"EVALUATING PERFORMANCE OF RANGE GRASSES UNDER DIFFERENT MICRO-CATCHMENTS AND FINANCIAL RETURNS FROM RESEEDING IN SOUTHERN KENYA"

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DECLARATION AND APPROVAL

DECLARATION

I, Bryan Peter Ogillo, do hereby declare that the work contained in this thesis is my original work and has never been submitted for a degree in any other university.

Signed .... Date 14/09/2010

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APPROVAL

This thesis has been submitted with our approval as University supervisors.

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DEDICATION

To my beloved parents, Mr. and Mrs. Otumba,

my dear siblings; Kennedy, Pamela, Bella, Lorna and Brenda,

and

my adored grandmother, Francisca Obonyo.

You are an inspiration in my life.

God bless you all!!

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ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of variance
ASALs	Arid and semi-arid lands
asl	Above sea level
BCR	Benefit-cost ratio
CC	*Cenchrus ciliaris*
CEC	Cation exchange capacity
CIGs	Common interest groups
CR	*Chloris roxburghiana*
DM	Dry matter
EM	*Enteropogon macrostachyus*
ES	*Eragrostis superba*
GoK	Government of Kenya
ha	Hectare
HH	Household head
ICARDA	International Centre for Agricultural Research in Dry Areas
ILRI	International Livestock Research Institute
IRR	Internal rate of return
ITCZ	Inter-tropical convergence zone
KARI	Kenya Agricultural Research Institute
KES	Kenya shillings
kg	Kilogram
LSD	Least significant difference
NGO	Non-governmental organization
NPV	Net present value
PGS	Pure germinating seeds
RAE	Rehabilitation of arid environments
SPSS	Statistical packages for social scientists
UoN	University of Nairobi
USCCTP	United States climate change technology program
wks	Weeks

ABSTRACT

A study was carried out in the southern rangelands of Kenya to test the effect of two micro-catchments – ox-furrows and crescent shaped pits (Kiboko range pits) on the performance and competitive interactions of mixtures and monocultures of four range grasses (*Cenchrus ciliaris, Chloris roxburghiana, Enteropogon macrostachyus* and *Eragrostis superba*). The study also evaluated the economic returns from the two reseeding approaches. A questionnaire survey was also administered to capture general issues regarding reseeding in the study area. On-farm and on-station seed samples for the four grasses were collected to compare their germination capacity. The germination tests were done in the laboratory at room temperature on standard petri-dishes over a period of 14 days. The effect of micro-catchments on the performance and competitive interactions among the grass species was tested in a split plot experimental design. The main-plot (27mx 6m) was the type of micro-catchment while the sub-plot (2.5m x 2.5m) was the species type either as mixtures or monocultures. The grasses were sown by hand at a seeding rate of 5kg per hectare. A quadrat (0.5m x 0.5m) placed in the middle of each sub-plot was used to monitor the following plant parameters: percent cover, plant density, tiller density, leaf density, plant height, aboveground biomass production and seed production. Data were collected at six, nine, twelve and sixteen weeks post sowing. An economic analysis of the two reseeding enterprises was done by computing the benefit-cost ratio (BCR) and internal rate of return (IRR). All costs, from the time of land preparation to hay harvesting were recorded. Hay harvested from the experimental plot was valued at prevailing market price and used as a proxy to the benefits accrued from reseeding.

The germination percent among the grass species was significantly different ($p \leq 0.05$). *Enteropogon macrostachyus* had the highest percent germination (98.7%) after 14 days. The germination percent for the other three grasses were: *C. roxburghiana* (52.5%), *E. superba* (44.2%) and *C. ciliaris* (41.1%). The germination percent between on-farm and on-station grass

seeds was significantly different ($p \leq 0.05$). In terms of species, only *C. ciliaris* showed a significant difference between on-farm and on-station grass seeds. However, the storage duration did not have a significant effect on the germination capacity of the grass seeds. There was a significant difference ($p \leq 0.05$) between ox-furrows and Kiboko range pits in percent cover and plant density (plants/m^2). However, the difference was not significant between the two micro-catchments in tiller density, leaf density, plant height, aboveground biomass production and seed production. Nevertheless, Kiboko range pits performed slightly better than ox-furrows in all the measured parameters. Among the grass species, there was a significant difference only in percent cover and plant density. *Cenchrus ciliaris* as a monoculture and in mixtures outperformed the other four grasses.

The BCR indicated that the reseeding approaches are viable undertakings. Kiboko range pits yielded a BCR of 2.5 and ox-furrows 2.6. Among the monocultures, *C. ciliaris* gave the highest benefits with a BCR of 3.7 and 3.2 under ox-furrows and Kiboko range pits, respectively. The least beneficial grass species was *E. superba* with a BCR of 1.0 and 1.3 in the ox-furrows and Kiboko range pits, respectively. The IRR for ox-furrows and Kiboko range pits were 22.6% and 23.6% respectively, which were higher than the lending rate of 14.76% for 2009.

In conclusion, on-farm grass seed production should be promoted in the study area to meet the rising demand for grass seeds, the farmer has the option of using either Kiboko range pits or ox-furrows as types of micro-catchments for reseeding purposes since both are economically viable, and *C. ciliaris* is the superior grass species and therefore should be promoted as the species of choice for reseeding in the southern rangelands of Kenya.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Arid and Semi-Arid Lands (ASALs) are characterized by high moisture deficits, variable as well as erratic rainfall and cover more than 80% of the Kenyan land size (Hansen *et al.* 1986; GoK, 2002). Livestock production under agro-pastoral and pastoral systems is the main source of livelihood for the people in the ASALs (Mbogoh and Shaabani, 1999). However, one of the major constraints to livestock productivity is inadequate supply of feeds both in quantity and quality (Nyangito *et al.* 2008). Declining availability of palatable and nutritious forage plant species, as a result of prolonged over-utilization of the rangeland pastures is common. Poor quality forage plant species dominate large areas of pasturelands and for the better part of the year; the grazing areas remain almost bare (Mnene, 2006). In East African rangelands, the status of natural pastures is on a downward trend (Coughenour *et al.* 1990; McPeak, 2001; Coughenour, 2004).

Rising human population pressure, changing land use and tenure systems have made it much more difficult for agro-pastoralists to respond to increasingly low feed availability and patchiness of key natural resources such as water and mineral licks in the ASALs (Herlocker, 1999; Muok *et al.* 2001). This has further been aggravated by land sub-division and sedentarization. This scenario has led to change in livestock production strategies in the ASALs, gradually changing from extensive to intensive semi-zero and/or zero grazing systems. The changes are closely linked to upgrading of the local cattle breeds *(Bos indicus)* by cross breeding with exotic breeds *(Bos taurus)* or bringing in higher yielding local breeds to boost production (Gitunu *et al.* 2004). This is translating to a growing demand for feeds to meet the higher feed requirements by the relatively larger and more productive animals.

Past studies have demonstrated that reseeding is one option to improving forage production in rangelands (Pratt and Gwynne, 1977; Mnene *et al.* 1998; Mnene, 2006; Opiyo, 2007; Mganga. 2009). The main aim of reseeding rangelands is to improve ground cover and boost biomass production (Pratt and Gwynne, 1977). However, more often than not reseeding activities fail due to scarcity and unreliability of rainfall in the ASALs. This has necessitated the use of various water harvesting techniques in order to capture the little rainfall received in the rangelands (Njenga, 1992). Micro-catchments in the form of range pits, ox-furrows and crescent-shaped pits have been used (Pratt and Gwynne, 1977; Mnene, 2006). These micro-catchments prevent soil erosion by reducing runoff especially in sloppy terrain and improve infiltration of water into the soil. However, the performance of the reseeded stands under these micro-catchments and their benefit-cost analysis is not fully documented and evaluated.

Efforts by Kenyan researchers in forage improvement have raised communities' awareness on the advantages of maintaining improved pastures (Gitunu *et al.* 2004). The approach has been over-sowing and reseeding degraded natural pastures with the aim of re-introducing depleted species and/or introducing other adapted ones. For the purpose of successful range reseeding, use of perennial grasses is preferred with the exception of arid environments where annuals grasses are more suited. This is because, perennial grasses are good in self-seeding which enables them to establish and spread fast, effectively covering the ground (Opiyo, 2007). These grasses are also known to have good grazing value and persistence. These attributes have amplified the demand for perennial grass seeds for pasture improvement. However, current supplies of forage seeds are unable to satisfy this demand. Furthermore, commercial forage seed producers and dealers are currently targeting only a few forage species, particularly forage plant species suitable for the medium and high potential areas (Gitunu *et al.* 2004). Forage species for ASALs have continued to receive little attention and their seeds are not readily available in the market. This has resulted in agropastoral farmers planting forage species that do not meet their production goals and/or those that are not adapted to their environments, leading to low pasture production which leads to poor livestock productivity.

To assist agropastoral farmers in the arid and semi-arid areas of Kenya, community-based seed bulking has been promoted by Kenya Agricultural Research Institute (KARI), the Ministry of Livestock and other development partners like World Vision (Gitunu *et al* 2004). However, the quality of seeds produced on-farm is not assured. Moreover, information on the suitable forage seeds for the varied soil types and climatic conditions in the ASALs is limited in terms of their performance under varying environmental conditions and their performance in mixtures (Mnene, 2006). In addition the economic benefits of different range reseeding approaches need to be evaluated (Ego and Kibet, 2003; Dolan *et al.* 2004; Mnene, 2006).

In view of the aforementioned, a study was undertaken to evaluate the effect of two micro-catchments, i.e., ox-furrows and crescent-shaped pits (Kiboko range pits) on the performance and competitive interactions of four range grasses – *Cenchrus ciliaris, Chloris roxburghiana, Enteropogon macrostachyus* and *Eragrostis superba*. Additionally, a benefit-cost analysis of the two micro-catchments was also examined.

1.2 PROBLEM STATEMENT

In ASALs, deterioration and degradation is a key challenge to livestock production. All over the world, degradation of natural vegetation is a common occurrence (Visser *et al.* 2007). This is partly attributed to the following factors; overgrazing, over-cultivation of agropastoral areas, deforestation and diminishing grazing areas due to use of rangelands for other purposes. In spite of this and in an effort to maintain livestock as the mainstay of ASAL livelihoods, upgraded and exotic breeds have been introduced. These breeds demand more feeds from an already degraded range and therefore the need for higher yielding pastures. One of the ways of arresting the situation is through reseeding by using superior grass species. However, the appropriateness of the available grass phenotypes in terms of drought tolerance, growth rates, biomass production and seed production is not fully assessed and documented (Mnene, 2006).

Establishment of reseeded pastures is constrained by lack of adequate moisture in ASALs. To increase the establishment rates, water harvesting is necessary. This can be achieved through use of micro-catchments such as contour ox-furrows, range pits and crescent-shaped pits (Kiboko range pits). Micro-catchments greatly increase the success rates of reseeding (Pratt and Gwynne, 1977; Mnene, 2006). However, there is need to determine suitable micro-catchments per range site and according to farmer's socio-economic status.

Following the awareness created about the benefits of reseeding by rural development actors, farmers in the southern rangelands of Kenya are taking up reseeding activities, thus creating demand for grass seeds (Gitunu *et al.* 2004). However, meeting the demand for quality grass seeds from the available seeds is not assured. In addition, reseeding with mixtures of grass species is preferred, but the competitive interactions of the preferred mixtures is not fully understood and documented for the farmers' benefit (Mnene, 2006).

Furthermore, the issue of benefits versus costs in many range projects, range reseeding included, has not been well-articulated in the past. Dolan *et al.* (2004) singled out the need for a socio-economic assessment of range reseeding and bush management technologies carried out in the southern Kenyan rangelands.

1.3 JUSTIFICATION

This study will contribute to livestock productivity in the southern rangelands by improving pasture production through range reseeding. However, range reseeding is hampered by several factors, the key ones being; inadequate soil moisture and inadequate quality pasture seeds. Availability of moisture is probably the most limiting factor to reseeding in the ASALs. The use of micro-catchments can greatly increase the utilization of this limited moisture in the ASALs.

Another limiting factor to successful reseeding is inadequate supply of quality seeds (Hanson, 1994; Mbogoh and Shaabani, 1999; ICARDA, 2000; Mnene, 2006). In Kenya, grass seeds that are available commercially are for *Setaria sphacelata* and *Chloris gayana* which do well in the humid and sub-humid areas. From concerted efforts by various stakeholders, communities in parts of southern rangelands have been sensitized on natural pasture improvement (Gitunu *et al.* 2004). This has led to an increased demand for pasture seed, which communities in these areas have tried to meet in various ways including setting up community-based seed bulking groups. Yet there is no clear guideline on which species are suitable for which area and the quality of grass seeds is not assured.

Several development agents have sensitized farmers on simple techniques of harvesting, processing and storing grass seeds based on International Livestock Research Institute (ILRI) techniques (Hanson, 1994) and revised by Mnene (2006); mainly to meet subsistence grass seed needs. This has resulted in farmers getting surplus seeds which they sell to fellow farmers and NGOs at prices ranging from approximately Kenya Shillings (KES) 300 to 1,200 per kilogramme depending on the grass species, subject to negotiation between the buyer and seller. However, the quality in terms of pure germinating seeds (PGS) is not assured. This being a potential alternative or additional source of income for farmers, it is necessary to ascertain the quality of seeds harvested on-farm in order to give the venture credibility and make it a commercially viable venture.

It is recommended as good practice to sow grass seeds in mixtures in range areas (Mnene, 2006). This is because the range is heterogeneous and therefore the different characteristics of the grasses will allow them to occupy and utilize particular niches in the range more efficiently. However, in terms of biomass production mixtures do not necessarily give the optimum production (Mganga, 2009). For purposes of range rehabilitation it is important to emphasize planting of mixtures. However, for purposes of biomass production monocultures are preferred. It is therefore crucial to carry out more tests on which grasses do best in mixtures and in monocultures.

This study therefore, forms part of research efforts to evaluating suitable range improvement strategies. Firstly, the study assessed the quality of seed harvested at on-farm level in order to give recommendations on how to produce good quality grass seeds to meet the ever rising demand. Secondly, it evaluated suitable grass genotypes for reseeding purposes and how these perform in monocultures and mixtures in order to give recommendations on the superior grass species for reseeding. Finally, the study evaluated micro-catchments for water harvesting to increase productivity of the reseeded stands and assessed the benefits and costs of reseeding operations at on-farm level. This was aimed at making recommendations on which reseeding enterprises are profitable to the farmer.

1.4 OBJECTIVES

The overall objective of this study was to generate pasture/range management information that can contribute to enhanced feed security and livestock production in agro-pastoral areas of the southern rangelands of Kenya through the use of appropriate micro-catchments and superior range grass species.

The specific objectives were:

1. Assess the germination capacity of *Cenchrus ciliaris, Chloris roxburghiana, Enteropogon macrostachyus* and *Eragrostis superba* harvested and stored on-farm and on-station.
2. Determine the performance in terms percent cover, plant density, tiller density, leaf density, plant height, aboveground biomass production and seed production of selected range grass mixtures and monocultures under two micro-catchments – ox-furrows and Kiboko range pits.
3. Determine the cost-effectiveness of range reseeding activities under ox-furrows and Kiboko range pits.

1.5 HYPOTHESES

The following hypotheses were tested:

1. There is no significant difference in the germination percentage between range grass seeds, harvested and stored, on-farm and on-station.
2. There is no significant difference in performance (percent cover, plant density, tiller density, leaf density, plant height, aboveground biomass production and seed production) of grasses in mixtures and monocultures in ox-furrows and Kiboko range pits.
3. The use of ox-furrows and Kiboko range pits as micro-catchments for range reseeding in the southern rangelands of Kenya is not economically viable.

1.6 THESIS ORGANIZATION

This thesis falls within five main chapters. The first chapter covers the introduction of the study, statement of the problem, justification of the study, objectives, hypotheses, and organization of the study. The second chapter looks at available literature pertaining to the problem being addressed. Chapter Three covers materials and methods including description of the study area, data sources and methods of data analyses. Chapter Four highlights the main results, discussions and interpretation of the results. Chapter Five wraps up with the general discussions, conclusions, key recommendations and limitations of the results of the study.

CHAPTER TWO

LITERATURE REVIEW

2.1 RANGE RESEEDING

Range reseeding is one of the options that have been tried in rangeland rehabilitation; others include pitting and over-sowing (Bogdan and Pratt, 1967; Mnene, 2006). Rehabilitation can be described as a re-engineering process that attempts to restore an area of land back to its natural or near natural state after it has been damaged by one disruption or another (Mganga, 2009). Reseeding has been practiced for several decades in different rangelands of the world under varying environmental conditions. In the USA the earliest attempts of range reseeding began during the late 1930s and early 1940s (TPWD, 2008). Successful reseeding has also been achieved in areas of low rainfall such as Thar Desert in India which receives, 100-500mm of rainfall annually and Cholistan Desert in Pakistan, which receives 100-250mm (Sinha *et al.* 1997).

In Kenya, reseeding has been tried out in the past (Mnene, 2006). In the 1950's and 1960's, a number of reseeding techniques were developed and introduced for rangeland rehabilitation. These techniques have been carried out in several places in Kenya such as Makueni. Machakos, Baringo and Kitui. However, Bekure *et al.* (1991) observed that unless the pastoralist had control over the land, it was only possible to undertake pasture improvement within the confines of reserve grazing areas commonly referred to by the Maasai as *'Olopololis'*.

Despite the many successes, there are various challenges to range reseeding; spatial and temporal variation in rainfall a characteristic of rangelands is one such challenge. Plant growth period is usually shortened because of unreliable and limited precipitation lasting a few days (De Groot *et al.* 1992). Moreover, frequent droughts are common in the rangelands. To maximise the use of the short spells of favourable plant growth, only plants that can establish quickly to maturity have a good chance of surviving to the next generation. Plant establishment may be achieved through the use of micro-catchments that enhance growth and survival of plants within the moisture limits (Rosenschein *et al.* 1999).

Range reseeding is costly and risky especially in arid and semiarid zones. The USCCTP (2005) notes that in many arid and semi-arid rangelands, the cost of restoring a degraded land may by far exceed the potential returns from livestock production. Assuming that seed stock is healthy, only two environmental factors will be a constraint to germination and establishment of a plant in the semi-arid rangelands i.e. soil type and moisture (Mnene, 2006; Mganga, 2009). These factors may be compounded by other factors including human interventions (burning and grazing) and individual plant species physiological differences. These factors affect seed germination and subsequent plant growth Traditional methods of reseeding degraded semi-arid and arid rangelands are expensive and often unsuccessful, due to the high rates of seed and seedling mortality and predation. As a general rule, seeding operations should not be attempted in areas with less than 300 mm of average annual rainfall because they are bound to fail (Pratt and Gwynne, 1977).

The primary reason for carrying out range reseeding is to improve existing ground cover and biomass to an extent or in a manner which may not be possible by grazing management alone (Pratt and Gwynne, 1977; Makokha *et al.* 1999). There are several ways in which this can be achieved, including but not limited to over-sowing into existing vegetation with a superior species, establishing a completely new pasture with or without the aid of irrigation, and reseeding a denuded land (Mnene, 2006; Opiyo, 2007). In order to improve the chances of success in reseeding degraded rangelands, it advisable to use grasses which are adapted to the local environment mostly native grass species (Musimba *et al.* 2004). The best grass species to use in a reseeding program are those not only native in the area but also found on range sites similar to those to be reseeded. Site conditions, soil type and rainfall amount; to a great extent, will determine the success of establishment of reseeded pastures (Opiyo, 2007).

One form of soil disturbance or another will in most cases be required in carrying out reseeding in rangelands (Mganga, 2009). Soil disturbances are aimed at enhancing seed penetration to the ground through provision of conditions suitable for germination, emergence and subsequent establishment of the plant species (Singh, 1987). Land preparation methods involving micro-catchments (range pits, crescent shape pits and ox-furrows) have been used in degraded rangelands for the purpose of opening up the soil surface as well as harvesting rainwater (Pratt and Gwynne, 1977; Mnene, 2006).

From the many attempts that have been made in Kenya to restore grass cover through reseeding, some important requirements for success have been learnt. These include: recognition of the ecological potential of the site; appropriate grasses for reseeding and enough seed of sufficient quality, the inclusion of land-management policy in the reseeding operations, grazing management and bush control where necessary, seedbed preparation and seed protection in keeping with site requirements, a period of total rest from grazing just after reseeding and adequate rains/moisture during the establishment season (Mnene, 2006: Opiyo, 2007).

Low cost techniques for the rehabilitation of rangelands and drylands are more sustainable. Soil disturbance by the use of an ox-drawn plough and hand hoes to create micro-catchments to trap enough moisture for seed germination are among the most economical practices for resource poor farmers in the drylands (RAE, 2007). Field preparation methods and techniques are defined by such factors as the size of area to be reclaimed, the degree of degradation, soil types, rainfall, the amount and type of invasive species, the presence of wildlife, and the financial and human resources available (RAE, 2007).

2.2 METHODS OF ESTABLISHING SEEDED STANDS FOR RANGE REHABILITATION

2.2.1 Rainfed seeded pasture stands

Rainfall is highly variable in the Eastern African region in both space and time (Herlocker, 1999). According to Pratt and Gwynne (1977), rainfall in Eastern Africa is highly erratic and unreliable in terms of amount, time and space. Rainfall variability from one year to another causes significant shifts in primary production. With this in mind, it would be risky and costly to rely solely on rainfall for establishment of pastures in the rangelands. However, with effective rainfall and water harvesting techniques, successful rehabilitation is possible. Several reseeding attempts over two or three rainy seasons may need to be undertaken in order to increase success rates in rainfed pasture establishment ventures (Mnene, 2006).

2.2.2 Sprinkler-irrigated seeded pasture stands

Irrigated pastures can provide an alternative source of forage for livestock especially during critical times like breeding and calving while at the same helping in soil conservation (Young *et al.* 1994). Irrigation to establish pasture stands must be done cautiously. The moment irrigation is started; the soil surface must be kept moist by frequent light irrigations until the seedlings have emerged. Any sealing or crusting of the soil surface prior to emergence may result in failure or poor pasture stand establishment (Holzworth and Wiesner, 2006). The irrigation amount and frequency will vary depending on: the weather, soil type, rooting depth and presence of subsoil impervious layers. Most pastures require between 4 and 6 acre-feet per acre (12,192m³ - 18,288m³ per hectare) of water per growing season (Young *et al.* 1994).

Sprinkler irrigation, also referred to as spray irrigation, has an advantage where: water supply is limited or expensive; the soil is shallow or sandy; or the terrain is rough or steep The main objective of a sprinkler system is to apply water as uniformly as possible to fill the root zone with water Water is distributed through a system of pipes usually by pumping. It is then sprayed into the air through sprinklers and friction between the air and the stream of water causes the stream to break apart into water droplets that fall on to the soil surface, similar to rainfall (Smajstrla and Zazueta, 2003). Irrigation schedules vary according to soil type. For soils which easily form crusts, a light and regular fine spray is recommended. The irrigation interval for sands or sandy loams is shorter ranging from one to two days as compared to fine textured soils which ranges from two to five days. The average application rate from the sprinklers (in mm/hr) should be less than the basic infiltration rate of the soil (Young *et al.* 1994). A variety of crops, for example fruit trees, vines and vegetables, broad acre crops and pasture; have been grown under sprinkler irrigation systems in varying soil types and terrains (Qassim, 2003).

2.2.3 Role of micro-catchments

Factors affecting germination and early seedling growth are often the primary determinants of the distribution of adult plants (De Jong and Klinkhamer, 1988; Mustart and Cowling, 1993; Snyman, 2004). Soil-moisture is a key environmental factor limiting seedling establishment in the semi-arid rangelands (Skoglund, 1992; Snyman, 1998; Schellenberg, 1999). To increase success rates of range restoration attempts some sort of soil disturbance by making micro-catchments is necessary (Curtin, 2002; van den Berg and Kellner, 2005). Different types of micro-catchments such as range pits, ox-furrows and crescent-shaped pits have been used for reseeding in the rangelands (Gitunu *et al.* 2004). The benefits of micro-catchments are: enhanced seed germination, better root growth, better establishment of seedlings and increased soil water retaining capacity (van der Merwe and Kellner, 1999; Snyman, 2003, Visser *et al.* 2007). In addition, micro-catchments also help the grass seeds trap enough water for a prolonged period of time thus improving the chances of the grass seeds germinating and establishing.

However, the effectiveness of various micro-catchments for range rehabilitation for plant species under different soil types is not fully evaluated and documented. There are previous studies involving use micro-catchments for example: Njenga (1992) tested the effect of ox-ploughed plots and burnt plots on three range grasses (*C. ciliaris*, *E. macrostachyus* and *E. superba*) while Mnene (2006) looked at effect three reseeding treatments (reseeding, pitting and pitting combined with reseeding) on four grasses (*C. ciliaris*, *C roxburghiana*, *E macrostachyus* and *E superba*) grown in mixtures and Opiyo (2007) carried out an experiment on the effect of two land preparation methods (tractor-ploughed and hand-cleared) on the three grasses (*C. ciliaris*, *E. macrostachyus* and *E superba*). From these studies it is clear that there still is need to carry out more research on micro-catchments in improving range especially by testing the different types of micro-catchments side by side under similar conditions.

2.3 RANGE GRASSES FOR RESEEDING

Within the tropics, rainfall is the major hydrological input to soil moisture; its quantity and availability to growing plants determines the geographical distribution of plants species

(Herlocker, 1999). Local perennial grasses have evolved adaptive mechanisms for survival under scarce moisture conditions and are preferred to introduced or exotic species for reseeding purposes because they have given best results in East African rangelands (Pratt and Gwynne, 1977; Opiyo, 2007). On the other hand annual grasses are more appropriate for reseeding in eco-climatic zones VI and VII where rainfall is low and cannot support perennial grasses (Pratt and Gwynne, 1977; Mnene, 2006). According to Mnene (2006) and Opiyo (2007) the grass of choice for reseeding should have the following attributes:

- drought tolerant to survive and perpetuate itself,
- good quantity of herbage of good grazing value,
- produce adequate amount of viable seed that can be easily harvested and;
- easy to establish.

Bogdan and Pratt (1967) recommended 32 grass species suitable for reseeding denuded rangelands in Kenya. Pratt and Gwynne (1977) mention six of these 32 grass species (*Cenchrus ciliaris, Chloris roxburghiana, Chloris gayana, Enteropogon macrostachyus, Eragrostis superba and Cynodon dactylon*), as the most useful in reseeding the rangelands. Down the line, ten important grass species were also identified and ranked by stakeholders in a participatory manner within the southern Kenya rangelands (Mbogoh and Shaabani, 1999; Mnene *et al.* 2000). The ten grass species in order of ranking based on farmer perception about animal preference, palatability and nutritive value, were as follows: *Eragrostis superba, Cenchrus ciliaris, Enteropogon macrostachyus, Chloris roxburghiana, Bothriocloa insculpta, Cymbopogon pospischilii, Cynodon plectostachyus, Digitaria macroblephara* *Panicum maximum* and *Themeda triandra.* Of these ten grasses, the first four ranked species (*C. Ciliaris, C. roxburghiana, E. superba* and *E. macrostachyus*) have been used in various studies by KARI Kiboko researchers (Gitunu *et al.* 2004). Other studies involving reseeding have also used either all or some of the four mentioned species in monocultures or in mixtures. For example, Opiyo (2007) and Mganga (2009) both used *C. Ciliaris*, *E. superba* and *E. macrostachyus* in their studies. Opiyo was investigating the effect of two types of land preparation – tractor-ploughed and by hand-cleared; on the morphometric characteristics of the grasses while, Mganga was studying the impact the grasses on rehabilitation of the degraded rangelands. The current study contributes to greater understanding of the role of micro-catchments and the effectiveness of different reseeding approaches in rangelands.

2.3.1 *Cenchrus ciliaris* L.

Cenchrus ciliaris (Buffel grass or African foxtail) is a persistent tufted perennial occasionally stoloniferous which occurs in a wide variety of types, some of which have become reputed cultivars (strains or varieties in cultivation) and it is one of the most drought-tolerant of perennial grasses (Pratt and Gwynne, 1977). The grass is native to tropical and sub-tropical Africa (Bogdan, 1977). Numerous cultivars have been created in order to improve productivity and vigour in extreme conditions of drought, disease, frequent fire and other factors (Duke, 1983).

Cenchrus ciliaris is an extremely variable species, tufted (sometimes shortly rhizomatous) perennial with types ranging from ascendant to erect, and branching culms with linear leaf-blades, flat or having enrolled margins. The grass species has a height of 12-120cm (Harker and Napper, 1960). The branching culms range from about 0.3-2.0m at maturity often forming mats or tussocks; culms erect or decumbent, with a knotty crown; sheaths glabrous to sparingly pilose. The inflorescence is dense and cylindrical, 2–12 cm long, 1–2.6 cm wide and purplish. The roots are dense, fibrous and long; and can reach to a depth of up to 160cm below the soil surface (Reed, 1976; Pratt and Gwynne, 1977).

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

Cenchrus ciliaris is highly nutritious grass and is considered excellent for pasture in hot, dry areas and is valued for its production of palatable forage and intermittent grazing during drought periods in the tropics. The grass, fed green, turned into silage, or made into hay is said to increase flow of milk in cattle and impart a sleek and glossy appearance. The fresh plant is reported to contain on a dry matter basis, 11.0% protein, 2.6% fat, 73.2% total carbohydrate, 31.9% fibre, and 13.2% ash: Similarly *C. ciliaris* hay is reported to contain 7.4% protein, 1.7% fat, 79.2% total carbohydrate, 35.2% fibre, and 11.7% ash (Gohl, 1981).

2.3.2 *Enteropogon macrostachyus* (Hochst. ex. A. Rich.) Monro ex Benth

Enteropogon macrostachyus (bush rye – Kenya, mopane grass – Zimbabwe), is a widely distributed grass species very common in arid and semi-arid areas where it grows in bush, in forest edges and to a lesser extent in open grassland (Kitalyi *et al.* 2002). This grass species occurs naturally in grasslands and rocky outcrops in semi-arid areas of tropical Africa from 300-1600m above sea level. It is abundant between Sultan Hamud and Voi, Kenya (Bogdan and Pratt, 1967); and on Kongwa ranch, Tanzania (van Rensburg, 1969). This grass species has been tried with moderate success for reseeding denuded pastoral land in Kenya receiving rainfall of 550-800mm annually (Kitalyi *et al.* 2002). Bush rye is a good grass for arid and semi-arid ecosystems because it is relatively drought resistant.

Enteropogon macrostachyus is tufted annual or perennial grass with erect culms of 30-100cm high. The leaf sheaths are without a keel. The surface of the sheath and the outer margins are glabrous. The leaf blades are narrow and flat, 10-60cm long and 1.5-10mm wide; and depending on the environment they are found, they may be leafy or stemmy. The grass is found in bushlands and grasslands on clay or sandy clay soils of the basement system plains but rare on soils derived from lava. In Kenya, the grass is commonly found growing within dense bush where it is somewhat protected from grazing (Hatch *et al.* 1984)

It is a very good seed-producer and seed can be collected rapidly by cutting the seed-heads or stripping the heads by hand. It should lend itself easily to mechanical harvesting. The grass is a highly palatable with 9-12% protein on dry matter basis. It is frequently grazed by wild and domestic herbivores (Bogdan and Pratt, 1967).

2.3.3 *Eragrostis superba* Peyr.

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

The grass is a tufted perennial 20-120cm high (Bogdan, 1958; Opiyo, 2007). The leaves are mainly basal and the culms are sturdy and erect. The leaf blades are up to 400mm long and 3-12mm wide. The inflorescence is 100-300mm long, with spikelets 6-16mm long and 3-10mm wide, purple tinted, ovate and jagged in outline, strongly flattened from the sides. Spikelets disarticulate below the glumes at maturity and fall as entire units. This grass species has a high shoot/root ratio (Taerum, 1977; Opiyo, 2007) which is a disadvantage during drought periods but has an advantage of having deep root system which go as far as 2.2m with 73% of the roots limited to the upper 0.4m from the soil surface, which enable the grass to make full use of light showers of rain (Opiyo, 2007).

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

Eragrostis superba contains about 12% crude protein on dry matter basis at early-flowering stage with 30-35 % crude fibre and it is highly palatable. Its seeds can be easily harvested from open grassland or at roadsides by stripping the ripe panicles. Mature spikelets each with numerous florets; detach easily with the caryopses enclosed (Bogdan and Pratt, 1967).

2.3.4 *Chloris roxburghiana* (Schult)

Chloris roxburghiana (horse tail grass or plume chloris) is a tufted perennial that grows 40-150 high at maturity; the lowest leaf-sheaths usually white or straw-coloured; panicle 5-15cm long, straw coloured or purple; spikelets long-awned (Meredith, 1955). It has characteristically flat shoot bases and dense, feathery panicles which are pale green or purple when young (Bogdan and Pratt, 1967). The inflorescence is yellow to purplish in colour. It is distributed between 0-1500m above sea level but occasionally occurs at higher level. The grass is abundant throughout the Kenya Agricultural Research Institute's National Range Research Centre (KARI Kiboko) on the open grassland with sandy clay, deep clay or firm red clay soils (Hatch *et al.* 1984).

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

Chloris roxburghiana has up to 16% crude protein and 30% crude fibre on dry matter basis at early flowering stage (Bogdan and Pratt, 1967). The grass produces millions (about 6.6 million) of naked caryopses per kilogram, which can easily be harvested by hand. Bogdan and Pratt (1967) recorded that the spikelets are not easily detached from the panicles due to the mating of the long, fine awns and so it is more convenient to cut the panicles and thresh the seeds later by rubbing the panicles between two pieces of rubber. They further suggested that one of the rubber surfaces should be a section of automobile tyre, the groove being adaptable to hold.

2.4 ECONOMIC ASPECTS OF RANGE IMPROVEMENT APPROACHES

In a feasibility report of projects undertaken by KARI Kiboko in the southern rangelands it was suggested that future research in range improvement should include some economic analysis (Dolan *et al.* 2004). Economic aspects of producing forage from range and pasture are concerned with obtaining optimum production from forage at the minimum cost (Nielsen, 1967; Workman and Tanaka, 1991). The economics of range reseeding lead directly to factors of input-output in production economics. The cost of improvement can be compared with the value of forage or benefits produced, and an estimate made as to the benefit-cost ratio or balance (Kearl and Robert, 1975; Clawson, 1983). Although range reseeding often increases forage production in rangelands, livestock producers have been generally reluctant to use it because of uncertainty about profitability. There is a general assumption that range rehabilitation efforts are costly in labour, land preparation, fertilizer, purchase of seed and installation of fencing (Chelishe and Kitalyi, 2002). It has also been argued that using established pasture is also costly in labour for cut-and-carry harvesting, controlling grazing time, preparing hay, and storing and maintaining the herbage.

The initial costs in reseeding may be high, but, published studies (Caton and Beringer, 1960; Kearl and Robert, 1975; Godfrey *et al.* 1979) shows that long-term benefits are high. However, the relationship of benefits to costs may be expressed in benefit-cost ratio, or may be expressed as the amount of the net benefits (total benefits minus total costs). The methods do not necessarily yield the same results (Workman and Tanaka, 1991). The evaluation must be made at optimum combination of inputs, which in turn depends on both physical and economic relationships (Clawson, 1983). For example, if one proposes to grow more grass, the more animals to consume it may be necessary, and this in turn means other adjustments in production process (Opiyo, 2007).

The costs involved are complex in benefit-cost ratio, for example what allowances should be made for the time and labour of the farmer who installs the practice. The interest rate to be charged on the investment of capital is also debatable. Expected rates of return, risk of failure, and availability and source of capital must all be considered. The use of internal rate of return is probably the most universally adapted method of determining the worth of an investment (Gardner, 1963; Nielsen, 1967; Prest and Ralph, 1975; Workman, 1981; Gittinger, 1982). The question of which of the three benefit cost analysis standard criteria to use in evaluating reseeding investment projects has been a long source of controversy among economist and range managers (Workman and Tanaka, 1991). The enquiry as to which criterion to rely on and which to disregard has come about simply because the three cost-benefit analysis criteria, as commonly calculated often produce contradictory results.

According to several study reviews of classic treatments of the problem of capital budgeting (Dean, 1954, Lorie and Savage, 1955), it is recommended that internal rate of return (IRR) rather than the net present value (NPV), be used as a criterion for ranking range improvement projects that are mutually exclusive due to limited investment funds. Advantages of IRR are:

(1) The calculated rate is directly comparable to the compound interest rate paid for borrowed capital,

(2) It is not necessary to take the difficult task of selecting the correct interest rate for NPV discounting calculations, and;

(3) IRR standardizes projects with respect to size and expected lifespan.

The listed advantages are based on the assumption that the net cash flow to a short lived project can be reinvested at the IRR generated by the project to give a useful lifespan equal to the longest lived project under consideration (Gardner, 1963; Workman, 1981). However, caution should be observed that the period of discounting should not exceed the expected lifespan of the range improvement project (Workman, 1981). Even if the improvement has the potential of long-term benefits, this period should not normally extend over a period of thirty years (Nielsen, 1967). Studies have shown that reseeded plots are only able to provide forage for livestock over a given period of time (Workman, 1981; Workman and Tanaka, 1991).

On the other hand, public land managers have long used benefit-cost ratio as the criterion for making decision on feasible and infeasible management alternatives. The benefit-cost ratio (BCR) expresses the feasibility of a given project as a ratio of present value of gross project benefits to present value of project investment and operating costs. According to Gittinger (1982), advantages of this method are that:

(1) It considers the time value of money,

(2) It accounts the cash flow over the entire project period, and;

(3) It can be used to show the level to which the costs could rise without making the project economically unattractive.

CHAPTER THREE

MATERIALS AND METHODS

3.1 STUDY AREA

3.1.1 Location and size

The study was undertaken in southern Kenya rangelands, in the larger Kibwezi District, that has been subdivided into two districts viz. Kibwezi and Makindu Districts (Figure 3.1). The study area lies between the latitudes 2°6'S and 3°S, and longitude 37°36'E and 38°30'E, respectively. Taita District borders the study area to the south, Kajiado District to the west, Kitui District to the east and Makueni District to the north. The study area has a total area of 3400 km² (CBS, 2000).

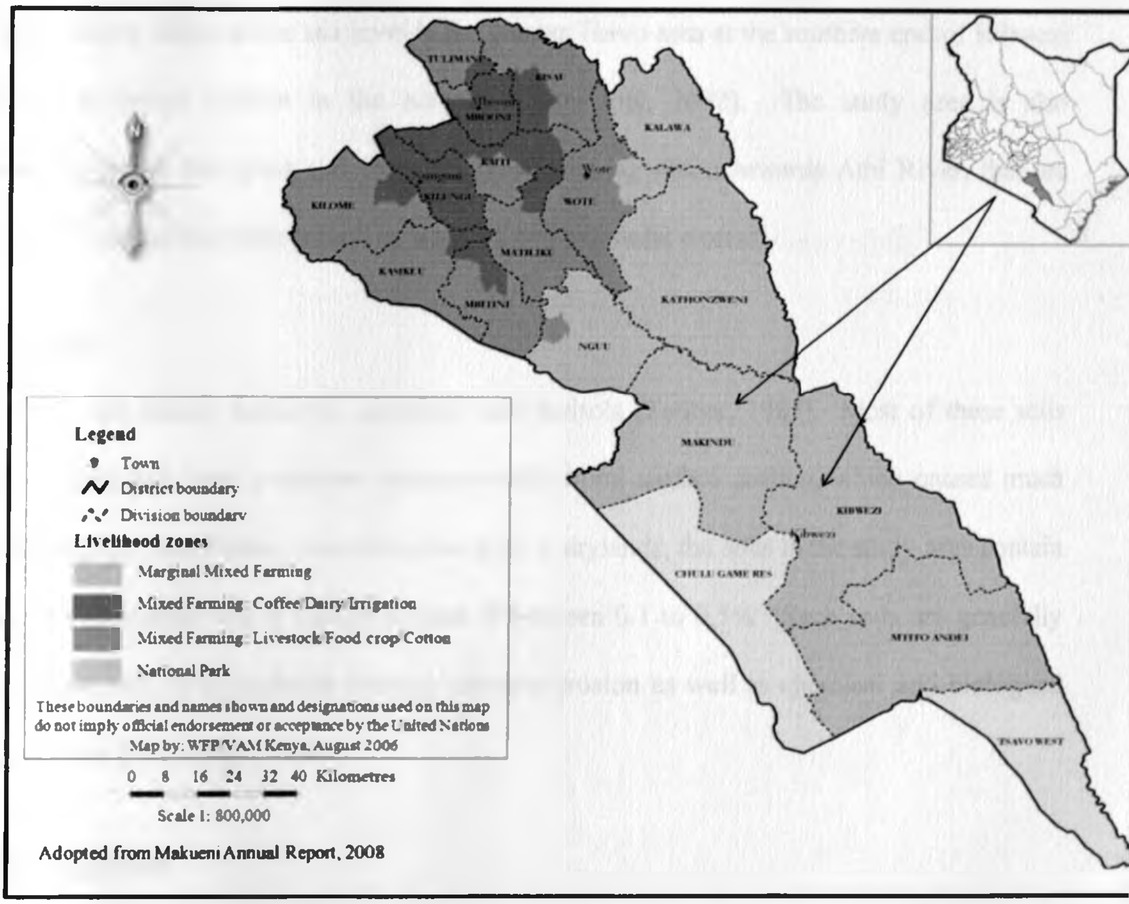


Figure 3.1: Map of Kenya showing the study area

3.1.2 Geology

The study area is covered by recent volcanic rocks that superimpose the basement complex system. Granite rocks are found around the Chyulu Hills which form a major water catchment area. The other areas are mostly composed of recent lava flows and volcanic cones. The flood plains and bottom lands occupy only minor portions. The rocks present in the district are grouped into basement system rocks and volcanic and superficial deposits (Baker, 1954; Saggerson, 1963; Touber, 1983).

3.1.3 Topography

The altitude of the study area varies from 600m to 1100m above sea level. The land rises slightly below 600m above sea level in the greater Tsavo area at the southern end of Kibwezi District to about 1,100m in the northern part (GoK, 2002). The study area is also characterised by low lying and eastward gently sloping plains towards Athi River, that are broken by occasional hills as well as seasonal and perennial rivers.

3.1.4 Soils

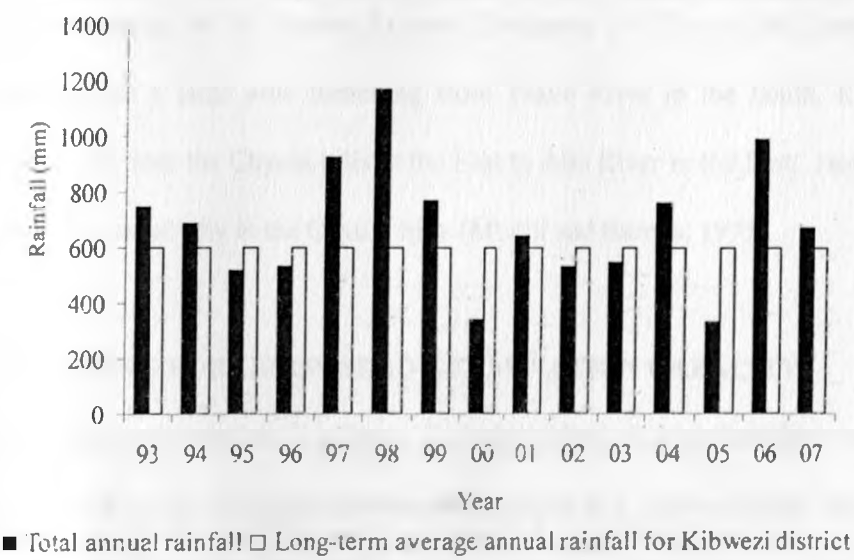
The soils are mainly ferralsols, cambisols and luvisols (Touber, 1983). Most of these soils are compact and have a massive structure with strong surface sealing, which causes much run-off during heavy rains. Just like other soils in drylands, the soils in the study area contain low organic matter with a carbon content of between 0.1 to 0.5%. Such soils are generally very vulnerable to degradation through physical erosion as well as chemical and biological degradation (El Beltagy, 2002).

3.1.5 Vegetation

The natural vegetation of the study area is woodland and savanna, with several tree species, mainly: *Acacia* spp. (A) e.g. *A. tortilis* (Forsk) Hayne and *A. mellifera* (Vahl) Benth, *Commiphora africana* (A. Rich) Engl, *Adansonia digitata* Linn and *Tamarindus indica* L. Shrubs include *Apis senegal* (L) willd and *Grewia* spp. The major perennial grasses in the area include *Cenchrus ciliaris* L., *Chloris roxburghiana* Schultz, *Panicum maximum* Jacq, *Eragrostis superba* Peyr, *Digitaria milanjiana* (Rendle) Stapf and *Enteropogon macrostachyus* Benth (Nyangito *et al.* 2008; Nyangito *et al.* 2009).

3.1.6 Climate

The climate of the study area is typically semi-arid, characterised by low and unreliable supply of soil moisture for plant growth. The climate of semi-arid Kenya is influenced by the seasonal shifts and intensity of the Inter-Tropical Convergence Zone (ITCZ) (Biamah, 2005). The average annual rainfall (Figure 3.2), evaporation and temperature are 600mm, 2000mm and 23°C, respectively (Michieka and van der Pouw, 1977; Braunn, 1977). Most of the rainfall is received between the months of October and December (Figure 3.3). The average monthly mean is about 40mm. The months of June to September are generally dry.



Source: Dwa Estate Ltd. Kibwezi

Figure 3.2: Study area annual rainfall (mm) and long-term average annual rainfall

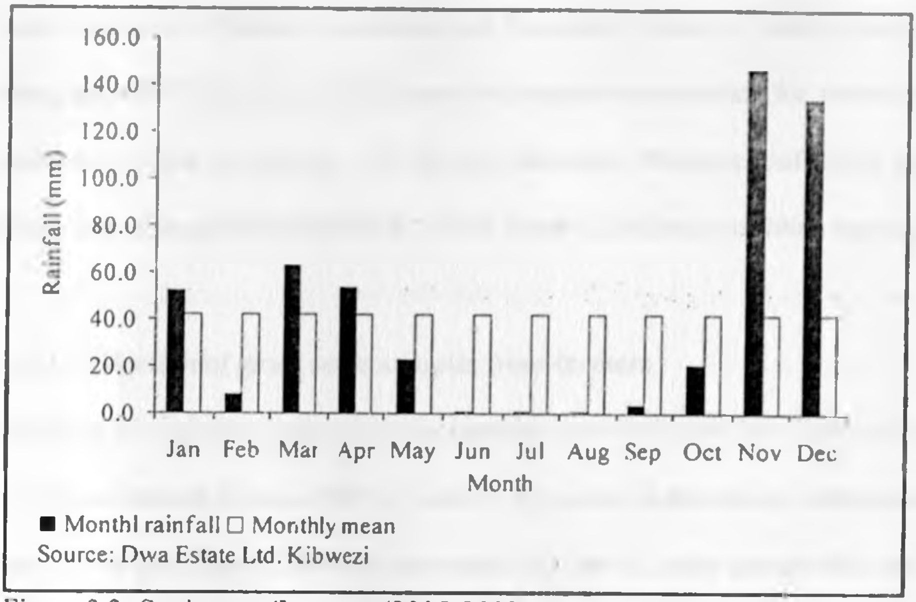


Figure 3.3: Study area five-year (2005-2009) mean monthly rainfall

3.1.7 Demography

The study area has a human population density of 85 persons per km² (GoK, 2002). The largest ethnic group in the area is the agro-pastoral Kamba community. Pastoralists and hunters were resident in the area for centuries throughout the pre-colonial period. The implementation of the Native Reserve Ordinance (NRO) in 1901 forced the removal of people from a large area stretching from Tsavo River in the South, Kiboko River in the North, and from the Chyulu hills in the East to Athi River in the East. However, some people remained, especially in the Chyulu hills (Mbithi and Barnes, 1975).

3.2 TESTING FOR GRASS SEED GERMINATION CAPACITY

Four range grass species, *C. ciliaris*, *C. roxburghiana*, *E. macrostachyus* and *E. superba* were used in the study. The grasses were the top four in a ranking of ten important range grass species by stakeholders in a participatory exercise in the southern Kenya rangelands (Mbogoh and Shaabani, 1999; Mnene *et al.* 2000). The other six grasses in the ranking were *Bothriocloa insculpta, Cymbopogon pospischilii, Cynodon plectostachyus, Digitaria* *macroblephara*, *Panicum maximum* and *Themeda triandra*. These grasses are perennials (Bogdan, 1977; Boonman, 1993) and are therefore appropriate for reseeding in rangelands because of their persistence. They have also been tried successfully in studies involving reseeding of rangelands (Herlocker, 1999; Mnene, 2006; Opiyo, 2007; Mganga, 2009)

3.2.1 Collection of grass seeds samples from farmers

Samples of available seeds of the four grasses were collected from farmers belonging to four Common Interest Groups (CIGs) involved in pasture improvement activities within the study area. The grass seeds had been harvested and stored under comparable on-farm conditions but were of varying storage duration. The germination tests were done concurrently with grass seeds of the four grasses harvested and stored on-station at KARI-Kiboko. The grass seeds were categorised into three groups based on storage period after harvesting as follows: Group I – 1 to 11 months, Group II – 12 to 24 months, and Group III – 25 to 35 months. The grouping was based on the fact that most range grasses break dormancy after a period of one year (Pratt and Gwynne, 1977)

3.2.2 Testing for germination of grass seeds in the laboratory

Naked grass seed caryopses were used. Different sandpaper grades according to grass seed size were used to extract the caryopses. The sandpaper grades used for the grasses were as follows: No. 1 for *C. ciliaris*, No. 0 for *C. roxburghiana*, No. P80 for *E. macrostachyus* and No. 2 for *E. superba* (Mnene, 2006). The procedure as used by Mnene (2006) for extracting the grass seed caryopses was adopted and is elaborated below:

1. A sheet of sandpaper measuring about size A5 (148mm X 210mm) was placed flat on a stable bench with the abrasive side of the paper facing upward.
2. A pinch of grass seeds was placed at the center of the sandpaper.

3. A second piece of sandpaper was placed on top of the seeds with its abrasive side facing down.
4. Then, while holding the lower piece of sandpaper down with one hand, gently but firmly the second sandpaper was used to rub against the other sandpaper in circular motions.
5. By checking now and then, the caryopses, which were mostly yellowish brown, were removed using a fine point pair of forceps without squeezing too hard to minimize chances of getting them damaged. The caryopses were placed in a petri dish. Additional seeds were placed and rubbed until the desired amount of caryopses – 100 in number were obtained.

The caryopses of each grass species were placed on a wet Whitman filter No. 91 in standard laboratory petri-dishes. Each petri-dish contained 25 naked grass caryopses replicated four times to make 100 seeds per sample. When testing seed quality by percent germination it is recommended to use 400 seeds, however, when seed stocks are limited the number can be reduced to 100 seeds (Veenendaal, 1991; HSU, 1994; ISTA, 1999). The amount of grass seeds from farmers was low because of the prolonged drought during the period of the study.

The petri-dishes were placed at room temperature. The filter paper was moistened with a few drops of distilled water when it appeared dry. The grass seeds that had germinated each day were recorded and removed from the petri-dishes. Germination was taken to have occurred when there was a visible emergence of the grass seed radical (HSU, 1994). Observations were made over a period of 14 days after which all germinated seeds were expressed as shown in equation 1.

$$\text{Percent seed germination} = \frac{\text{Total number of seeds germinated}}{\text{Seeds per petri-dish x Replicates}} \times 100 \quad \text{.........................} (1)$$

For the purpose of this study, grass seeds from KARI Kiboko were used as a proxy to grass seeds harvested and stored on-station.

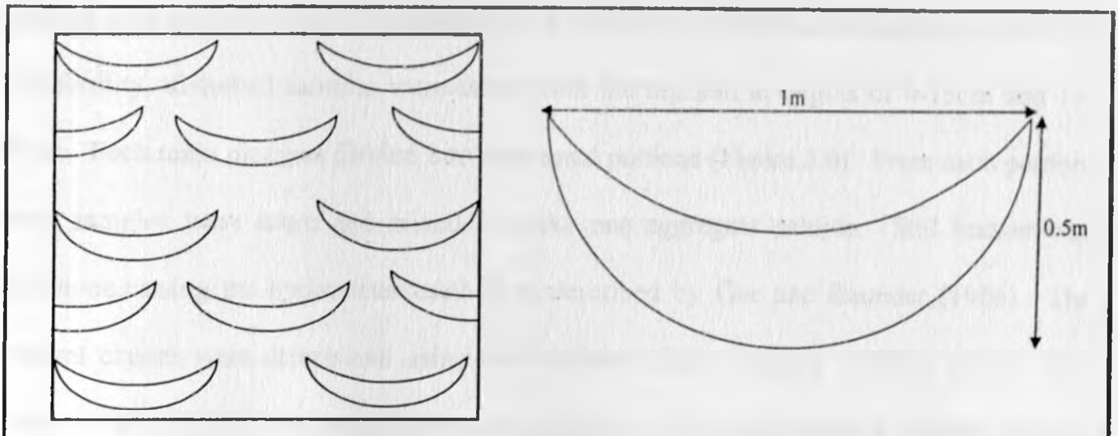
3.3 FIELD EXPERIMENTAL DESIGN

Field experiments to test performance of the grasses in mixtures or monocultures in the two micro-catchments were carried out under irrigation. Irrigated water was used to ensure establishment of the grasses in the experimental plots at a rate of 25mml/hr/day in the morning for 7 weeks.

The experimental design was a split plot. The main plots were the type of micro-catchments, i.e., contour ox-furrows and crescent shaped pits (Kiboko range pits). Kiboko range pits, similar to what was used by Mnene (2006), are crescent shaped pits 15cm deep and made using hand hoes in checkerboard manner along the contours. The pits are 0.5m apart within the same row while the gap between the rows is 0.5m. The layout and dimensions of the pits is illustrated in Figure 3.4.

The sub-plots were species type in monoculture or mixtures. The grass species used were *C. ciliaris, C. roxburghiana, E. macrostachyus* and *E. superba*. Seeds of known viability of the four grasses harvested and stored at KARI Kiboko Range Research Station were used. Sowing was done on 25th, November 2009 by hand along on top of the ridges of the pits and furrows at a seeding rate of 5kg/ha.

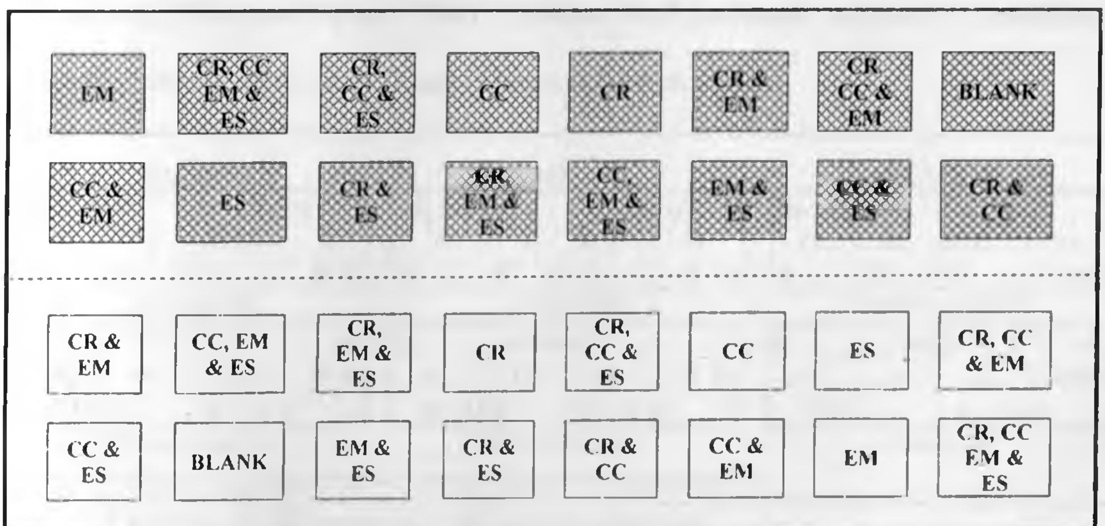
The subplots measured 2.5m by 2.5m (Figure 3.4) with 1m path in between. The main plots measured 27m by 6m with a 2m path in between. In total there were 16 sub-plots in each main-plot. These were four monocultures – *C. ciliaris, C. roxburghiana, E. macrostachyus* and *E. superba* and eleven combinations of two, three or four of the grasses which were randomly allocated to the sub-plots. One of the sub-plots was left blank, with no sowing done.



(a) Layout of Kiboko range pits in the sub-plot (b) Dimensions of a Kiboko range pit

Figure 3.4: Graphic presentation of Kiboko range pits

The plots were replicated thrice, each measuring 27m by 14m with a 2m path in between. The layout of one of the plots is shown in Figure 3.5:



CC=*C. ciliaris*, CR=*C. roxburghiana*, EM=*E. macrostachyus* and ES =*E. superba*
The dotted line represents the demarcation between the main plots; ox-furrows (shaded boxes) and Kiboko range pits (clear boxes)

Figure 3.5: Layout of experimental plots

3.4 ECOLOGICAL DATA COLLECTION

3.4.1 Soil data

Soil parameters were collected once, 12 weeks post sowing, the same time aboveground biomass data was collected. To determine soil moisture, soil texture, soil organic matter and soil fertility, disturbed samples were taken from the top soil at depths of 0-15cm and 15-30cm. Each main plot was divided into four equal portions (Figure 3.6). From each portion, three samples were taken and mixed to make one aggregate sample. Soil texture was determined using the hydrometer method as described by Gee and Baunder (1986). The textural classes were determined using the standard USDA Triangle (USDA, 1975). Soil chemical analysis for nitrogen, phosphorus, potassium, carbon and cation exchange capacity (CEC) were done according to procedures described by Miller and Keeney (1982).

To determine soil bulk density and soil porosity, 12 undisturbed soil core samples were taken from depths of 0-15cm and 15-30cm in each main-plot. Bulk density was determined by the core method (Blake and Hartge, 1986). Constant head parameter was used to determine saturated hydraulic conductivity (Ksat) (Klute and Dirksen, 1986).

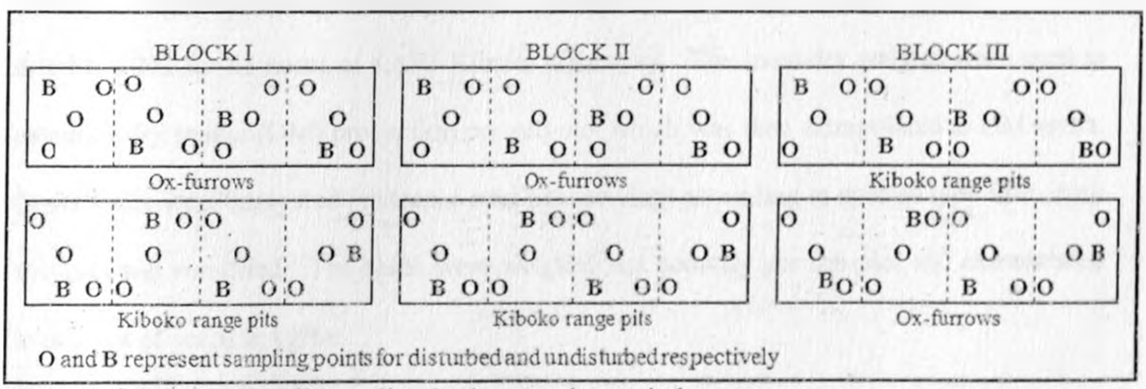


Figure 3.6: Layout for soil sampling in the experimental plots

3.4.2 Vegetation data

Data were collected at six, nine, twelve and sixteen weeks post sowing representing;

seedling, vegetative (elongation), flowering, seed-setting and maturity stages, respectively. The following plant parameters were measured: percent cover, plant density, tiller density, leaf density, plant height, aboveground biomass production and seed production. All these parameters were measured in a 0.5m by 0.5m quadrat placed at the center of each sub-plot.

Percent cover was estimated by gridded ocular estimates whereby: the area covered by a species was expressed as a percentage of area of the quadrat. Plant density was estimated by counting the individual plants within the quadrat and then expressed as number of plants per metre squared. To monitor tiller density, leaf density and plant height; one grass plant per species was marked for monitoring in each sub-plot. Tiller density was measured by counting the number of visible tillers in each plant. Leaf density was recorded by counting the number of leaves per grass plant. Plant height was measured in cm using a steel ruler, from the base (crown) of the plant to the last leaf (flag leaf) of the main shoot (Figure 3.7).

Aboveground biomass production was obtained only once at flowering stage (twelve weeks post sowing) by clipping at 5cm stable height. Materials harvested from each quadrat were placed in labelled collection bags, separated into the various grass types. They were oven-dried at 60°C for 48 hours at KARI Kiboko laboratory. The oven-dry weights were used to calculate dry matter (DM) production per sub-plot which was then extrapolated to DM kg/ha. Grass seeds were harvested (sixteen weeks post sowing) according to species type from each sub-plot and sun-dried. The seeds were weighed and quantity per sub-plot and extrapolated to amount of seeds in kg/ha.

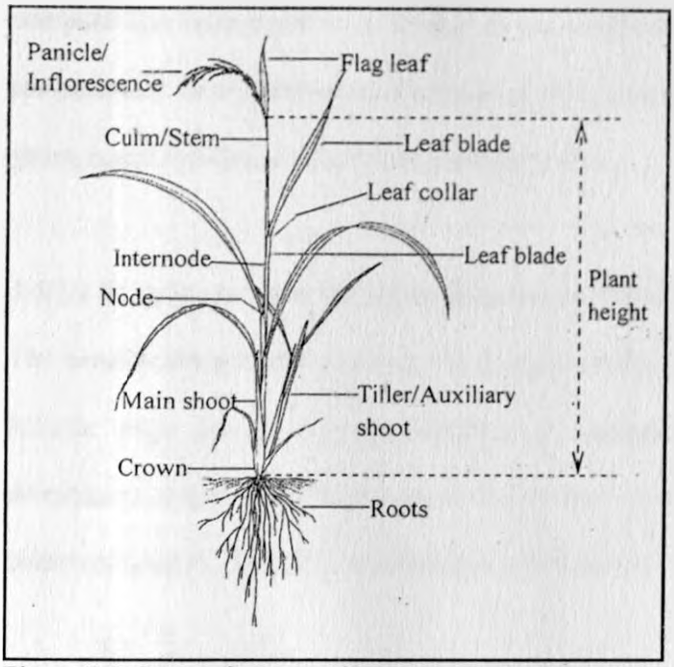


Figure 3.7: Parts of a grass plant

3.5 COLLECTION OF SOCIO-ECONOMIC DATA

3.5.1 Data collection on benefits and costs of reseeding investments

Data on reseeding costs were recorded at the time reseeding was done. The costs included labour (i.e., for land preparation, sowing, weeding, harvesting of hay, harvesting of grass seeds, packaging and storage of grass seeds), equipment (machetes and hoes), fencing and purchase of seeds. The costs were calculated using 2009 prices to give a standard base for reference and comparison. The risk of failure used was 20% since drought is expected once in every five years within the study area. Vallentine (1980) and Opiyo (2007) working under similar environments also used a figure 20% to compute risk as an indirect cost. Interest on direct costs was 14.76%, the average lending rate by commercial banks in 2009, based on the figures from Central Bank of Kenya (CBK, 2010). The fixed costs, including depreciation, interest on machinery investment, and taxes were not estimated since the ox-plough used to make the contour furrows was hired. The benefit was hay harvested from the reseeded plots valued at KES 200 per 30kg bale based on the prevailing market price in the study area. The computations were based on a 20-year project life for the two investments. The grasses used are perennial. With proper care and self reseeding, the reseeded pasture can last for about 20 years, hence the choice of a 20-year project period.

3.5.1.1 Benefit-cost ratio (BCR) and internal rate of return (IRR)

The benefit-cost analysis was used to compare benefits and costs from the ox-furrow and the Kiboko range pits to give an indication of whether the projects would break even on investments while the IRR was calculated to find out if the project would sustain itself on borrowed capital. The BCR was computed as shown in Equation 2 (Opiyo, 2007):

$$BCR = \sum_{t=1}^{n} \frac{B_t}{(1+i)^t} \Big/ \sum_{t=1}^{n} \frac{C_t}{(1+i)^t} \quad \text{.......... (2)}$$

Where B_t = incremental benefits at time t, C_t = incremental costs at time t, i = prevailing interest rate and n = number of years. The selection criterion for BCR is to accept the investment with a ratio equal or greater than one.

The IRR is expressed mathematically as shown in Equation 3 (Opiyo, 2007):

$$\sum_{t=1}^{t=n} \frac{B_t - C_t}{(1+i)^t} = 0 \quad \text{.......... (3)}$$

Where B_t = incremental benefits at time t, C_t = incremental costs at time t, i = internal rate of return and n = number of years. The selection criterion for IRR is to accept investment with IRR equal to or greater than the lending rate.

3.5.2 Household survey

A questionnaire survey was conducted to capture general issues concerning range reseeding in the study area. The respondents were members of common interest groups (CIGs) involved in pasture improvement for livestock production in the study area where KARI Kiboko and other development agents have been carrying out on pasture improvement activities.

The questionnaire contained dichotomous, multi-choice and open ended questions to capture the diverse issues on reseeding programmes. The survey involved forty households selected from the study area Pre-testing was done in ten households not involved in the main survey. Pre-testing ensured that questions were simple, phrased in a manner that would imply the same meaning to all respondents, not leading, well sequenced and not too long (Nyariki 2009). Each interview took about 30 to 45 minutes, which reduced the chances of boring the respondent and thus ensuring fairly accurate responses.

3.5.2.1 Sampling Procedure

Purposive sampling was done targeting areas where previous work on pasture improvement had been done by KARI Kiboko within the study area. With the assistance of the extension officers from the Ministry of Livestock, a list of CIGs in the study area was made, from which four CIGs were randomly selected. From a central location of each of the CIGs, random transect walks were done and ten members were interviewed.

3.5.2.2 Field Enumerators

Two officers from KARI Kiboko Research Centre were used as enumerators since they were familiar with the study area and subject matter and also did not have language barrier problem. The officers were involved in the process of questionnaire formulation, pre-testing and administration.

3.6 STATISTICAL ANALYSES

Statistical analyses were done using SPSS. Analyses of Variance (ANOVA), both one-way and two-way, were carried out to determine the differences in germination rates of the grasses and the effects of the micro-catchments and species type on grass growth parameters. Levene's test was used to check for the equality-of-variances. Mean separation was carried out using Tukey HSD where equal-variances assumption was valid, and Games-Howell where equal-variances assumption was not met. Robust tests of equality-of-means, and Welch and Brown-Forsythe statistics were used to further validate the results of the ANOVA. The survey data were subjected to descriptive statistical analysis.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 GERMINATION TESTS IN THE LABORATORY

4.1.1 Effect of species on percentage grass seed germination

After fourteen (14) days of observation, there was a significant difference ($p \leq 0.05$) in seed germination percentage among the four grass species (Table 4.1). Seeds of *Enteropogon macrostachyus* had the highest germination percentage (98.7%) followed by *Chloris roxburghiana* (52.5%). The percent seed germination for *Cenchrus ciliaris* was 41.1% while that of *Eragrostis superba* was 44.2%. The grass that reached pick germination the fastest was *E. macrostachyus* by the second day (Figure 4.1). The other three grasses reached pick germination on average by the 8th day after which there was no more germination. The seeds that did not germinate by the 14th day were presumed to be dormant. Similar results have been reported about the germination behaviour of these four range grasses (Mnene, 2006; Opiyo, 2007; Mganga, 2009). However, the germination rates were not as high for *E. macrostachyus* (Mnene - 70%, Opiyo - 20% and Mganga - 53%) as was recorded in this experiment. This could be attributed to differences in storage periods of the grass seeds used.

Table 4.1: Germination percentage of grass seeds after a period of 14 days

Species	Germination percentage (%)
Cenchrus ciliaris	$41.05^{a} \pm 3.08$
Chloris roxburghiana	$52.58^{b} \pm 2.52$
Enteropogon macrostachyus	$98.72^{c} \pm 0.32$
Eragrostis superba	$44.20^{a} \pm 1.32$

Column means with different superscripts differ significantly at $p \leq 0.05$, LSD=4.88

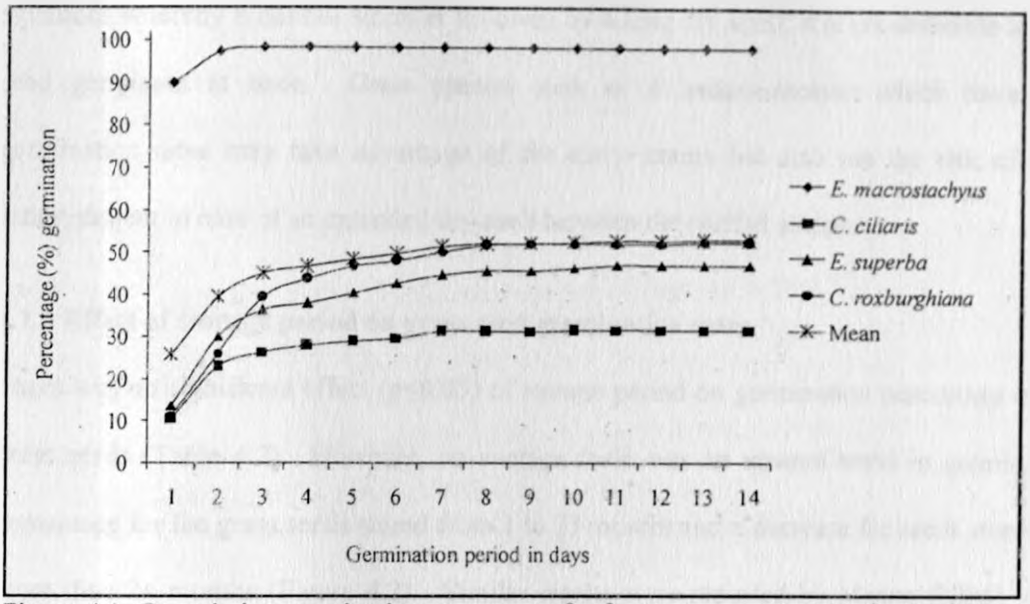


Figure 4.1: Cumulative germination percentage for four grasses over a 14 day period

Differences observed among the grass species in terms of percent seed germination may be attributed to the intrinsic properties of the seeds, most likely seed dormancy and hardness of seed integument (Mnene, 2006; Opiyo, 2007; Mganga, 2009). The other factors are external and include climatic and soil factors. Most range seeds are hygroscopic, which may contribute to low germination percentages (Opiyo, 2007). In some cases exposure of dry seeds to moisture may worsen the dormancy often leading to fungal infection (Chin and Hanson, 1999; Tweddle *et al.* 2003). In this study *C. ciliaris* was observed to be the most prone to fungal infections. Similar findings were reported by Mnene (2006).

The higher percent germination exhibited by *E. macrostachyus* could be attributed to its dormancy mechanism which involves only the integument while; the other three species may have both the embryo and/or the integument related dormancy (Mnene, 2006). Grasses have different tolerance to moisture stress (Veenendaal, 1991; Opiyo, 2007), which may also further explain the difference in germination rates among the four grasses. Fast germination is desirable in rangelands in order to utilize the little moisture available. However, in situations whereby a rainfall storm is followed by a long dry spell, it is not desirable that all seed germinate at once. Grass species such as *E. macrostachyus* which have high germination rates may take advantage of the early storms but also run the risk of none establishment in case of an extended dry spell between the rainfall storms.

4.1.2 Effect of storage period on grass seed germination rates

There was no significant effect ($p \leq 0.05$) of storage period on germination percentage of the grass seeds (Table 4.2). However, on average there was an upward trend in germination percentage for the grass seeds stored from 1 to 23 months and a decrease for seeds stored for more than 24 months (Figure 4.2). Similar results were reported by Mnene (2006) while studying the germination of the four grasses that had been stored for a period of between 0 and 72 weeks at KARI-Kiboko. These results suggest that the peak germination for these range grasses is reached at 24 months after harvest. The implication of these results is that these range grass seeds have a shelf life beyond which the quality of the seeds begins to drop. Therefore, the seeds cannot be stored indefinitely. As a general rule, it is recommended to use range seeds that have been stored for at least one year in order get to a good germination (Pratt and Gwynne, 1977). From these results it also not advisable to use grass seeds that have been stored for more than three years for reseeding purposes.

Table 4.2: Germination percentage of grass seeds according to storage period

Storage period (Months)	Overall Mean	*C. ciliaris*	*C. roxburghiana*	*E. superba*
1 to 11	$44.62^a \pm 3.91$	$38.37^a \pm 4.37$	$51.00^a \pm 6.40$	$44.50^a \pm 5.58$
12 to 23	$49.64^a \pm 2.54$	$48.71^a \pm 5.70$	$55.57^a \pm 2.84$	$44.63^a \pm 2.93$
24 to 35	$42.52^a \pm 1.52$	$36.34^a \pm 3.34$	$46.67^a \pm 6.27$	$44.56^a \pm 1.75$
LSD (5%)	10.70	15.60	9.33	0.14

Column means with different superscripts differ significantly at $p \leq 0.05$
Seed samples of *E. macrostachyus* were only in one group (12-23 months), and thus omitted in this analysis

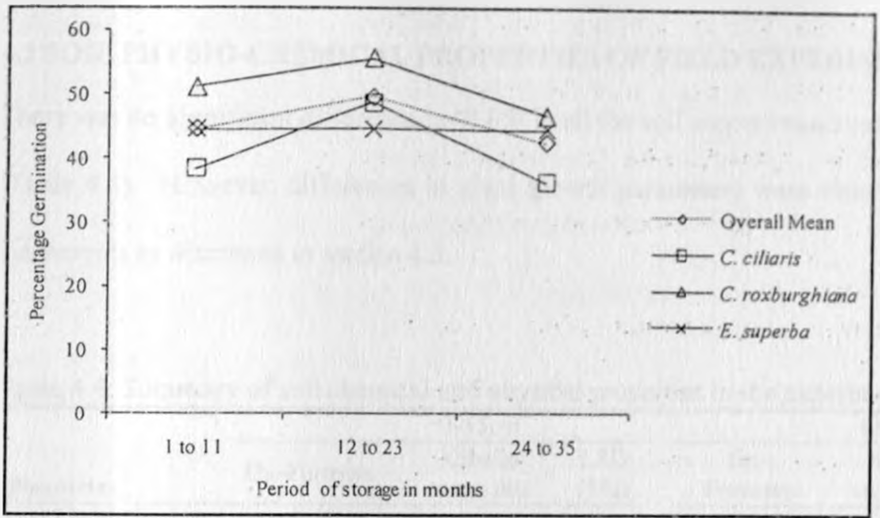


Figure 4.2: Germination percentage for grass seeds of different storage periods

4.1.3 Germination rates of grass seeds harvested on-station and on-farm

The mean germination rates for grass seeds harvested and stored under on-farm conditions were significantly ($p \leq 0.05$) different from those harvested and stored under on-station conditions (Table 4.3). However, on species basis, only *C. ciliaris* had a significant difference in germination rates between on-farm and on-station seeds.

Table 4.3: Percent germination of grass seeds harvested on-station and on-farm

	Overall Mean	*C. ciliaris*	*C. roxburghiana*	*E. macrostachyus*	*E. superba*
On-station	$65.00^{b} \pm 4.00$	$62.00^{b} \pm 5.58$	$54.67^{a} \pm 4.39$	$99.33^{a} \pm 0.45$	$44.00^{a} \pm 2.03$
On-farm	$52.26^{a} \pm 1.46$	$36.73^{a} \pm 3.25$	$51.89^{a} \pm 3.04$	$98.60^{a} \pm 0.37$	$44.21^{a} \pm 1.33$
LSD (5%)	12.65	24.44	3.76	0.82	0.33

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

There is a general shortage of range grass seeds especially for the four grasses used in this study. The demand for range grass seeds can be met by involving farmers in community based seed multiplication for as it would result in production of grass seeds of similar quality to that of seeds from on-station. However, there is need for more studies to verify or confirm the observation of low germination percentage for *C. ciliaris* seeds from on-farm.

4.2 SOIL PHYSIO-CHEMICAL PROPERTIES OF FIELD EXPERIMENTAL PLOTS

There was no significant difference ($p \leq 0.05$) in all the soil properties across comparable plots (Table 4.4). However, differences in grass growth parameters were observed in the micro-catchments as discussed in section 4.3.

Table 4.4: Summary of soil chemical and physical properties in the experimental plots

	0-15cm			15-30cm		
Parameter	Ox-Furrows	Kiboko range pits	LSD (5%)	Ox-Furrows	Kiboko range pits	LSD (5%)
pH 0.01M $CaCl_2$	7.50^{a}±0.05	7.60^{a}±0.04	0.10	7.17^{a}±0.05	7.23^{a}±0.07	0.07
Carbon (%)	0.64^{a}±0.06	0.65^{a}±0.05	0.01	0.48^{a}±0.05	0.50^{a}±0.05	0.02
Nitrogen (%)	0.10^{a}±0.01	0.11^{a}±0.03	0.01	0.06^{a}±0.01	0.06^{a}±0.01	0.00
Sodium cmol/kg	1.29^{a}±0.33	0.90^{a}±0.26	0.39	1.37^{a}±0.35	1.08^{a}±0.35	0.28
Potassium cmol/kg	1.23^{a}±0.26	1.19^{a}±0.29	0.04	1.24^{a}±0.28	1.42^{a}±0.30	0.18
Calcium cmol/kg	3.00^{a}±0.70	1.87^{a}±0.45	1.13	3.46^{a}±0.90	1.31^{a}±0.12	2.15
Magnesium cmol/kg	2.44^{a}±0.52	2.15^{a}±0.49	0.29	1.87^{a}±0.40	2.85^{a}±0 82	0.98
CEC cmol/kg	8.77^{a}±0.52	7.26^{a}±0.59	1.51	9.01^{a}±0.78	8.18^{a}±0.70	0.83
Phosphorous ppm	13.25^{a}±1.75	18.92^{a}±3.64	5.67	8.38^{a}±1.53	12.21^{a}±2.84	3.83
Ksat cm/h	10.33^{a}±2.23	10.03^{a}±1.99	0.29	2.01^{a}±0.79	4.43^{a}±1.90	2.42
Bulk Density	1.51^{a}±0.02	1.46^{a}±0.03	0 05	1.62^{a}±0.03	1.57^{a}±0.02	0.06
Moisture (%)	7.37^{a}±0.02	8.29^{a}±0.03	1.05	8.46^{a}±0.03	9.75^{a}±0.02	1.25
Textural Class	Sandy loam	Sandy loam	-	Sandy loam	Sandy loam	-

Row means within similar soil depths, having different superscripts, differ significantly at $p \leq 0.05$

4.3 EFFECT OF MICRO-CATCHMENT AND SPECIES ON VEGETATION CHARACTERISTICS

This sub-section reports and discusses the effect of micro-catchment and species on various attributes measured under field conditions. The field conditions did not favour *Chloris roxburghiana* as by the time data collection began it had not germinated and therefore it was omitted in the results and discussions.

4.3.1 Effect of micro-catchment and species on percent grass cover

The combined effect of micro-catchment and species was significant ($p \leq 0.05$) on percent cover of the grasses; six, nine and twelve weeks post sowing (Table 4.5). The micro-catchment effect was also significant (Table 4.6). The Kiboko range pits generally had higher cover percentages than the ox-furrows throughout the experimental period (Figure 4.3). The better performance in terms of percent cover in the Kiboko range pits than the ox-furrows could be attributed to better water infiltration and retention. The is alluded to in the slightly higher moisture content in the Kiboko range pits (9.0%) as compared to ox-furrows (7.9%) 5 weeks after irrigation was stopped (Table 4.4). The ability to cover the ground quickly is desirable as this reduces the raindrops that directly hit the soil surface thus, reducing the effect from splash erosion.

Table 4.5: Combined effect of micro-catchment and species on percent grass cover

Species	Six: Ox-Furrows	Six: Kiboko range pits	Six: LSD (5%)	Nine: Ox-Furrows	Nine: Kiboko range pits	Nine: LSD (5%)	Twelve: Ox-Furrows	Twelve: Kiboko range pits	Twelve: LSD (5%)
	Weeks post sowing								
CC	$1.3^{a}\pm0.7$	$3.7^{a}\pm1.7$	2.3	$17.7^{a}\pm12.8$	$17.0^{a}\pm4.4$	0.6	$40.7^{a}\pm18.4$	$44.7^{a}\pm6.7$	4.0
EM	$1.7^{b}\pm1.7$	$21.3^{c}\pm3.7$	19.7	$8.0^{b}\pm2.5$	$31.0^{c}\pm6.9$	23.0	$22.0^{b}\pm9.9$	$21.3^{b}\pm4.1$	0.7
ES	$0.3^{d}\pm0.3$	$3.0^{d}\pm2.5$	2.7	$0.3^{d}\pm0.3$	$9.7^{d}\pm8.7$	9.3	$2.7^{c}\pm1.8$	$13.3^{c}\pm7.9$	10.7
CC&EM	$2.3^{e}\pm0.3$	$33.3^{f}\pm9.2$	31.4	$10.0^{e}\pm3.8$	$51.7^{f}\pm7.3$	41.7	$22.3^{d}\pm6.4$	$65.7^{e}\pm4.8$	43.3
CC&ES	$1.7^{g}\pm0.7$	$4.3^{g}\pm2.9$	2.7	$12.0^{g}\pm5.9$	$27.7^{g}\pm8.2$	15.7	$35.0^{f}\pm8.7$	$54.7^{f}\pm5.2$	19.7
EM&ES	$4.7^{h}\pm3.7$	$15.3^{h}\pm5.5$	10.7	$23.3^{h}\pm19.9$	$19.3^{h}\pm1.8$	4.0	$24.7^{g}\pm5.7$	$35.0^{g}\pm5.9$	10.3
CC, EM & ES	$5.0^{i}\pm5.0$	$3.7^{i}\pm2.3$	1.33	$10.3^{i}\pm7.9$	$28.7^{i}\pm8.8$	18.33	$30.0^{h}\pm12.9$	$50.7^{h}\pm5.9$	20.7

Row means within the same week, having different superscripts, differ significantly at $p\leq0.05$
CC=*C. ciliaris*, EM=*E. macrostachyus* and ES =*E. superba*

Table 4.6: Percent cover of grasses in the micro-catchments

Micro-catchment	Weeks post sowing: 6 wks	9 wks	12 wks
Ox-Furrows	$2.4^{a}\pm0.9$	$11.7^{c}\pm3.5$	$25.3^{d}\pm4.1$
Kiboko range pits	$12.1^{b}\pm2.9$	$26.4^{c}\pm3.6$	$40.8^{e}\pm4.3$
LSD (5%)	19.5	14.8	15.4

Column means with different superscripts, differ significantly at $p\leq0.05$

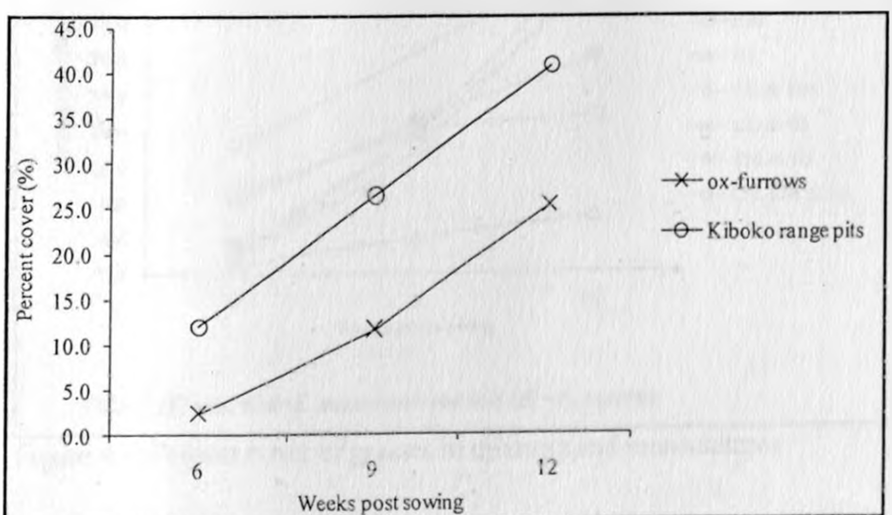
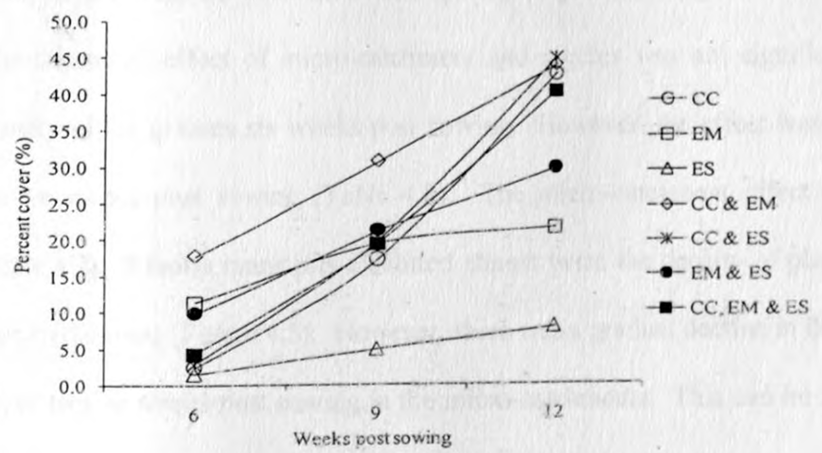


Figure 4.3: Percent grass cover in micro-catchments

The species effect was significant ($p \leq 0.05$) on the cover of the grasses, on the sixth and twelfth week post sowing. However, the effect was not significant on the ninth week (Table 4.7). In all cases, *C. Ciliaris* as a monoculture exhibited highest percent cover than its combinations in mixtures. *Eragrostis superba* as a monoculture exhibited the least percent cover compared to *C. ciliaris* and *E. macrostachyus*. The grass mixture which having the highest percent cover of 44% was of *C. ciliaris* and *E. macrostachyus* (Figure 4.4). Similar results were observed by Opiyo (2007) whereby he found that *E. superba* was the least adapted grass while carrying experiments on two types of land preparation methods (tractor-ploughed and hand-cleared). The results are also in agreement with Mganga (2009) who reported that on average two-grass mixture plots had a higher cover percentage of 42%, compared to plots under monocultures which had an average basal cover of 35%. It is probable that two grass mixtures exploit better the available growth micro-climates than monocultures. Above two mixtures, overcrowding may lead to competitive interactions between the grasses. This is supported by these results where three grass mixtures generally had less cover than two grass mixtures (Figure 4.4).



CC=*C. ciliaris*, EM=*E. macrostachyus* and ES =*E. superba*

Figure 4.4: Percent cover of grasses in mixtures and monocultures

Table 4.7: Percent cover of grasses in mixtures and monocultures

Species	Weeks post sowing		
	Six	Nine	Twelve
CC	$2.5^{a}\pm0.9$	$17.3^{a}\pm6.0$	$42.7^{b}\pm8.8$
*CC with EM	$0.8^{a}\pm0.9$	$13.2^{a}\pm6.0$	$18.8^{ab}\pm6.2$
*CC with ES	$1.3^{a}\pm0.6$	$14.0^{a}\pm8.0$	$30.3^{ab}\pm8.0$
*CC with EM & ES	$1.3^{a}\pm0.9$	$8.3^{a}\pm3.7$	$18.0^{ab}\pm3.1$
EM	$11.5^{ab}\pm4.8$	$19.5^{a}\pm6.1$	$21.7^{ab}\pm4.8$
*EM with CC	$17.0^{c}\pm7.9$	$17.7^{a}\pm5.7$	$25.2^{ab}\pm8.7$
*EM with ES	$6.8^{a}\pm3.7$	$12.8^{a}\pm6.0$	$23.3^{ab}\pm4.1$
*EM with CC & ES	$3.0^{a}\pm1.6$	$9.8^{a}\pm4.6$	$15.2^{a}\pm5.3$
ES	$1.7^{a}\pm1.3$	$5.0^{a}\pm4.4$	$8.0^{a}\pm4.3$
*ES with CC	$1.7^{a}\pm0.9$	$5.8^{a}\pm2.8$	$14.5^{a}\pm6.0$
*ES with EM	$3.2^{a}\pm2.5$	$8.5^{a}\pm4.6$	$6.5^{a}\pm3.9$
*ES with CC & EM	$0.0^{a}\pm0.0$	$1.3^{a}\pm0.6$	$7.2^{a}\pm2.2$
CC & EM	$17.8^{c}\pm8.1$	$30.9^{a}\pm10.0$	$44.0^{b}\pm10.3$
CC & ES	$3.0^{a}\pm.1.4$	$19.8^{a}\pm5.7$	$44.8^{b}\pm6.3$
EM & ES	$10.0^{ab}\pm3.8$	$21.3^{a}\pm9.0$	$29.8^{ab}\pm4.3$
CC, EM & ES	$4.3^{a}\pm2.5$	$19.4^{a}\pm6.7$	$40.4^{b}\pm7.9$
LSD (5%)	13.5	25.8	32.3

Column means with different superscripts differ significantly at $p\leq0.05$
CC=*C. ciliaris*, EM=*E. macrostachyus* and ES =*E. superba*
*Means for individual grasses species in mixtures

4.3.2 Effect of micro-catchment and species on plant density

The combined effect of micro-catchment and species was not significant ($p\leq0.05$) on the density of the grasses six weeks post sowing. However, the effect was significant nine and twelve weeks post sowing (Table 4.8). The micro-catchment effect was also significant (Table 4.9). Kiboko range pits exhibited almost twice the density of plants per metre square than ox-furrows (Figure 4.5). However, there was a gradual decline in density of plants from six to twelve weeks post sowing in the micro-catchments. This can be attributed to phasing out of weaker seedlings due to competition and declining soil moisture.

The species had a significant ($p\leq0.05$) effect on the grass density; six, nine and twelve weeks post sowing (Table 4.10). *Enteropogon macrostachyus* as a monoculture had the highest plant density compared to the other grasses (Figure 4.6). The performance by *E. macrostachyus* mirrored the germination results in the laboratory. However, *C. roxburghiana* which had the second best germination in the laboratory had not germinated by the twelfth week post sowing. These results suggest that other factors in field conditions, most probably soil factors and ambient temperature did not favour the germination of *C. roxburghiana*. It has been reported (Mnene, 2006) that apart from moisture, the soil factor is critical in determining the survival of any plant species.

The mixture with the highest density and also the second best overall was that of *E. macrostachyus* and *E. superba*. Generally higher plant densities were exhibited in mixtures as compared to monocultures. The differences in plant densities between monocultures and mixtures could because the different niches within the range are occupied better by mixtures than by monocultures.

Table 4.8: Combined effect of micro-catchment and species on grass density (plants/m^2)

	6 weeks			9 weeks			12 weeks		
Species	Ox-Furrows	Kiboko range pits	LSD (5%)	Ox-Furrows	Kiboko range pits	LSD (5%)	Ox-Furrows	Kiboko range pits	LSD (5%)
CC	$51^a \pm 2$	$147^a \pm 34$	96	$52^a \pm 12$	$112^b \pm 8$	60	$40^a \pm 6$	$113^b \pm 14$	73
EM	$55^a \pm 12$	$309^a \pm 88$	255	$69^a \pm 26$	$237^a \pm 69$	168	$65^a \pm 26$	$195a^a \pm 57$	129
ES	$12^a \pm 9$	$35^a \pm 29$	23	$15^a \pm 1$	$47^a \pm 23$	32	$9^a \pm 5$	$33a^a \pm 17$	24
CC&EM	$156^a \pm 45$	$229^a \pm 90$	73	$59^a \pm 9$	$207^b \pm 35$	148	$51^a \pm 10$	$115^b \pm 5$	64
CC&ES	$48^a \pm 10$	$89^a \pm 11$	41	$41^a \pm 14$	$91^a \pm 23$	49	$36^a \pm 10$	$64^a \pm 9$	28
EM&ES	$120^a \pm 48$	$153^a \pm 48$	33	$109^a \pm 49$	$111^a \pm 14$	2	$92^a \pm 37$	$100^a \pm 11$	8
CC, EM & ES	$85^a \pm 13$	$196^a \pm 18$	111	$63^a \pm 32$	$179^b \pm 25$	116	$41^a \pm 20$	$148^b \pm 16$	106

Row means within the same week having different superscripts differ significantly at $p \leq 0.05$
CC=*C. ciliaris*, EM=*E. macrostachyus* and ES =*E. superba*

Table 4.9: Density (plants/m^2) of grasses in the micro-catchments

Micro-catchment	Weeks post sowing		
	Six	Nine	Twelve
Ox-Furrows	$75^a \pm 13$	$58^c \pm 10$	$48^e \pm 8$
Kiboko range pits	$166^b \pm 25$	$140^d \pm 17$	$110^f \pm 13$
LSD (5%)	90	82	61

Column means within the same week, with different superscripts differ significantly at $p \leq 0.05$

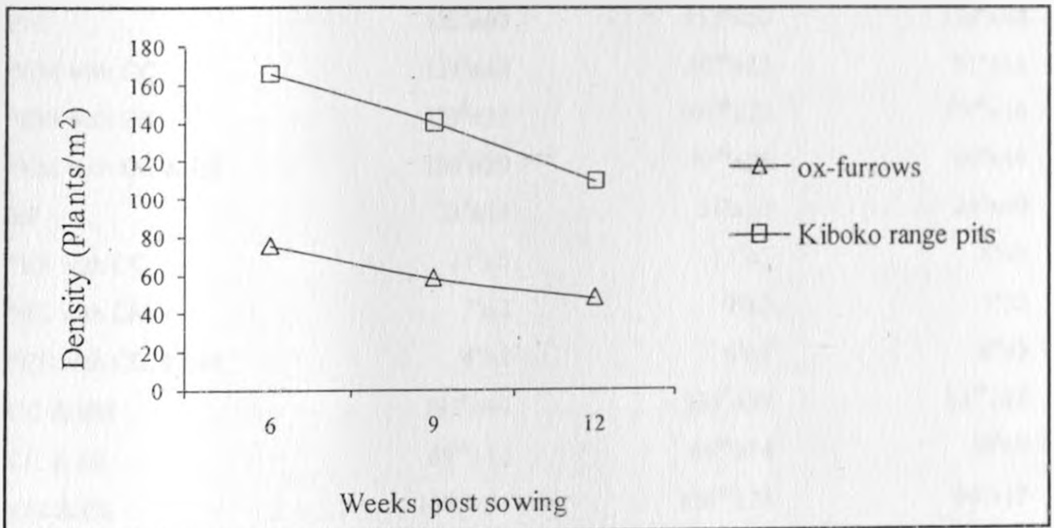


Figure 4.5: Grass density (plants/m^2) in the micro-catchments

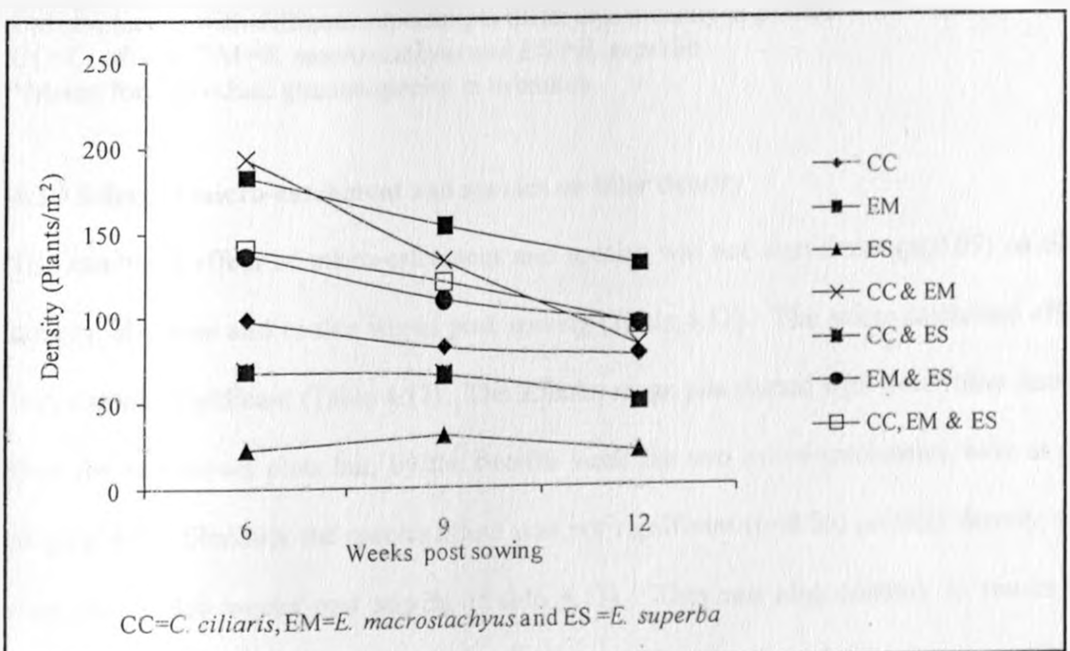


Figure 4.6: Grass density (plants/m^2) of mixtures and monocultures

Table 4.10: Density (plants/m^2) of grasses in mixtures and monocultures

Species	Weeks post sowing Six	Nine	Twelve
CC	99^{ab}±27	82^{ab}±15	77^{ab}±18
*CC with EM	59^{a}±13	43^{a}±10	32^{a}±4
*CC with ES	48^{a}±14	53^{a}±14	42^{a}±8
*CC with EM & ES	37^{a}±10	43^{a}±10	31^{a}±6
EM	182^{b}±69	153^{b}±50	130^{c}±40
*EM with CC	134^{b}±42	90^{ab}±33	51^{a}±13
*EM with ES	130^{b}±31	101^{ab}±22	89^{ab}±16
*EM with CC & ES	100^{b}±29	72^{ab}±25	69^{a}±19
ES	23^{a}±14	31^{a}±12	21^{a}±10
*ES with CC	21^{a}±5	13^{a}±3	8^{a}±3
*ES with EM	7^{a}±3	9^{a}±3	7^{a}±2
*ES with CC & EM	4^{a}±2	6^{a}±1	6^{a}±3
CC & EM	193^{b}±44	133^{b}±37	83^{ab}±15
CC & ES	69^{ab}±12	66^{ab}±16	50^{a}±9
EM & ES	137^{ab}±31	110^{ab}±23	96^{c}±17
CC, EM & ES	141^{ab}±33	121^{ab}±32	106^{c}±26
LSD (5%)	118	102	62

Column means with different superscripts differ significantly at $p \leq 0.05$
CC=*C. ciliaris*, EM=*E. macrostachyus* and ES =*E. superba*
*Means for individual grasses species in mixtures

4.3.3 Effect of micro-catchment and species on tiller density

The combined effect of micro-catchment and species was not significant ($p \leq 0.05$) on tiller density; six, nine and twelve weeks post sowing (Table 4.11). The micro-catchment effect was also not significant (Table 4.12). The Kiboko range pits started with lower tiller density than the ox-furrows plots but, by the twelfth week the two micro-catchments were at par (Figure 4.7). Similarly the species effect was not significant ($p \leq 0.05$) on tiller density; six, nine and twelve weeks post sowing (Table 4.13). They are also contrary to results by Mganga (2009) who found out that the tiller density differed among the three grasses. These results are similar to both Opiyo (2007) and Mganga (2009), in that; *C. ciliaris* had the highest number of tillers followed by *E. macrostachyus* and *E. superba.*

Table 4.11: Combined effect of micro-catchment and species on tiller density

	6 weeks			9 weeks			12 weeks		
Species	Ox-Furrows	Kiboko range pits	LSD (5%)	Ox-Furrows	Kiboko range pits	LSD (5%)	Ox-Furrows	Kiboko range pits	LSD (5%)
CC	$2^a \pm 2$	$4^a \pm 2$	3	$4^a \pm 3$	$5^a \pm 3$	1	$17^a \pm 8$	$23^a \pm 8$	6
EM	$3^a \pm 1$	$4^a \pm 2$	2	$10^a \pm 3$	$6^a \pm 3$	4	$19^a \pm 8$	$19^a \pm 8$	2
ES	$4^a \pm 2$	$0^a \pm 0$	3	$0^a \pm 0$	$3^a \pm 3$	3	$10^a \pm 9$	$13^a \pm 9$	4
CC&EM	$4^a \pm 1$	$6^a \pm 2$	3	$8^a \pm 3$	$6^a \pm 3$	2	$20^a \pm 8$	$11^a \pm 8$	2
CC&ES	$3^a \pm 2$	$3^a \pm 2$	2	$4^a \pm 3$	$6^a \pm 3$	2	$19^a \pm 8$	$16^a \pm 8$	4
EM&ES	$4^a \pm 1$	$7^a \pm 2$	4	$8^a \pm 3$	$8^a \pm 3$	1	$12^a \pm 8$	$19^a \pm 8$	8
CC, EM & ES	$2^a \pm 1$	$5^a \pm 2$	4	$9^a \pm 3$	$5^a \pm 3$	4	$13^a \pm 8$	$12^a \pm 8$	2

Row means within the same week, having different superscripts differ significantly at $p \leq 0.05$
CC=*C. ciliaris*, EM=*E. macrostachyus* and ES =*E. superba*

Table 4.12: Tiller density of grasses in the micro-catchments

Micro-catchment	Weeks post sowing		
	Six	Nine	Twelve
Ox-Furrows	$5^a \pm 1$	$7^a \pm 1$	$16^a \pm 3$
Kiboko range pits	$3^a \pm 1$	$6^a \pm 1$	$16^a \pm 3$
LSD (5%)	2	3	6

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

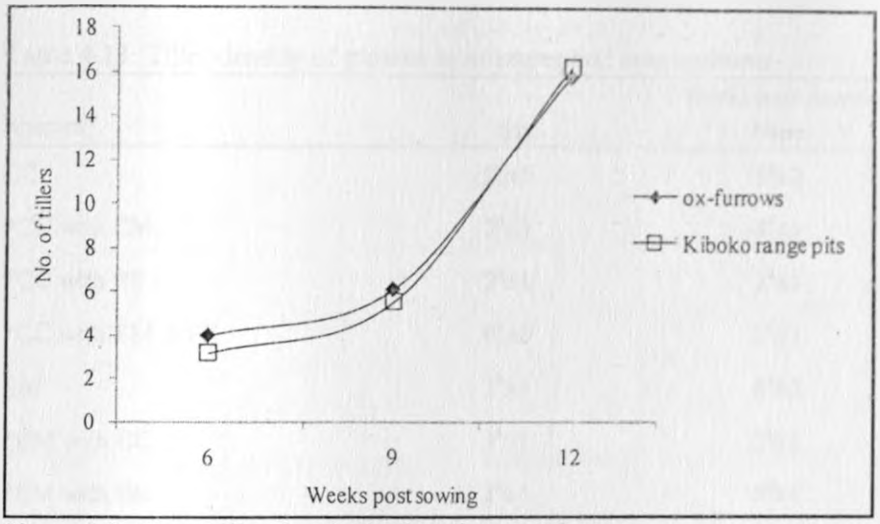


Figure 4.7: Grass tiller density in the micro-catchments

Cenchrus ciliaris started with the least number of tillers but by the twelfth week it had the highest number of tillers (Figure 4.8). Higher tiller density is an important attribute of plants as it increases chances of survival and amount of foliage cover (Skerman and Riveros, 1990; Laidlaw, 2005). Moreover, it is an indicator of resource use and control by the different grass species. Species that control more growth resources are more competitive and in this case *C. ciliaris* is the better resource-competitor compared to the other two grasses.

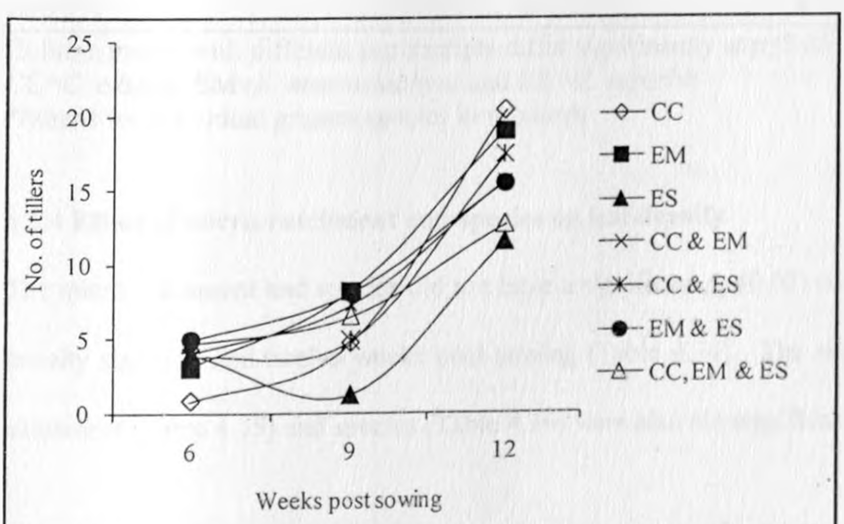


Figure 4.8: Grass tiller density of mixtures and monocultures

Table 4.13: Tiller density of grasses in mixtures and monocultures

Species	Weeks post sowing		
	Six	Nine	Twelve
CC	$2^a\pm1$	$5^a\pm2$	$20^a\pm5$
*CC with EM	$2^a\pm1$	$4^a\pm1$	$8^a\pm1$
*CC with ES	$2^a\pm1$	$3^a\pm1$	$10^a\pm3$
*CC with EM & ES	$0^a\pm0$	$2^a\pm1$	$5^a\pm1$
EM	$3^a\pm1$	$8^a\pm2$	$19^a\pm7$
*EM with CC	$3^a\pm1$	$3^a\pm1$	$8^a\pm1$
*EM with ES	$2^a\pm1$	$5^a\pm1$	$6^a\pm2$
*EM with CC & ES	$0^a\pm0$	$1^a\pm1$	$5^a\pm1$
ES	$4^a\pm1$	$3^a\pm1$	$12^a\pm3$
*ES with CC	$1^a\pm1$	$2^a\pm1$	$7^a\pm1$
*ES with EM	$3^a\pm2$	$5^a\pm2$	$10^a\pm4$
*ES with CC & EM	$3^a\pm1$	$3^a\pm2$	$3^a\pm2$
CC & EM	$5^a\pm1$	$7^a\pm2$	$16^a\pm3$
CC & ES	$3^a\pm1$	$5^a\pm1$	$17^a\pm2$
EM & ES	$5^a\pm2$	$8^a\pm2$	$16^a\pm5$
CC, EM & ES	$3^a\pm1$	$6^a\pm3$	$13^a\pm3$
LSD 5%	6	9	17

Column means with different superscripts differ significantly at $p\leq0.05$
CC=*C. ciliaris*, EM=*E. macrostachyus* and ES =*E. superba*
*Means for individual grasses species in mixtures

4.3.4 Effect of micro-catchment and species on leaf density

The micro-catchment and species did not have a significant ($p\leq0.05$) combined effect on leaf density six, nine and twelve weeks post sowing (Table 4.14). The single effects of micro-catchment (Table 4.15) and species (Table 4.16) were also not significant.

Table 4.14: Combined effect of micro-catchment and species on grass leaf density

Species	Weeks post sowing: Six			Nine			Twelve		
	Ox-Furrows	Kiboko range pits	LSD (5%)	Ox-Furrows	Kiboko range pits	LSD 5%	Ox-Furrows	Kiboko range pits	LSD (5%)
CC	$8^a±5$	$8^a±1$	4	$54^a±45$	$41^a±8$	55	$269^a±203$	$209^a±67$	181
EM	$12^a±5$	$11^a±1$	4	$33^a±15$	$17^a±3$	18	$58^a±28$	$51^a±12$	9
ES	$4^a±1$	$9^a±7$	6	$5^a±1$	$17^a±4$	15	$39^a±20$	$84^a±41$	62
CC&EM	$9^a±3$	$10^a±3$	4	$16^a±5$	$39^a±12$	28	$76^a±26$	$89^a±32$	18
CC&ES	$5^a±1$	$11^a±3$	7	$22^a±6$	$39^a±14$	21	$113^a±20$	$125^a±53$	23
EM&ES	$12^a±5$	$14^a±5$	8	$30^a±19$	$22^a±6$	11	$50^a±21$	$61^a±36$	17
CC, EM & ES	$7^a±3$	$7^a±2$	6	$45^a±34$	$24^a±8$	24	$71^a±51$	$50^a±11$	24

Row means within the same week, having different superscripts differ significantly at $p \leq 0.05$
CC=*C. ciliaris*, EM=*E. macrostachyus* and ES =*E superba*

Table 4.15: Leaf density of grasses in the micro-catchments

Micro-catchment	Weeks post sowing: Six	Nine	Twelve
Ox-Furrows	$8^a±1$	$29^a±7$	$96^a±26$
Kiboko range pits	$11^a±1$	$27^a±6$	$96^a±26$
LSD (5%)	4	19	35

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

The results are similar with Opiyo (2007) who found in that *C. ciliaris* had the highest number of leaves per shoot followed by *E. macrostachyus* and *E. superba*. *Cenchrus ciliaris* had almost double the number of leaves compared to the other two grass species. Grass leaf density is an important criterion; as the higher the number of leaves enables the plant to achieve greater photosynthetic capacity resulting in faster growth (Briske, 1991; Nobel *et al.* 1993). This therefore, gives the plant a competitive advantage in utilization of scarce nutrients and water. In this case *C. ciliaris* had a head start in grass mixtures over *E. macrostachyus* and *E. superba*. The leafy structure is suited for photosynthesis but, may be also conducive for rapid water loss through transpiration (Pratt and Gwynne, 1977; Mnene, 2006). However, plants in arid and semi-arid environments have adaptive features to reduce water loss.

Table 4.16: Leaf density of grasses in mixtures and monocultures

Species	Weeks post sowing		
	Six	Nine	Twelve
CC	8ᵃ±2	48ᵃ±12	239ᵃ±97
*CC with EM	3ᵃ±1	11ᵃ±3	37ᵃ±8
*CC with ES	4ᵃ±2	17ᵃ±6	70ᵃ±20
*CC with EM & ES	3ᵃ±1	8ᵃ±3	23ᵃ±9
EM	11ᵃ±2	25ᵃ±7	55ᵃ±14
*EM with CC	6ᵃ±3	16ᵃ±5	47ᵃ±17
*EM with ES	5ᵃ±2	10ᵃ±3	22ᵃ±8
*EM with CC & ES	4ᵃ±2	22ᵃ±8	33ᵃ±11
ES	8ᵃ±5	7ᵃ±4	61ᵃ±22
*ES with CC	4ᵃ±3	13ᵃ±8	49ᵃ±12
*ES with EM	8ᵃ±5	16ᵃ±4	33ᵃ±9
*ES with CC & EM	0ᵃ±0	2ᵃ±1	5ᵃ±2
CC & EM	9ᵃ±2	27ᵃ±8	83ᵃ±19
CC & ES	8ᵃ±2	30ᵃ±8	119ᵃ±25
EM & ES	13ᵃ±3	26ᵃ±9	55ᵃ±19
CC, EM & ES	7ᵃ±2	32ᵃ±13	61ᵃ±24
LSD (5%)	13	50	241

Column means with different superscripts differ significantly at $p \leq 0.05$
CC=*C. ciliaris*, EM=*E. macrostachyus* and ES =*E. superba*
*Means for individual grasses species within mixtures

4.3.5 Effect of micro-catchment and species on plant height

The combined effect of micro-catchment and species was not significant ($p \leq 0.05$) on plant height at six, nine and twelve weeks post sowing (Table 4.17). The single effects of micro-catchment (Table 4.18) and species (Table 4.19) were also not significant. Kiboko range pits plots had on average taller plants than ox-furrow plots (Figure 4.9). *Cenchrus ciliaris* recorded higher plant heights both as a monoculture and in mixtures. From week six to twelve, there was a gradual increase in the height for *E. macrostachyus* and *E. superba*. However, for *C. ciliaris* there was a sharp rise from the ninth week (Figure 4.10). This implies that *C. ciliaris* had a higher growth rate and therefore was a better competitor than *E. macrostachyus* and *E. superba*.

Table 4.17: Combined effect of micro-catchment and species on grass height (cm)

	6 weeks			9 weeks			12 weeks		
Species	Ox-Furrows	Kiboko range pits	LSD (5%)	Ox-Furrows	Kiboko range pits	LSD (5%)	Ox-Furrows	Kiboko range pits	LSD (5%)
CC	6.0^a±4.0	6.3^a±2.6	0.4	19.7^a±14.2	14.5^a±5.5	5.5	40.0^a±15.9	43.0^a±9.9	5.0
EM	6.3^a±2.2	5.7^a±1.5	0.9	21.7^a±14.3	8.2^a±0.2	13.9	34.7^a±17.5	14.7^a±3.2	21.3
ES	0.2^a±0.2	2.0^a±2.0	1.9	3.0^a±0.0	18.5^a±16.5	15.7	18.5^a±4.5	27.5^a±21.5	10.2
CC&EM	4.9^a±0.5	7.2^a±0.6	2.5	9.3^a±3.6	14.7^a±2.6	5.8	21.3^a±3.8	33.7^a±9.4	12.9
CC&ES	3.0^a±1.0	4.4^a±2.2	1.7	12.3^a±3.9	14.5^a±5.8	2.7	41.3^a±11.7	43.7^a±5.5	2.6
EM&ES	9.0^a±1.7	8.8^a±2.6	0.5	9.5^a±4.3	11.8^a±4.6	2.5	14.0^a±6.6	32.7^a±10.7	19.4
CC, EM & ES	4.5^a±1.5	4.5^a±0.8	0.8	9.6^a±7.4	11.4^a±3.5	2.2	45.3^a±18.5	23.7^a±9.5	22.6

Row means within the same week, having different superscripts differ significantly at $p \leq 0.05$
CC=*C. ciliaris*, EM=*E. macrostachyus* and ES =*E. superba*

Table 4.18: Height of grasses in the micro-catchments

	Weeks post sowing		
Micro-catchment	Six	Nine	Twelve
Ox-Furrows	1.9^a±0.6	5.9^a±2.7	30.6^a±4.8
Kiboko range pits	2.6^a±0.9	6.8^a±2.5	31.5^a±4.4
LSD (5%)	0.7	0.9	0.9

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

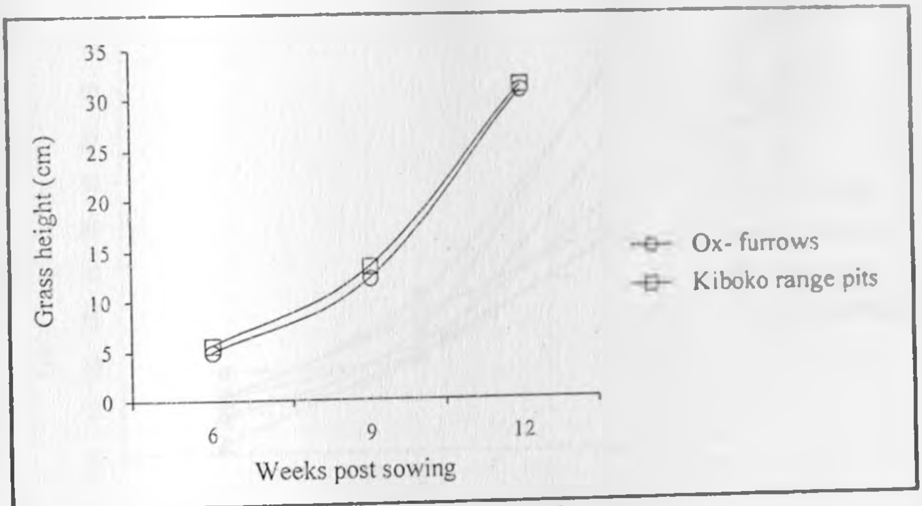
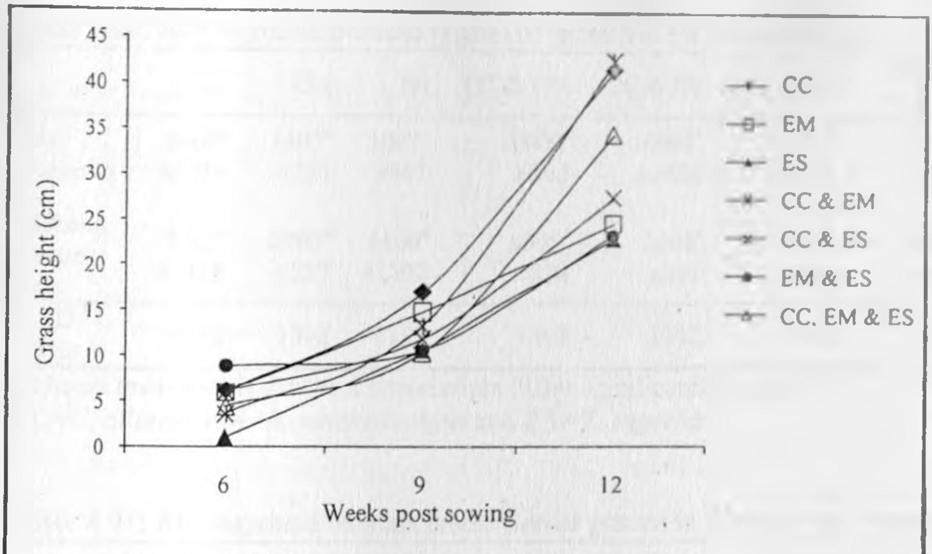


Figure 4.9: Grass height (cm) in the micro-catchments

Table 4.19: Height of grasses in mixtures and monocultures

Species	Weeks post sowing Six	Nine	Twelve
CC	6.2ª±2.2	15.4ª±5.1	41.5ª±8.3
*CC with EM	2.6ª±1.2	5.3ª±1.9	14.0ª±4.9
*CC with ES	2.1ª±1.1	7.3ª±4.0	21.8ª±4.9
*CC with EM & ES	2.2ª±0.3	2.4ª±1.3	13.2ª±5.9
EM	6.0ª±1.2	14.9ª±4.6	24.7ª±8.3
*EM with CC	3.4ª±0.7	6.6ª±2.0	13.5ª±3.1
*EM with ES	8.9ª±1.4	9.1ª±4.2	15.6ª±4.9
*EM with CC & ES	2.3ª±1.3	2.8ª±1.1	17.6ª±5.8
ES	3.3ª±2.8	12.4ª±5.7	23.2ª±10.2
*ES with CC	1.8ª±1.5	6.1ª±2.1	20.7ª±9.2
*ES with EM	0.0ª±0.0	1.6ª±0.4	7.7ª±4.8
*ES with CC & EM	0.0ª±0.0	3.6ª±1.8	3.7ª±1.5
CC & EM	6.0ª±0.6	11.9ª±4.6	27.5ª±8.3
CC & ES	3.9ª±1.3	13.4ª±4.6	42.5ª±8.3
EM & ES	8.9ª±1.4	10.7ª±4.6	23.3ª±8.3
CC, EM & ES	4.5ª±0.6	8.8ª±5.2	34.5ª±8.3
LSD (5%)	6.7	9.2	23.6

Column means with different superscripts differ significantly at $p \leq 0.05$
CC=*C. ciliaris*, EM=*E. macrostachyus* and ES =*E. superba*
*Means for individual grasses species in mixtures



CC=*C. ciliaris*, EM=*E. macrostachyus* and ES=*E. superba*

Figure 4.10: Grass height (cm) of mixtures and monocultures

Other studies by Skerman and Riveros (1990) reported higher plants heights in the opened up soil surface plots than burnt plots which they attributed to increased moisture retention, increased uptake of water and nutrients by plants, good aeration and root penetration by the seedlings. Njenga (1992) and Mnene (2006) have also observed differences in plant heights among the three grasses. For instance, Njenga working with *C. ciliaris*, *E. macrostachyus* and *E. superba* in the southern rangelands of Kenya reported higher plant heights in ox-ploughed plots than burnt plots.

4.3.6 Effect of micro-catchment and species on aboveground biomass production

The combined effect of micro-catchment and species was not significant ($p \leq 0.05$) on aboveground biomass production (Table 4.20). The single effect of micro-catchment was not significant. Similarly the species effect (Table 4.21) was not significant on biomass production. The higher biomass production in the Kiboko range pit plots than the ox-furrows could be attributed to better opening up of the soil, more water infiltration and retention and availability to plants thus; allowing for easier root penetration resulting in rapid plant growth.

Table 4.20: Aboveground biomass (kg/ha) of grasses in the micro-catchments

	CC	EM	ES	CC & EM	CC & ES	EM & ES	CC, EM & ES	Overall
Ox-Furrows	3800^a ±3219	1467^a ±333	1067^a ±967	1000^a ±305	6067^a ±2488	2467^a ±968	2000^a ±346	2553^a ±1232
Kiboko range pits	3333^a ±1168	2000^a ±757	1400^a ±1200	4000^a ±872	3466^a ±291	1200^a ±200	3333^a ±1988	2676^a ±925
LSD (5%)	1392	1392	1392	1392	1392	1392	1392	1392

Column means with different superscripts differ significantly at p≤0.05
CC=*C. ciliaris*, EM=*E. macrostachyus* and ES =*E. superba*

Table 4.21: Aboveground biomass production of grasses in mixtures and monocultures

Species	kg/ha
CC	4280^a±1664
*CC with EM	1267^a±504
*CC with ES	2100^a±865
*CC with EM & ES	1589^a±855
EM	1733^a±520
*EM with CC	1233^a±958
*EM with ES	936^a± 593
*EM with CC & ES	510^a± 469
ES	1233^a±721
*ES with CC	2666^a± 634
*ES with EM	897^a± 264
*ES with CC & EM	567^a± 300
CC & EM	2500^a±787
CC & ES	4766^a±1262
EM & ES	1833^a±525
CC, EM & ES	2666^a±950
LSD (5 %)	3533

Column means with different superscripts differ significantly at p≤0.05
CC=*C. ciliaris*, EM=*E. macrostachyus* and ES =*E. superba*
*Means for individual grasses species within mixtures

Opiyo (2007) reported that, tractor-ploughed plots had higher biomass production than the hand-cleared plots. Hanselka *et al.* (1992) working in Texas USA, also observed a double increase in biomass production of *C. ciliaris* in disc-ploughed plots as compared to the non-ploughed plots. This they attributed to the ability of the plough to remove the hard surface soil and reduce the weeds to a manageable level.

The combination of *C. ciliaris* and *E. superba* gave the highest biomass production. While, among the monocultures, *C. ciliaris* had the highest biomass production followed by *E. macrostachyus* and *E. superba*. The differences in biomass production between the grass species has been reported by others (Chelishe and Kitalyi, 2002; Mnene, 2006; Mganga, 2009). Mganga (2009) attributed the difference in biomass production between mixtures and monocultures and among difference grass species to the growth and morphological characteristics of the grasses as explained under plant density.

4.3.7 Effect of micro-catchment and species on grass seed production

The micro-catchment and species combined effect was not significant ($p \leq 0.05$) on seed production. Similarly the micro-catchment effect was also not significant (Table 4.22). However, there was a significant difference in seed production among the grass species (Table 4.23). Even though not significant, the Kiboko range pits had more grass seeds harvested per ha as compared to the ox-furrows plots. Mixtures generally, had higher seeds per ha than monocultures. *Cenchrus ciliaris* ranked highest in seed production followed by *E. macrostachyus* and *E. superba*.

Table 4.22: Seed production (kg/ha) of grasses in the micro-catchments

	CC	EM	ES	CC & EM	CC & ES	EM & ES	CC, EM & ES	Overall
Ox-Furrows	$80^a \pm 9$	$77^a \pm 21$	$53^a \pm 11$	$90^a \pm 3$	$160^a \pm 36$	$192^a \pm 64$	$213^a \pm 41$	$124^a \pm 26$
Kiboko range pits	$80^a \pm 5$	$48^a \pm 8$	$96^a \pm 56$	$133^a \pm 3$	$226^a \pm 74$	$180^a \pm 23$	$226^a \pm 67$	$141^a \pm 34$

Column means with different superscripts differ significantly at $p \leq 0.05$, LSD=70
CC=*C. ciliaris*, EM=*E. macrostachyus* and ES =*E. superba*

Table 4.23: Seed production of grasses in mixtures and monocultures

Species	Kg/ha
CC	$80^{ab}\pm5$
*CC with EM	$58^{ab}\pm6$
*CC with ES	$95^{ab}\pm6$
*CC with EM & ES	$73^{ac}\pm7$
EM	$63^{a}\pm12$
*EM with CC	$54^{a}\pm8$
*EM with ES	$30^{a}\pm8$
*EM with CC & ES	$57^{a}\pm8$
ES	$75^{ab}\pm27$
*ES with CC	$98^{a}\pm45$
*ES with EM	$106^{b}\pm45$
*ES with CC & EM	$90^{a}\pm50$
CC & EM	$112^{b}\pm10$
CC & ES	$193^{bc}\pm40$
EM & ES	$136^{b}\pm40$
CC, EM & ES	$220^{c}\pm35$
LSD (5%)	182

Column means with different superscripts differ significantly at $p\leq0.05$
CC=*C. ciliaris*, EM=*E. macrostachyus* and ES =*E. superba*
*Means for individual grasses species within mixtures

These finding in grass seed production are similar to what was reported by Mganga (2009). However, in Mganga's case, *E. superba* as a monoculture had the highest amount of seeds per ha followed by *C. ciliaris* and *E. macrostachyus*. The differences in seed production among the grass species can be attributed to the morphological characteristics of the grasses. *Eragrostis superba* has much bigger spikelets of 6-16mm long compared to *Cenchrus ciliaris* and *Enteropogon macrostachyus* which have spikelets measuring 3.5-5mm and 7-10mm long, respectively.

4.4 BENEFIT-COST RATIO OF RESEEDING APPROACHES

The direct costs of reseeding in the study area were estimated at KES 20,740 and 20,340 for ox-furrows and Kiboko range pits, respectively. The total initial investment costs were estimated at KES 27,949 for ox-furrows and KES 27,410 for Kiboko range pits. The additional annual costs (weed control, fence maintenance, hay harvesting and risk of failure) were estimated at KES 5,148 and 5,148 for the ox-furrows and Kiboko range pits, respectively. Data on inputs required and costs in the investments are presented in Table 4.24.

The results (Table 4.25) show that most of the reseeding projects broke even except for *E. superba* which had a BCR less than one. The highest net returns were from *Cenchrus ciliaris* under the ox-furrows. From these results there is an indication that reseeding the area using the three grasses for biomass production is economically feasible

The BCR reveals that each shilling invested yields more than a shilling, and IRR shows that all species yield an annual compounded rate of interest greater than the 14.76% cost of borrowing. However, *E. macrostachyus*, under ox-furrows, and *E. superba* in both micro-catchments had IRR values less than 14.76%. This implies that in situations where capital is not a constraint, the farmer can invest in both methods in any of micro-catchments. On the other hand, where capital is a constraint the farmer may invest profitably in reseeding using *C. ciliaris* planted in either of the micro-catchments and *E. macrostachyus* planted in Kiboko range pits.

Table 4.24: Summary of input requirements and costs of reseeding (KES per ha)

Item	Unit Cost	Ox-plough furrows	Kiboko range pits
Direct Costs			
Purchase of seeds 5kg/ha	1,000	5,000	5,000
Machetes (4)	250	1,000	1,000
Hand hoes (4)	450	-	1,800
Clearing of land (10 man-days/ha)	165	1,650	1,650
Hire of ox-plough (4500/ha)	-	4,500	-
Maintenance of ox-plough	1,000	1,000	-
Making of Kiboko range pits (20 man-days)	165	-	3,300
Sowing (15 man-days)	165	2,475	2,475
Fencing (6 man-days)	165	990	990
Weed control (10 man-days)	165	1,650	1,650
Hay harvesting (15 man-days)	165	2,475	2,475
Subtotal		*20,740*	*20,340*
Indirect Costs			
Risk of failure (20%)		4,148	4,068
Interest on direct costs (14.76%)		3,061	3,002
Sub-Total		*7,209*	*7,070*
Total Costs		27,949	27,410

Table 4.25: Comparison of two range reseeding investments using BCR and IRR

Item	Project	
	Ox-furrows	Kiboko range pits
Project life (years)	20	20
Initial cost of reseeding (KES)	27,949	27,410
Additional annual costs	5,148	5,148
All 3 Grasses		
Total Annual return (KES)	17,017	17,840
BCR at 14.76% discount rate	2.5	2.6
IRR	22.6	23.6
Cenchrus ciliaris		
Total Annual return (KES)	25,333	22,220
BCR at 14.76% discount rate	3.7	3.2
IRR	34.9	30.5
Enteropogon macrostachyus		
Total Annual return (KES)	9,780	13,333
BCR at 14.76% discount rate	1.4	1.9
IRR	13.6	18.0
Eragrostis superba		
Total Annual return (KES)	7,113	9,333
BCR at 14.76% discount rate	1.0	1.3
IRR	9.0	12.4

In many situations, capital will always be a constraint and therefore an optimum combination of investments that will break even should be chosen. In this case *C. ciliaris* is the most profitable grass species for reseeding because it had the highest BCR of 3.7. On the other hand *E. superba* is the least cost effective grass because it had the lowest BCR (1.0). Opiyo (2007) reported that two methods of land treatment, tractor-ploughed and hand-cleared were both economically viable using the three grasses (*C. ciliaris*, *E. macrostachyus* and *E. superba*). However, in Opiyo's case, *E. macrostachyus* had the highest BCR followed by *C. ciliaris* and *E. superba*. The reason for this difference could be attributed to the different soil conditions, seeding rates and methods of pasture establishment used.

These results confirm what has been reported by others that range reseeding can be economically viable (Nielsen, 1967; Sneva, 1970; Godfrey *et al.* 1979). In this study both range reseeding investments were feasible and profitable. Opening up the soil surface by using ox-plough and preparing land using a hand hoe to make Kiboko range pits are both viable investments for pasture production in the southern rangelands of Kenya.

4.5 RESULTS OF SOCIO-ECONOMIC SURVEY

4.5.1 Age of respondents and household heads

From the survey of the common interest groups members interviewed (Figure 4.11), the respondents were as follows: household heads (HH) (47.5%), spouses of the HH (47.5%), daughter-in-law to the HH (2.5%) and daughters to the HH (2.5%). In terms of gender, male were 45% and female 55%. The age (years) distribution of the respondents was as follows: above 60 (35%), 50-59 (35%), 40-49 (12.5%), 30-39 (15%) and 18-29 (2.5%). The age of the HH followed a similar trend – above 60 (46%), 50-59 (32%), 40-49 (19%), 30-39 (3%) and 18-29 (0.0%). This statistic reveals that the majority of respondents and household heads were senior adults.

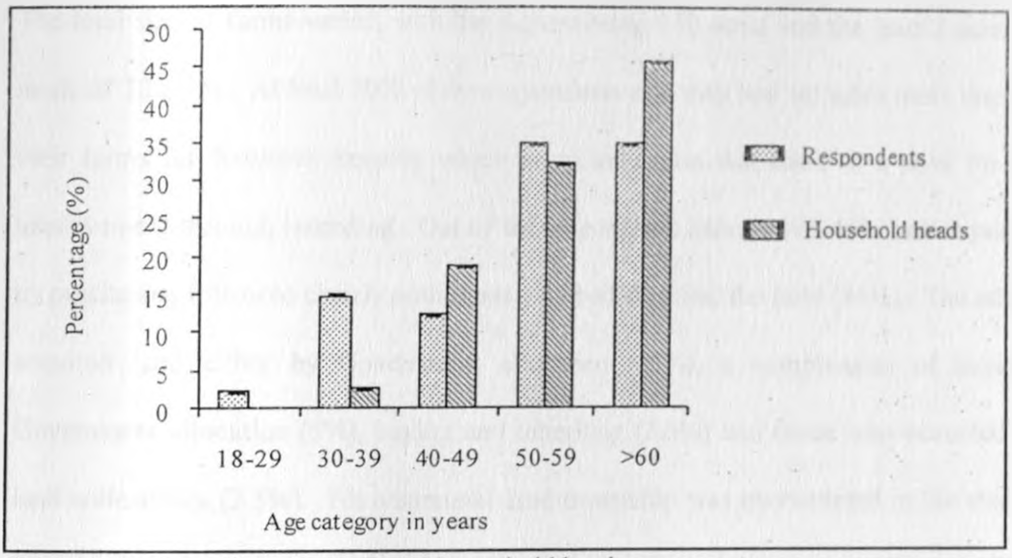


Figure 4.11: Age of respondents and household heads

4.5.2 Education level of respondents and household heads

The education level of the respondents was as follows: tertiary education (5%), secondary education (20%), primary education (62.5%) and no formal education (12.5%). Similarly the education level of HH was: tertiary education (2.5%), secondary education (24.3%), primary education (62.2%) and no formal education (10.8%) (Figure 4.12). These results suggest that the education level of most HHs was fair enough to enable them make informed decisions about range reseeding operations on their farms.

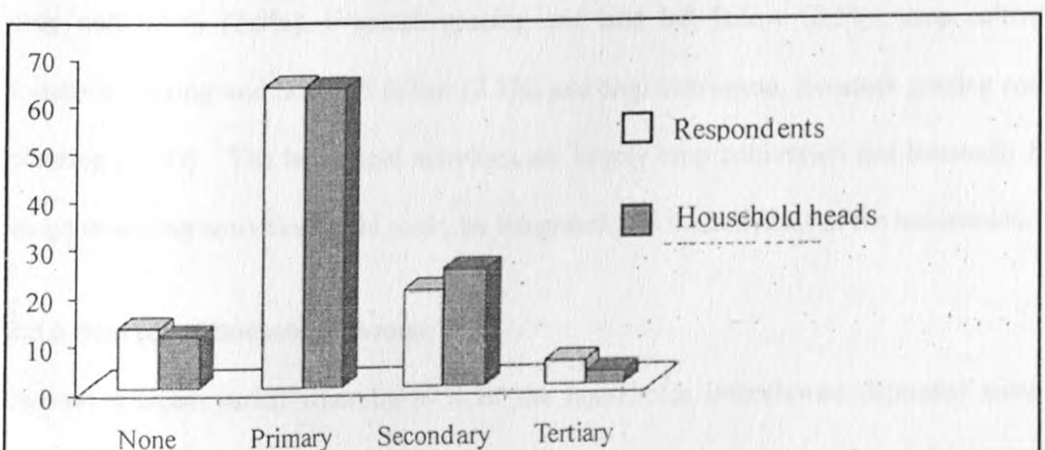


Figure 4.12: Education levels of respondents and household heads

4.5.3 Farm size and land acquisition

The total size of farms varied, with the highest being 150 acres and the least 2 acres with a mode of 10 acres. At least 50% of the respondents said they had set aside more than half of their farms for livestock keeping which is an indication that there is a need for pasture improvement through reseeding. Out of the respondents interviewed 40% had acquired land by purchasing followed closely with those who had inherited the land (35%). The others had acquired land either by Government allocation (15%), a combination of buying and Government allocation (5%), buying and inheriting (2.5%) and those who occupied family land collectively (2.5%). No communal land ownership was encountered in the study area. This implies that any range improvement activities through range reseeding are likely to succeed because most of the farmers have control and access to the land.

4.5.4 Farm activities

Most of the farms (70%) were managed by the HH, 17.5% by the spouse of the HH, 10% by both the HH and the spouse and 2.5% by the eldest daughter to the HH. The major activities in the households were as follows: crop cultivation and livestock grazing (70%), livestock grazing (10%), crop cultivation, livestock grazing, bee keeping and land left fallow (10%), crop cultivation (2.5%), livestock grazing and land left fallow (2.5%), crop cultivation, livestock grazing and land left fallow (2.5%) and crop cultivation, livestock grazing and tree planting (2.5%). The household activities are largely crop cultivation and livestock; hence range reseeding activities could easily be integrated into the activities of the households.

4.5.5 Sources of household income

Income sources varied whereby 37% of the households interviewed depended solely on farming for their livelihood. Livestock sales were a key component to farming income within the preceding 12 months of the survey, 87.5% of the respondents had sold livestock against

12.5% who did not. Sales per livestock species were goats (50.0%), cattle (39.6%), sheep (8.6%) and donkeys (1.7%). The reasons for sale of livestock by the households were varied and included: drought (38.5%), household needs (28.9%), school fees (11.5%), off-take (1.9%), and meeting hospital bills (1.9%). Most of the livestock were sold below the normal market price because of the effect of prolonged drought. Only 43.4% of those who sold livestock were satisfied with the prices offered for their livestock, while 56 6% indicated that the prices were very low to the extent of a mature bull selling for as little as KES 500 per head. The rest of the households supplemented farm income with other sources as follows: off-farm business (30%), remittances from relatives (15%), salaries (7%), off-farm business and remittances from relatives (5%), casual labour (3%) and off-farm business and wages from casual labour (3%) (Figure 4.13).

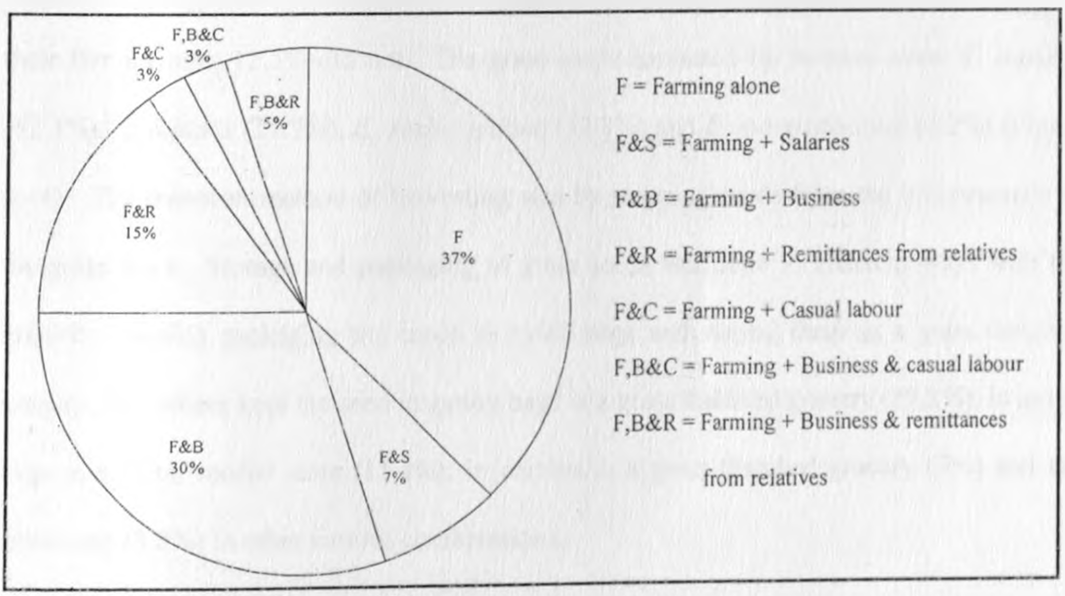


Figure 4.13: Sources of household income

These findings suggest that reseeding can be implemented not only to support livestock farming but also to diversify household income through the sale of pasture seed and hay.

4.5.6 Reseeding practice

Among the households interviewed, 97.5% practiced reseeding while 2.5% did not. The farmers reseeded a number of grass species on their farms. The grasses planted were: *E. superba* (46.2%), *C. ciliaris* (32.1%), *C. roxburghiana* (10.3%), *E. macrostachyus* (7.7%), *Cynodon plectostachyus* (2.6%) and other unidentified spp. (1.3%) (Figure 4.14). The grass seeds for reseeding were acquired through various means: harvesting on on-farm (66.7%), from KARI (10.3%), from neighbours (5.1%), purchasing (5.1%), from neighbours and KARI (3.8%), University of Nairobi (UoN) (3.8%), and from the group's store (2.6%). The remaining percentage (2.6%) used vegetative parts ('splits') for reseeding. The cost for grass seeds ranged from KES 0 to KES 1000 per kg of grass seed.

In terms of grass seed harvesting, 87.5% of the households practiced grass seed harvesting on their farms while, 12.5% did not. The grass seeds harvested by farmers were: *E superba* (52.3%), *C. ciliaris* (27.7%), *C. roxburghiana* (13.8%) and *E. macrostachyus* (6.2%) (Figure 4.14) The common method of harvesting was by stripping seeds from the inflorescence of the grass plant. Storage and packaging of grass seeds was done in different ways with the majority (44.6%) packaging the seeds in nylon bags and storing them in a grass thatched granary. The others kept the seed in gunny bags in a grass thatched granary (29.2%), in nylon bags in an iron roofed store (15.4%), in cartons in a grass thatched granary (7%) and the remaining (3.8%) in other various combinations.

The reseeded acreage varied among the households as follows: less than one (46.3%), one to two (13.8%), two to three (6.3%), three to ten (12.5%) and on terraces (21.3%) (Figure 4.15). Less than half of the households (42.5%) indicted that they had adequate grass seeds for reseeding while 57.5% did not. These results indicate that there is potential for integrating range reseeding activities in the study area by availing more seeds to the households.

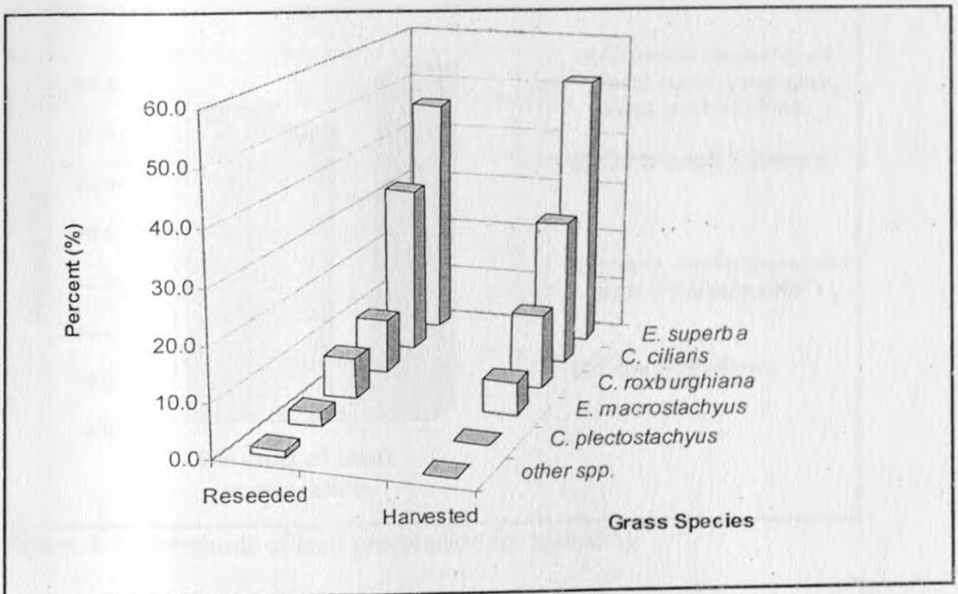


Figure 4.14: Grass seeds planted and harvested on-farm

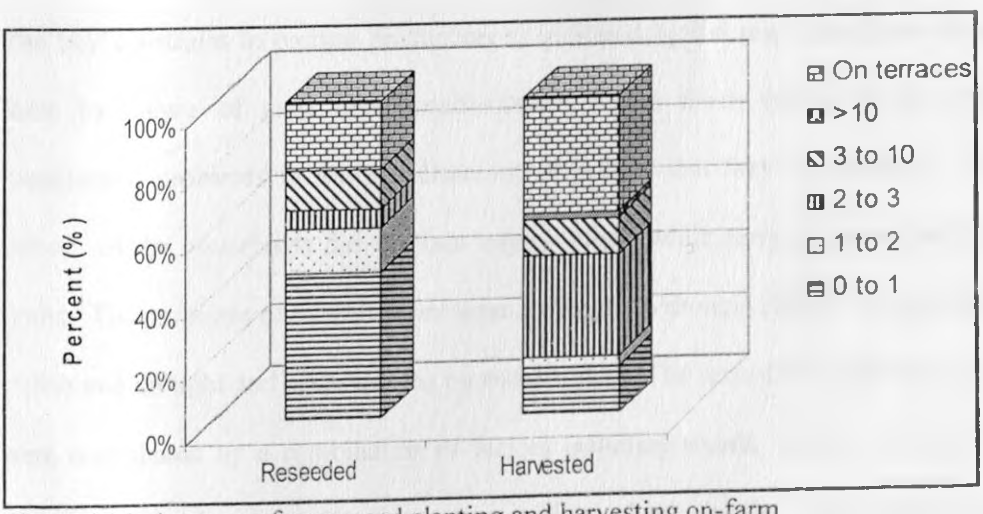


Figure 4.15: Acreage of grass seed planting and harvesting on-farm

The most common (46.9%) method of land preparation for reseeding purposes was through clearing using slashes, machetes, axes and hoes (Figure 4.16). The other methods were making ox-furrows (43.7%) and crescent-shaped pits (Kiboko range pits) (9.4%). None of the respondents indicated using motorized equipment such as a tractor, to prepare land for reseeding. This means that reseeding operations in the study area are not highly mechanized.

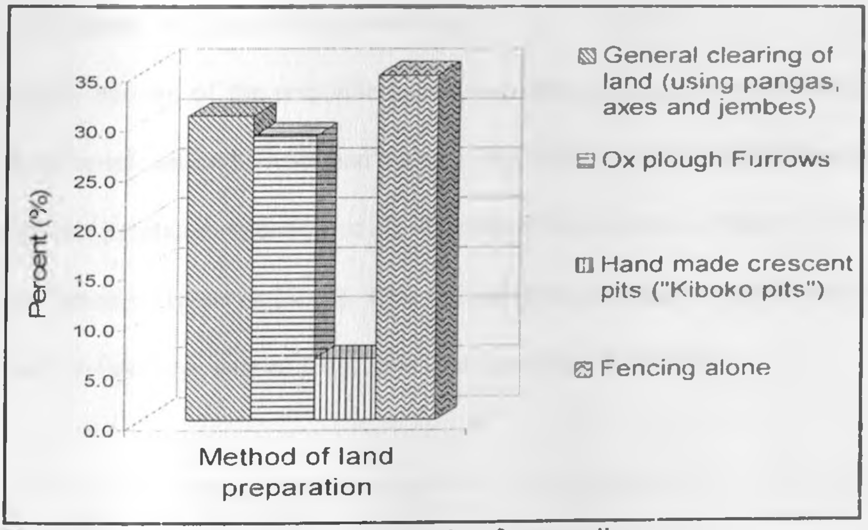


Figure 4.16: Methods of land preparation for reseeding

4.5.7 Constraints to pasture production

The key constraint to pasture production as indicated by the respondents was drought that leads to failure of grass seed establishment. Two thirds (65%) of the respondents experienced problems in the establishment of grasses that they had planted. Thirty-five percent of the households did not face any problems while carrying out reseeding in their farms. The problems of establishment were attributed to drought (20%), drought and termites (10%) and drought and seeds carried by runoff (5%). The rest of the problems of reseeding were contributed by a combination of factors including weeds, termite damage, failure to germinate, birds and insects damage as well as slow growth. More than half of the respondents (57.5%) did not seek any solution to the problems, while 42.5% sought assistance. Five percent of those who sought assistance got adequate assistance while 95% indicated that they were not satisfied with the assistance given. To solve these constraints, several solutions were suggested such as irrigated pasture production, directing runoff to the termite moulds to kill termites, training of farmers on pasture production practices and offering financial assistance to farmers carrying out range reseeding activities.

4.5.8 Benefits of practicing reseeding

Eighty percent of the respondents indicated that practicing grass reseeding on their land had been beneficial and 17.5% had not seen the benefits. Two and half percent of the respondents had not practiced reseeding at all. The benefits mentioned (Figure 4.17) included grazing for the farmers' livestock (50%). Other benefits were leasing of pastureland, making hay for sale and on-farm use, sale of grass seeds, and grass for thatching.

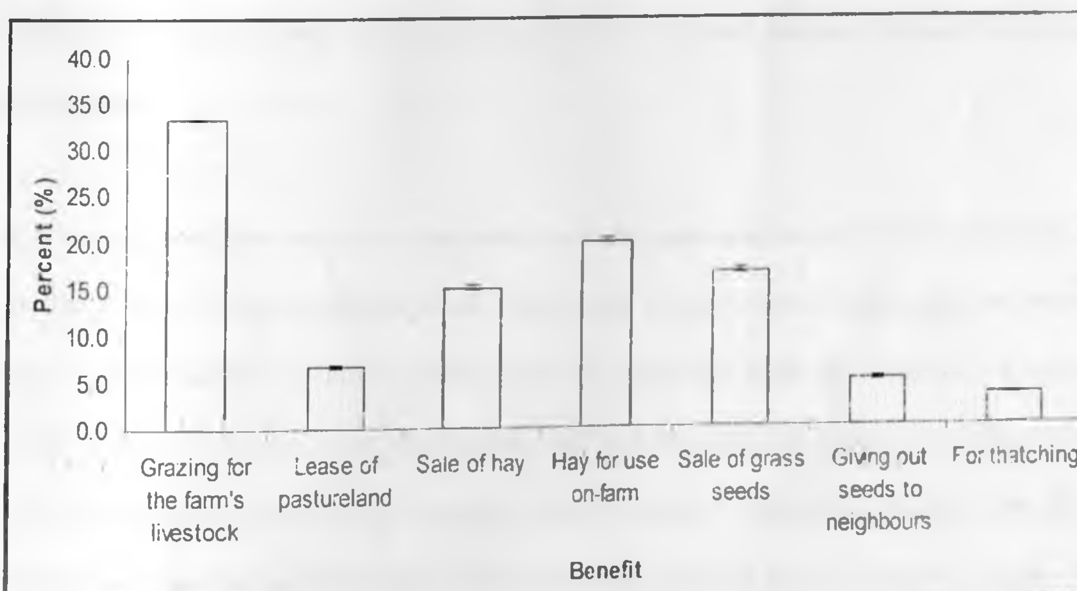


Figure 4.17: Benefits of practicing reseeding on-farm

CHAPTER FIVE

GENERAL DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

5.1 GENERAL DISCUSSIONS

The results of this study have significant implication to pasture improvement activities in the rangelands of southern Kenya. Generally the seed viability of *E. macrostachyus* was the highest followed by *C. roxburghiana, E. superba* and *C. ciliaris*. These variations in germination percentages may be attributed to intrinsic properties of the grass seeds such as dormancy and hardness of the integument. One of the first steps to successful germination is to ensure the viability of the seeds. There was no significant difference in germination percentages for grass seeds stored for different periods. There was a significant difference in the overall germination of grass seeds from farmers and those from on-station seed bulking centres such as KARI-Kiboko. However, in terms of species only *C. ciliaris* showed a significant difference in germination rates between on-station and on-farm grass seeds. Germination may fail even with the right conditions for growth because the seed is dormant or not viable.

The study showed that vegetative characteristics of the grass species are positively influenced by the type of micro-catchment used. The plots under Kiboko range pits had better performance than the ox-furrows plots, in all the vegetation attributes measured. Percent cover and plant density were significantly different between the two micro-catchments; while, tiller density, leaf density and plant height were not. Therefore, it is likely that, the Kiboko range pits had modified the structure of the soil slightly better than the ox-furrows.

In terms of aboveground biomass and seed production, plots with Kiboko range pits performed better than ox-furrows. The difference was, however, not significant. The aboveground biomass production was the basis of calculating the BCR and IRR of the reseeding approaches. All the reseeding activities broke even with the exception of *E superba* in the ox-furrow plots. Kiboko range pits a BCR of 2.5 while ox-furrows a BCR of 2.6. The IRR was 23.6% for Kiboko range pits and 22.6% for ox-furrows both of which were above 14.76% – the average lending rate by commercial banks in 2009. These results suggest that these range reseeding activities are viable, even with borrowed capital, in the rangelands of southern Kenya.

The grass species with the best performance in the field was *C. ciliaris*, followed by *E. macrostachyus* and *E. superba*. This was contrary to laboratory conditions whereby *C. ciliaris* had the lowest germination. Thus, in the field other factors influenced seed germination such as soil crusting and ambient temperatures. These factors could have contributed to *Chloris roxburghiana* not having germinated by the twelfth week post sowing. The results suggest that *C. ciliaris* is a better competitor both as a monoculture and in mixtures than the other three grasses used in this study. *Cenchrus ciliaris* was also the most profitable grass species as it gave the highest BCR.

A survey carried out showed that the farmers in the study area practiced range reseeding. A good number also ventured into harvesting and storing grass seeds on their farms. The grass that was harvested and planted by majority of the farmers was *E. superba*. The farmers were faced with several constraints in their grass reseeding efforts within the study area. The main constraint was drought which affected germination and establishment of the reseeded grass stands. The farmers practicing grass reseeding indicated they had benefited from reseeding. The benefits included increased grazing period, hay for sale or domestic use, grass seeds for sale, grass for thatching and protection of soil from erosion.

5.2 CONCLUSIONS

From this study, the following were the main conclusions:

- The grass seed harvested and stored by farmers is of similar quality in terms of germination to those harvested and stored on-station seed bulking centre such as KARI, partly because the seeds are harvested in their natural state without an attempt of selection for superior varieties.

- The opening up of the soil surface either by use of a hoe to make Kiboko range pits or an ox-plough to make ox-furrows yields similar results in terms of vegetative attributes and aboveground biomass production of the reseeded grasses.

- Use of Kiboko range pits and ox-furrows are economically viable micro-catchments for reseeding in similar conditions in the southern rangelands. From the survey it was evident that most of the farmers used ox-furrows for reseeding as opposed to Kiboko range pits. This is despite the evidence that Kiboko range pits performed better than ox-furrows. The likely reason is that Kiboko range pits are more labour intensive.

- *Cenchrus ciliaris* is the superior species both as a monoculture and in mixtures. This is because it out-competed the other grasses in all the vegetative attributes measured in the field. It also had the highest aboveground biomass production and thus was the most profitable grass for range reseeding enterprise in the southern rangelands of Kenya.

5.3 RECOMMENDATIONS

The following are some of the recommendations arising from this study:

- To spearhead seed production for pasture improvement, agro-pastoralists should be encouraged to bulk grass seed on-farm. This is because the seed quality from on-farm currently is as good as any seed from on-station. Further, studies on how to improve the quality of range grass seeds should continue with the aim of coming with certified grass varieties suitable for the southern Kenya rangelands.

- *Cenchrus ciliaris* should be promoted as a grass species of choice for reseeding in the semi-arid areas of southern Kenya. However, studies on how to improve the performance of the other three grasses should be undertaken especially for *Eragrostis superba* which recorded the lowest performance even though it was the most preferred species by farmers.

- To increase the success of range reseeding activities in the southern rangelands, the use of micro-catchments such as Kiboko range pits and ox-furrows should be employed as both are economically feasible. The Kiboko range pits are more suitable for reseeding smaller acreages (≤ 1) since they are more labour intensive as compared to ox-furrows which are easily made by an ox-plough and therefore bigger acreages can be covered.

- Studies on competitive interactions among grass species should be done for a longer period to conclusively ascertain the seasonal competitive interactions among the grass species.

5.4 STUDY LIMITATIONS

The findings in this study apply to the study area and may not necessarily represent all similar areas because of the temporal and spatial variations in environmental (mainly edaphic and climatic) and anthropogenic factors within the rangelands. The study also covered only one growing season and does not capture seasonal variations, which can be quite large in a range setting.

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