of plant allometry in which there is increased growth of root hairs and aquaporins while maintaining or reducing the shoot because of reduced soil moisture (Comas *et al.*, 2013). In addition, reduced plant heights can lower the above-ground biomass (Arshad *et al.*,

2016). The observed higher plant height in *C. plectostachyus*, *C. citratus* and *E. macrostachyus* are attributed to their ability to grow and establish faster. *Enteropogon macrostachyus* has been found to have a better competitive advantage in germination because its dormancy is integument dependent, unlike others like *E. superba* and *C. ciliaris* that depend on both the integument and embryo dormancy (Opiyo *et al.*, 2011; Mganga *et al.*, 2015; Koech *et al.*, 2016). However, the heights of *C. gayana*, *E. macrostachyus*, *C. ciliaris* and *E. superba* reduced after anthesis as a result of encroachment by stray goats that grazed the tagged plants in the experimental plots. The selection by the goats is an indicator of their preferred species. *Cynodon plectostachyus* which is a perennial grass has a vigorous tiller recruitment capacity which facilitates vegetative propagation and its spread hence faster growth and increased height (Clayton and Harlan, 1970). *Cynodon plectostachyus* has small leaves that control transpiration rate and increase water use efficiency, therefore, promoting more growth (Medrano *et al.*, 2015). *Cymbopogon citratus* competitive ability is attributed to its hardiness and resistance to drought (Joy *et al.*, 2006). The observed slower increment in the plant height and tiller production with time for all the species is a function of low soil moisture regardless of supplemental irrigation. Anwar *et al.* (2012), Mann *et al.* (2013), Jeremiah *et al.* (2013) and Koech *et al.* (2016) also observed reduced plant height of the grasses under rainfed as compared to the irrigated ones. Increased rainfall variability causes plant water stress that alters plant carbon cycling processes like net productivity (Knapp *et al.*, 2002), which consequently stunts the growth of the plant. In the current study soil disturbance done using hoes and forks during the experiment may have failed to harvest sufficient water for growth and development of grasses. This is consistent with Opiyo *et al.* (2011) who concluded that ripped plots by machines like tractors disturb the soil in a way that increases water harvesting for the grass than hand clearing using machetes.

Higher biomass yields in the ASALs are required to meet the feed demands by the animals. *Cynodon plectostachyus* provided higher biomass yields in comparison to other grass species. This is attributed to its growth form and morphological characteristics. The grass species is more stemmier (Roche, 2013) as compared to *C. ciliaris*. *Enteropogon macrostachyus* had equally a higher biomass yield which was attributed to its faster germination that gives it a head start in competition (Kadmon and Schimida, 1990). Low biomass yield by *E. superba* unlike in other studies by Mganga *et al.* (2010), Opiyo *et al.* (2011) and Koech *et al.* (2016) can be attributed to its high shoot to root ratio that might have caused most of the plants to die from water stress when the drought persisted. Bulle *et al.* (2010) and Koech (2014) working in northern and southeastern Kenya respectively observed similar results as this study where they reported that *C.gayana* produced more biomass than *C. ciliaris* and *E. superba* at maturity stage under a rainfed regime.

Morphometric characteristics like plant height, tiller numbers, leaves per tiller among others have been found to correlate positively and significantly with aboveground biomass (Laidlaw, 2005; Zhu *et al.*, 2002). Zerga *et al.* (2016), while working with bread wheat in Ethiopia, found that tillers had a positive association with the plant height, while Opiyo *et al.* (2011) working in Kenya found that a high number of tillers resulted to higher foliage conquering with the current study findings. Production of tillers is a function of new leaf appearance (Bahmani *et al.* 2000). *Cymbopogon citratus* exhibited late tillering in this study which could be attributed to late new leaf appearance. *Cynodon plectostachyus* performed better than all the other grass species in terms of tiller numbers and the biomass yield. Closely following is the *C. ciliaris*, *E. macrostachyus* and *C. gayana*. These grasses have been marked for fodder production in many arid areas (Lugusa, 2015; Koech *et al.*, 2016). Whereas it is unpalatable to animals due to the

high citral content (Buba, 2015; Mekonen *et al.*, 2015; Lee *et al.*, 2016), *C. citratus* was found to provide relatively high aboveground biomass.

6.5 Conclusion

Morphometric characteristics contribute significantly to the total aboveground biomass. High tiller and leaves per tiller production in the early stage is crucial to high aboveground biomass. *Cynodon plectostachyus* chosen by the local community recorded the highest average plant height, number of leaves on the primary shoot and on tillers, number of tillers and total aboveground biomass. *Cynodon plectostachyus*, *Enteropogon macrostachyus* and *Chloris gayana* where two were chosen by the community and ranked 1st and 3rd in aboveground biomass production.

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CHAPTER SEVEN

General conclusions and recommendations

7.1 Conclusion

The study assessed the effectiveness of using tropical range grasses in soil erosion reduction and fodder provision. A survey, FGDs, KIIs and direct observation were used to determine the local preferred grass species and their reasons. The results showed that *Cynodon plectostachyus*, *Chloris gayana*, *Pennisetum clandestinum*, *Cymbopogon citratus* and *Themeda triandra* were highly preferred and deemed more suitable for rehabilitation. Fodder provision was considered primary to soil conservation in selecting the grass species suitable for rehabilitation. The results also revealed that decision making is influenced by the needs and way of life of the people.

A field experiment was conducted to quantify the effectiveness of *Cynodon plectostachyus*, *Chloris gayana*, *Cymbopogon citratus*, *Cenchrus ciliaris*, *Enteropogon macrostachyus*, *Eragrostis superba* and natural regeneration grassroots in soil erosion control. Rainfall simulation of 116mm hr⁻¹ was used to generate runoff after all the aboveground was clipped to soil level. The results showed that the sediment production reduced as the grasses advanced with maturity attributed to increase in fine root length as they possess erosion reducing potential. The surface runoff increased with maturity which is attributed to absence of aboveground biomass to intercept the rain and lower its velocity giving it time to infiltrate. *Cymbopogon citratus*, *Cynodon plectostachyus* and *Cenchrus ciliaris* had more below ground biomass, extensive root lengths and lesser sediment rates as compared to the other grass species.

Further, the study quantified the morphometric and aboveground biomass production of the grasses. Morphometric characters were collected at 8, 10 and 12 weeks after planting and

biomass harvested destructively after 16 weeks of planting. Morphometric parameters significantly influence the aboveground biomass of the grasses. The mean tiller numbers and leaves per tiller were generally low in all the species. However, *Cynodon plectostachyus* produced more tillers, leaves per tiller and aboveground biomass. *Enteropogon macrostachyus* and *Chloris gayana* followed respectively in biomass production.

Finally, the study results revealed that the community chosen grasses performed better in soil erosion reduction and in fodder production. In fodder production, however, encroachment by goats indicated preference of *Chloris gayana*, *Enteropogon macrostachyus*, *Cenchrus ciliaris* and *Eragrostis superba*. The study's premise was soil conservation and fodder provision can be achieved with synergy. However, the encroachment revealed a trade-off in using the same species for both roles.

7.2 Recommendations

- Community involvement in the selection of grass species for rehabilitation should be prioritised in the implementation of interventions for controlling land degradation efforts in the ASALs. This is because of environmental knowledge and decision-making skills based on their needs and priorities in identifying suitable grass species for rehabilitation.
- There is a need for identification of ecotypes that can alleviate the trade-offs of palatability presented by key grass species for erosion control.
- Long-term studies of both aboveground and belowground biomasses in soil erosion reduction for tropical range grasses should be conducted.

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