

**IMPACT OF GRASS RESEEDING TECHNOLOGY ON REHABILITATION OF
THE DEGRADED RANGELANDS: A CASE STUDY OF KIBWEZI DISTRICT,
KENYA**

BY

MGANGA KEVIN ZOWE

(BSc. Range Management)

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COLLEGE OF AGRICULTURE AND VETERINARY SCIENCES
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DECLARATION AND APPROVAL

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I, Mganga Kevin Zowe, hereby declare that the work contained in this thesis is my original work and has never been submitted for a degree in any other university.

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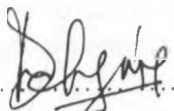
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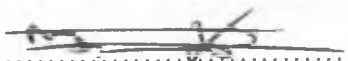
This thesis has been submitted with our approval as University supervisors.

Signed  Date 19/08/2009

PROF. NASHON K.R. MUSIMBA

Signed  Date 06/04/09

PROF. DICKSON M. NYARIKI

Signed  Date 19/08/2009

DR. MOSES M. NYANGITO

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DEDICATION

*This thesis is dedicated to
our family.*

My dear parents Mr. & Mrs. Mganga, sister Wakesho and niece Shighi.

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Asanteni sana.

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LIST OF ABBREVIATIONS AND SYMBOLS

ACZ	- Agro-climatic zones
ALDEV	- Arid Lands Development Board
ANOVA	- Analysis of Variance
ASAL	- Arid and Semi Arid Lands
a.s.l	- Above sea level
° C	- Degree Celsius
CBS	- Central Bureau of Statistics
CC	- <i>Cenchrus ciliaris</i>
CCD	- Convention to Combat Desertification
CF	- Crude Fibre
CLO	- Crown Lands Ordinance
CP	- Crude Protein
DM	- Dry Matter
E _o	- Average annual evaporation
EM	- <i>Enteropogon macrostachyus</i>
ES	- <i>Eragrostis superba</i>
FAO	- Food and Agriculture Organisation of the United Nations
FGD	- Focus Group Discussion
ft	- feet
g	- gram (s)
GoK	- Government of Kenya
ha	- Hectare
hr	- hour (s)
ICRAF	- International Centre for Research in Agroforestry
IFAD	- International Fund for Agricultural Development
ILRI	- International Livestock Research Institute
KARI	- Kenya Agricultural Research Institute
KEFRI	- Kenya Forestry Research Institute
KEMRI	- Kenya Medical Research Institute
Kg	- Kilogramme (s)
Kg/ha	- Kilogramme per hectare
KREMU	- Kenya Range Ecological Monitoring Unit
Ksat	- Saturated Hydraulic Conductivity
LARMAT	- Land Resource Management and Agricultural Technology
LUCID	- Land Use Change Impacts and Dynamics
m	- meter (s)
m/yr	- meters per year
min	- minute (s)
ml	- milliliter (s)
mm/hr	- millimeter per hour
NAP	- National Action Programme
NRO	- Native Reserve Ordinance
R	- Average Rainfall
RAE	- The Rehabilitation of Arid Environments

SPSS	- Statistical Package for Social Sciences
SSA	- Sub Saharan Africa
UNCCD	- United Nations Convention to Combat Desertification
UNDP	- United Nations Development Programme
UNEP	- United Nations Environmental Programme
USA	- United States of America
USCCTP	- United States Climate Change Technology Program
USDA	- United States Department of Agriculture
WMO	- World Meteorological Organisation

ABSTRACT

A study was undertaken at Kibwezi division of Kibwezi district to investigate and evaluate the practice and success factors responsible for the range rehabilitation work undertaken by the Dryland Husbandry Project (DHP) in conjunction with local communities. The work involved the identification of most frequently used grasses, through visits and discussions with community groups and key informants.

The general objective of this study was to contribute to greater understanding of the land degradation problem in the drylands and the grass reseeding technology used in addressing the problem. Improvement in soil hydrological properties; increased infiltration, reduced runoff and sediment production and percentage ground cover were used to measure success in rehabilitation. A regression analysis was used to establish the primary contributors of land degradation in the study area. The identified grass species whose seed were available were tested for germination viability, established in field plots and monitored from germination, vegetative stage and early seed development. Three sites; two under rainfed and one under irrigation, were employed to test the reseeding capacity of the three grasses seeds commonly used for rehabilitation in the area: *Cenchrus ciliaris*, *Enteropogon macrostachyus* and *Eragrostis superba*.

Seed viability tests results showed that *Enteropogon macrostachyus* had the highest percentage germination under all treatments. Under controlled laboratory conditions, at 20°C, it had a percentage germination of 46%, whereas both *Cenchrus ciliaris* and *Eragrostis superba* had 0% percent germination. A repeat of the same experiment under the same conditions at 20°C after 9 months showed higher seed germination in all the three grass species. *Enteropogon macrostachyus* had the highest percentage germination of 85%, whereas *Cenchrus ciliaris* and *Eragrostis superba* had a percent germination of 40% and 21%, respectively. Under room temperatures of 30°C, in the study area, *Enteropogon macrostachyus* had the highest percentage seed germination of 53%, whereas *Cenchrus ciliaris* and *Eragrostis superba* had 12 and 10%, respectively. The differences observed among the grass species in terms of percent seed germination may

be explained by the intrinsic properties of the seeds such as dormancy and tegumental hardness, and climatic factors especially ambient temperatures.

Increasing grass height improves the soil hydrological properties. That is, there was a general increase in the infiltration capacity, a decrease in runoff and sediment produced with an increase in grass height. *Cenchrus ciliaris* had a greater influence in increasing the soil infiltration capacity and reducing runoff. *Enteropogon macrostachyus* and *Eragrostis superba* were ranked second and third, respectively. Established grasses positively influenced on the soil physical properties, for example, bulk density.

Plots under *Enteropogon macrostachyus* had the highest percentage plant frequency, basal cover, plant and tiller densities compared to the other plots. Plots under *Cenchrus ciliaris* and *Eragrostis superba* were ranked second and third, respectively for the same vegetation attributes. Biomass yields on dry matter basis varied across the different stages of development. *Enteropogon macrostachyus* had higher biomass yields at the early vegetative stages while plots under *Eragrostis superba* and *Cenchrus ciliaris* were ranked second and third, respectively. At the seed setting stage, *Cenchrus ciliaris* had the highest biomass yields followed by *Eragrostis superba* and *Enteropogon macrostachyus*. Plots under *Eragrostis superba* had the highest seed production compared to plots under *Cenchrus ciliaris* and *Enteropogon macrostachyus*.

Seventy six percent (76%) of the farmers interviewed practice grass reseeding as a means of rehabilitating their degraded individual farms. *Eragrostis superba* is the most preferred species, primarily due to its role in improving livestock productivity. *Cenchrus ciliaris*, *Chloris roxburghiana* and *Enteropogon macrostachyus* were ranked second, third and fourth, respectively. Other uses of the grasses include; sale of hay and grass seed as a source of income, thatching of houses and granaries, and soil conservation. Most of the farmers prefer sowing the grass seeds as pure stands as opposed to mixtures. Hand sowing along micro-catchments created by hand held hoes and/or ox-driven ploughs is the most preferred method of sowing grass in the study area. However, broadcasting is also practiced. Reduction of grass cover was cited to be the most important form of

visible land degradation in the area. Increase in woodland vegetation, livestock numbers and cultivated area were the most significant contributors to the current vegetation change.

The important factors favoring range rehabilitation through reseeding in the area include sufficient amount of moisture, creation of micro-catchments, use of the indigenous grass species and proper seed bed preparation. The main conclusions in this study were: sufficient moisture is the most critical ecological factor which contributes to successful reseeding, established grass stands improve soil physical, hydrological and chemical properties, grass mixtures give better cover compared to pure stands and that human factors as opposed to climatic factors are the most important contributors to land degradation in the study area.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE PROBLEM

Land degradation according to UNCCD (2003), is the reduction of the soil's capacity to produce in terms of quantity and quality of goods and services. It can also be defined as the diminution or loss of biological or economic productivity, which includes deterioration of soil, vegetation and water, and is by one or a combination of processes acting upon land. Bull and Allison (2001) attribute these processes to climatic variations, human activities, or a combination of the two. The United Nations Convention to Combat Desertification (UNCCD) defines desertification as a process of land degradation in the arid, semi-arid and dry sub-humid areas, resulting from various factors including both climatic variation and change in human activities. Land degradation occurs in the forms of impoverishment and depletion of vegetative cover, loss of biophysical and economic productivity through exposure of the soil surface to wind and water erosion, salinization and water logging leading to deterioration of physical, chemical and biological soil properties.

The drylands of the world, comprising the hyper-arid, arid, and semi-arid regions with annual moisture deficits greater than 50% are considered the most threatened by land degradation. These drylands are estimated to cover 47% of the earth's surface (GEF/IFAD, 2002). In these areas land degradation of which desert encroachment is only a small part, is widespread and thus very important. In addition, the wetland enclosures in the drylands are affected by desertification through deforestation and subsequent erosion of soils and loss of soil nutrients. The semi-arid to weakly arid areas of Africa are particularly vulnerable as they have fragile soils, localized high population densities and generally a low input form of agriculture. Africa is particularly threatened because the land degradation process affects about 46% of the continent (WMO, 2005). It has been estimated that approximately 30-40% of Kenya's arid and semi-arid lands are quickly degrading and that another 2% has completely been lost through this process (Keya, 1991). In Kenya, high rates of soil loss upto 50 tonnes per hectare per year from degraded

grazing lands in semi arid areas are common (Nyangito *et al.* 2009). According to Nyangito *et al.* (2009) grazing contributes about 34.5% of the total soil degradation.

Although some land degradation is attributable to natural causes (climate change, droughts, and localized weather events), a substantial part can be attributed to human activities. Drylands are characterized by limited availability of arable land, limited and highly variable rainfall and scarcity of water resources. The demands placed on land and water resources by rapidly expanding populations, through agricultural intensification, urbanization and industrialization have combined to intensively exploit these natural resources. Moreover, resource use strategies are largely exploitative leading to land degradation. The principal causes of degradation in the drylands are:

- Removal of vegetation through: cutting and uprooting trees and shrubs, ploughing previously uncultivated and marginal land for annual cropping and overgrazing natural rangelands.
- Intensification of cultivation using inappropriate cultural practices that degrade soil fertility and encourage erosion, and overuse of irrigation that leads to poor drainage, water logging, rising water-tables and salinization.

Overgrazing and deforestation removes the vital soil cover, exposing the soil to erosion. Over-cultivation which refers to the cropping of the land without replenishing the plant nutrients exhausts the soil, destroying its structure and fertility. The reduction of land productive potential through degradation is not only linked to destructive human activities, but also associated with human-induced global warming and climate change on a worldwide scale (GoK/NAP, 2002; UNCCD, 2003). The destruction of forests that are important carbon sinks contribute to higher CO₂ concentrations in the atmosphere thus global warming.

Reseeding can be described as the process of introducing new seed to replenish a depleted seed bank. Grass reseeding technology has been used successfully as a means of

rehabilitating degraded rangelands in East Africa (Jordan, 1957; Bogdan and Pratt, 1967, Musimba *et al.* 2004), thus reversing the degradation process. From the above, increased trends of land degradation is threatening the livelihoods of the drylands people. These drylands are home to a large percentage of people affected by endemic poverty. In an effort to address this situation, grass reseeding technology has been tried. The grasses used were not only those adapted to the local environmental conditions, but also native and indigenous to the degraded area. In the current study, the grass reseeding technology used by the Kamba agropastoralists was validated and documented. Furthermore, the ecological factors contributing to successful reseeding and range rehabilitation were also determined.

1.2 THE PROBLEM STATEMENT

The problem of land degradation in drylands has continued to worsen over the past two decades, therefore prompting the need for better understanding of the causal pathways and to develop more effective approaches to sustainable management of the vast dryland ecosystems (UNCCD, 2003). The problem has increasingly attracted more attention in the recent past than before, probably because of its widespread and the very fact that it undermines the United Nations Agenda 21, a multifaceted blue print for achieving sustainable development worldwide. According to IFAD (2001), one quarter of the earth's surface, an area covering 3.6 billion hectares, is threatened by the problem of degradation. Since 1990, six million hectares of productive land is being lost annually. Land degradation is both a cause and consequence of rural poverty, that is, degradation leads to poverty and poverty leads to further land degradation in a vicious cycle.

Kenya's rangelands, which form a vast part of the Arid and Semi-Arid Lands (ASALs) cover over 80% of total land surface (Herlocker, 1999; GoK/NAP, 2002) and are no exception to the widely documented threat of land degradation. The rangelands in Kibwezi district are going through a period of profound change that is posing a very great threat to their productivity. Rapid population growth and the migratory trends from the high potential areas to these fragile ecosystems has increased the population density

intensifying pressure on the land and heightening the risk of degradation of the soils and vegetation. The woody species are quickly replacing the more preferred grassland vegetation. Overgrazing, common in the study area, leaves the soil unprotected from the disastrous impact of the sun, wind and flash floods, has accelerated land degradation in Kibwezi district. The degradation of the soil and range resources has reduced the supply and these resources to fulfill the basic household needs e.g. water and food. Land degradation in other ASAL districts of Kenya is also clearly documented by various authors: In Kajiado (Krugmann, 1996), Marsabit (Keya, 1998) and Baringo (Johansson and Svensson, 2002). Land degradation has become a global problem (IFAD, 2001). Rehabilitating the Kenyan rangelands, therefore, calls for strategic interventions to arrest this worrying trend.

1.3 JUSTIFICATION

Land degradation is a global problem facing us today. It requires immediate global attention. The problem of land degradation can be reversed through revegetation, for example through grass reseeding technology. However, restoration technologies are generally unreliable in arid and semi-arid environments where precipitation is highly unpredictable. There is need therefore to come up with appropriate and effective methods and technologies to combat the land degradation process through revegetation. It should be noted however that technologies which have succeeded in one area are not necessarily appropriate in all the other areas. Proper scrutiny is required before adoption.

Rehabilitation can be described as a re-engineering process that attempts to restore an area of land back to its natural state after it has been damaged as a result of some sort of disruption. Rehabilitation using grass reseeding technologies have been employed successfully in low rainfall areas around the world. For example, Thar Desert in India, which receives an average annual rainfall of 100-500mm (Sinha *et al.* 1997), Cholistan Desert in Pakistan, which receives an average annual rainfall of 100-250mm and the semi-arid parts of Baringo district in Kenya, which receives an average annual rainfall of between 300-700mm. This is because, grasses have good self seeding ability, so that with

proper management, they can establish and spread quickly to give a good cover. Grasses that have been used with good results in reseeded Kenya and other East African countries are local indigenous species (Mnene, 2005).

Despite the widespread success of grass reseeded technologies in combating land degradation, there is need to research on the multi-dimensional benefits derived from the grasses used for rehabilitation. This is of great importance because most of the farmers will tend to practice rehabilitation technologies in their individual lands, if they can derive additional benefits from it, other than just combating the land degradation problem.

This case study authenticates the role of grass reseeded technology in combating land degradation in Kibwezi district, Kenya and also establishes the multi-dimensional benefits of the grasses used for rehabilitation among the Kamba agropastoral community. The variability of climate in the study area that makes the success of the technology unpredictable further necessitated site specific evaluations.

The findings of this study will help ameliorate the livelihoods of the Kamba community in Kibwezi district that are predominantly agro-pastoralists as rehabilitated areas will increase the resource base of the local community and enable them increase the area under cultivation. In addition, reseeded areas will provide a reliable source of forage for livestock, thus improving food security among the Kamba community in Kibwezi district. The grasses evaluated in this study were *Cenchrus ciliaris*, *Enteropogon macrostachyus* and *Eragrostis superba* which are not only adapted to the local environment conditions but are also native and indigenous to the study area.

1.4 OBJECTIVES

The general objective of this study is to contribute to greater understanding of land degradation process in the drylands and the technologies for addressing it.

The specific objectives of the study were to:

1. Determine the ecological factors which contribute to successful reseeding in the study area.
2. Evaluate the grass reseeding rehabilitation technology in the study area.
3. Establish the chronology of primary production attribute changes of the grass species used in range rehabilitation.
4. Establish the rate of degradation and find out whether this can be linked to human settlements among other factors in the study area.

1.5 HYPOTHESES

The following hypotheses were tested:

1. H_A : Pure grass stands as opposed to grass mixtures give the best rehabilitation results in the study area.
2. H_A : Land degradation in the study area can be attributed more to human settlements than any other factor.

CHAPTER TWO

LITERATURE REVIEW

2.1 LAND DEGRADATION

Land Degradation implies reduction of resource potential by one or a combination of processes acting on the land. These processes include water erosion, wind erosion and sedimentation by those agents, long-term reduction in the amount or diversity of natural vegetation and salinization and sodication. Degradation of natural vegetation is a worldwide phenomenon (Visser *et al.* 2007). It is also described as the aggregate diminution of the productive potential of the land, including its major uses (rainfed, arable, irrigation and rangeland), its farming systems (e.g. small-holder subsistence) and its value as an economic resource. This link between land degradation and its effect on land use is central to nearly all published definitions of land degradation. A degraded land can be defined as land which due to natural processes or human activity is no longer able to sustain properly an economic function and/or the original ecological function. Under the United Nations Convention to Combat Desertification (UNCCD), desertification is defined as land degradation in arid, semi-arid and dry sub-humid areas, resulting from various factors including climate variations and human activities (IFAD, 2001). These areas cover 40% of the Earth's surface (IFAD, 1998). Arid and semi-arid areas are defined as areas falling within the rainfall zones of 300-560 mm and 450-900 mm, respectively (Biamah, 2005). These areas are characterised by short growing periods (1-74 and 75-119 growing days, respectively), thus are not suitable for cultivation. Rainfall patterns are unpredictable and are subject to great fluctuations. Land degradation occurs under a wide variety of conditions and environments. Nevertheless, some environments are more at risk of degradation. Dryland ecosystems are vulnerable to over-exploitation and inappropriate land use.

The problem of land degradation is difficult to grasp in its totality. The use of indicators of degradation is more appropriate to use in trying to understand the land degradation problem. Indicators are variables which may show that land degradation has taken place and are not necessarily the actual degradation itself. According to USCCTP (2005), the

indicators of land degradation include poor soil cover, dominance of undesirable plant species, low soil quality, or in the extreme, erosion of top soil. According to Snel and Bot (2005), the indicators of land degradation can be grouped into 3 broad categories; biophysical indicators (degradation of soil, water and vegetation cover), socio-economic indicators (poverty and food insecurity) and institutional indicators (failures in the public/government, private/market, civil/community sectors and civil strife). Furthermore, degradation is normally evident in a decline in productivity, a loss of biodiversity and an increasing rate of erosion (Visser *et al.* 2007). It is also possible to conclude that rangeland degradation from excellent to poor under arid and semi-arid conditions results in a subsequent but proportional increase in dominance of unpalatable, undesirable (increasers) and invader species over the desirable (decreasers) vegetation types (Kassahun *et al.* 2008). However, the condition of the soil is one of the best indicators of land degradation since it integrates a variety of important processes particularly; vegetation growth, overland flow of water, infiltration, land use and management.

The causes of land degradation in the arid, semi-arid and sub-humid climate are many and varied. Climate plays a part. Typically rainfall is low and unpredictable. The type of soils and nature of the terrain may add to the land's vulnerability. However, the most important contributor to land degradation in these areas is the use made by people of these lands i.e. although some land degradation is attributable to natural causes (climate change, droughts, and localized weather events), most of it can be attributed to human activities. Land degradation and erosion are closely associated with human activities on rangelands (Farahpour, 2003). Some researchers consider climate to be the major contributor to the degradation processes, with human factors playing a relatively minor supporting role. Other researchers reverse the significance of these two factors. A third group of researchers blame climate and man more or less equally (Glantz and Orlovsky, 1983). Processes that lead to land degradation involve complex interactions between societal factors e.g. poor land management and increasing population pressures, and natural climatic factors e.g. cyclical and short-term droughts. The most frequently recognized main causes of land degradation are:

- Overgrazing of rangelands,
- Over-cultivation of croplands.
- Water logging and salinization of irrigated lands
- Deforestation, and
- Pollution and Industrial causes.

Overgrazing and deforestation removes the vital soil cover, exposing the soil to erosion. Over-cultivation which refers to the cropping of the land without replenishing the plant nutrients exhausts the soil, destroying its structure and fertility. Poorly drained irrigation systems makes the soils salty, waterlogged and unproductive (IFAD, 1998). USCCTP (2005) indicates that land degradation is usually the result of inappropriate management, especially during periods of extended droughts or unusual weather conditions. Continuous population growth boosts land degradation and thus conversion of ecosystems such as forests and rangelands into less productive lands have resulted to land degradation and loss of valuable land (Farahpour, 2003). However, high population density on its own is not necessarily related to land degradation. Rather it is what the population does to the land that determines the extent of land degradation. People can be a major resource in reversing a trend towards degradation (WMO, 2005). In this study range reseeding technology is one among the many strategies used to reverse rangeland degradation.

2.2 COMBATING LAND DEGRADATION IN KENYA

Kenya has a long history of activities to combat desertification and mitigate the effects of drought dating back to 1940's. The Kenyan government, just like other governments and development agents in the world, has made many attempts to rehabilitate degraded arid and semi-arid rangelands. The general aims of restoration are, in most cases, to increase vegetation cover, increase biodiversity and to increase the production potential for improved grazing capacity (Bakker *et al.* 1996). The Kenyan government aimed at trying to reverse the trend of loss of vegetation cover, which in turn leads to loss of soil fertility and soil erosion. Soil erosion is the single most visible and notorious form of environmental degradation in the study area. Over the past three to four decades, semi-arid environments in Kenya have experienced some unprecedented soil degradation due

to an ever increasing human and livestock population (Biamah, 2005). Ironically, it is also probably the most reversible, that is, the most responsive to restoration and rehabilitation. Past experiments in range management and land rehabilitation (e.g. research and project reports from Baringo, Machakos and Kitui districts from the 1930s to present) suggest that many of the degraded sites, if fenced and protected, are likely to recover rather quickly and dramatically. Until such measures are taken, however, many areas will produce less fodder, food, and other goods and services essential to rural life.

Community based rehabilitation processes have rarely been successful and often undocumented. Herlocker (1999) cited a case study from Samburu district, Kenya as an example of this. Bogdan and Pratt (1967) have also highlighted some rehabilitation work in the early post independence days of Kenya. Several bodies including governmental, inter-governmental, non-governmental and donor agencies have been involved in community initiatives to combat land degradation and mitigate the effects of drought in Kenya. For example, the Reclamation of Arid Environments (RAE) Charitable Trust is a non-profit making organization, which works in the drylands of Kenya, with the aim of reclaiming denuded drylands. It has been able to reclaim degraded areas in Baringo District, using grass reseeding technology.

The African Land Development Board (ALDEV) was created in 1946 to address the serious effects of land degradation. The Kenya Rangeland Ecological Monitoring Unit (KREMU) was established in 1975 to monitor ecological changes in the drylands. The GoK/NAP (2002) report observes that most activities to combat desertification have fallen short of the desired expectations because of among other reasons sectoral approach, uncoordinated funding, inadequate policies and inadequate involvement of the local communities. In addition to this, the GoK/NAP (2002) report points out that it is important to take into account the historical background and take cognisance of the lessons learnt in the past attempts to combat land degradation in Kenya.

The management of Kenya's drylands has been guided by several cross-sectional policy instruments most of which came to force long before Kenya ratified the Convention to

Combat Desertification (CCD). Kenya ratified the convention in 1997 with the view of joining the World Community to combat desertification (GoK/NAP, 2002). Some of the policy instruments include:

- Swynnerton Plan of 1954
- Sessional Paper No. 10 of 1965 on African Socialism and its Application to Planning in Kenya.
- District Focus for Rural Development (1982).
- Sessional Paper No. 1 of 1986 on Economic Management for Renewed Growth.
- Development Policy for Arid and Semi-arid Areas of 1992.
- National Environmental Action Plan of 1994.
- Sessional Paper No. 1 of 1994 on Recovery and Sustainable Development of the year 2010.
- National Development Plans for 1974-1979, 1980-1984, 1985-1989, 1990-1992, 1993-1997 and 1998-2002.
- Sessional Paper No. 6 of 1999 on Environment and Development.
- Poverty Reduction Strategy Paper of 2001.
- National Policy for the Sustainable Development of Arid and Semi arid Lands of Kenya of 2004

Of the mentioned policy instruments, the following have had the greatest impact.

2.2.1 THE SWYNNERTON PLAN OF 1954

During the colonial period, much of Kenya was divided into independent reserves and high potential areas for colonial settlement agriculture. The persistent low productivity on the reserves and a growing political insurrection in some parts of Kenya led to a liberal proposal for land-tenure reform, which continues to shape the evolving landscape in Ukambani and all of Kenya. The Swynnerton Plan of 1954 was supposed to address African land problems by reforming land tenure, consolidating fragmented holdings, issuing freehold title, intensifying and developing African agriculture, providing access to credit, and removing restrictions on growing crops for export (Bradshaw, 1990). It consisted of a three-phase programme: (1) land adjudication to "phase out" customary

tenure; (2) land consolidation into one block per household to eliminate small, dispersed parcels, to allow greater specialization, and to realize economies of scale in cash crop production; and (3) land registration to provide for security of ownership and to establish a land market. Overall, the aim was to facilitate increased investment and employment in agriculture and to increase rural incomes and the "productivity" of land (Okoth-Ogendo, 1991). The plan was predicated on an assumption that explicitly "successful" or wealthy African farmers would "be able to acquire more land and bad or poor farmers less, creating a landed and a landless class" (Swynnerton 1955, 10, cited in Wangari 1991).

The Swynnerton plan emphasized the need to de-stock the pastoralists in the marginal areas and introduce grazing control. In addition, it also aimed at providing the African farmer with secure title to private property so as to encourage him invest his labour and profits into the development of his farm. This minimized the destruction of the environment thus combating the land degradation problem.

2.2.2 SESSIONAL PAPER NO. 10 OF 1965 ON AFRICAN SOCIALISM AND ITS APPLICATION TO PLANNING IN KENYA

This Sessional Paper was drafted immediately after independence to facilitate the so called Africanization of the Kenyan economy and public service. It was aimed at ensuring a rapid economic development and social progress for all Kenyans. In the phrase "African Socialism," the word "African" was not introduced to describe a continent to which a foreign ideology was to be transplanted. It was meant to convey the African roots of a system that was in it African in its characteristics. African Socialism is a term describing an African political and economic system that is positively African not being imported from any country or being a blueprint of any foreign ideology. The principal conditions the system had to satisfy were to draw on the best of the African traditions, be adaptable to new and rapidly changing circumstances and not rest for its success on a satellite relationship with any other country or group of countries.

Under African socialism, the power to control resource use resided with the state. Idle and mismanaged farms owned by the Kenyan citizens or foreigners were not permitted. Production and yields were also influenced by government extension officers and

research. All this ensured the conservation of our heritage for the future generations through the adoption and implementation of policies designed to conserve natural resources.

2.2.3 THE NATIONAL POLICY FOR THE SUSTAINABLE DEVELOPMENT OF ARID AND SEMI ARID LANDS OF KENYA, 2004

This policy document was formulated through a participatory and consultative process, which was spearheaded by Arid Lands Resource Management Project and United Nations Development Programme, UNDP. The process involved relevant stakeholders including government departments, research institutions e.g. ILRI, KARI, KEFRI, ICRAF, KEMRI, among others. The objective of the policy is to provide a coherent and practical framework for the implementation and realization of a new vision for ASAL development in Kenya. This policy reflects the Government's commitment to overcome challenges facing the Arid and Semi arid lands and was aimed at reversing the negative trends prevailing in the ASALs e.g. land degradation, in order to uplift the socio-economic welfare of ASAL inhabitants. According to the policy document, one of the weaknesses of common land tenure is that it does not confer adequate incentives and sanctions for efficient utilisation and management of common property resources, which leads to what is commonly referred to as the "tragedy of the commons". In trying to address this challenge, the policy seeks to improve ASAL land tenure and land use policies.

2.3 RANGE RESEEDING

Range reseeding is not new in Kenya (Mnene, 2005). Reseeding can be described as the process of introducing new seed to replenish a depleted seed bank. During the 1950's and 1960's, a number of reseeding techniques were developed and introduced for rangeland rehabilitation. Rehabilitation can be described as a re-engineering process that attempts to restore an area of land back to its natural state after it has been damaged as a result of some sort of disruption. Some had the options of pitting and re-seeding or over-sowing (Mnene, 2005). Some techniques were tried in several districts such as Machakos, Taita-Taveta, Baringo and Kitui. Much later Bekure *et al.* (1991) demonstrated some of the same approaches in Kajiado district, but it was 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 (*Olopololis* in Maasai).

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. In addition, restoration technologies are unreliable in environments where precipitation is unpredictable. Rangeland climates are characterised by large spatial and temporal variations in rainfall. The moisture conditions suitable for active growth are usually short-lived, unpredictable in many instances (De Groot *et al.* 1992). 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 should not be attempted in areas with less than 300 mm of average annual rainfall because they are apt to fail. Mnene (2005) reported that when a seed stock is healthy, only two environmental factors will stop it from germinating and establishing in the semi-arid rangelands, namely soil type and moisture. Apart from soils and rainfall, other factors including human interventions (burning and grazing) and individual species physiological differences affect germination and subsequent growth. For example, seed weight plays a role in this process. Relatively small seeds would have a lower germination potential than the fully developed ones, which are often larger. Another example is seed dormancy, a natural mechanism for a species' perpetuity by ascertaining conditions just right for seed germination. Seed dormancy varies between species (Mnene, 2005).

Successful reseeding has however been made in low rainfall areas e.g. Thar Desert in India where the rainfall ranges between 100-500mm annually, 90% of which is received between July and September (Sinha *et al.* 1997). This is only achievable with water management. Water harvesting techniques such as pitting, contour furrows and trenches are important for the creation of both micro-catchments and macro-catchments. In Burkina Faso, farmers carve half-moon shaped micro-catchments in checkerboard

fashion along the slopes of their land, situated in such a way as to capture and retain rainwater (IFAD, 2007). Half-moons are used to:

- Rehabilitate degraded land for crop cultivation and fodder production
- Conserve water and fertile soil
- Improve soil fertility, with the addition of compost
- Expand cultivated areas, and
- Improve the infiltration and stock of water in the soil.

Such techniques are used in reducing run-off, thus ensuring that the grass seeds get enough water for a prolonged period of time thus improving their chances of germination and establishment.

The primary purpose of range reseeding is to improve existing ground cover and biomass to an extent or in a manner not possible by grazing management alone (Pratt and Gwynne, 1977; Makokha *et al.* 1999). This can be accomplished by;

- 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, 2005; Opiyo, 2007).

The ecological stresses in dryland ecosystems, especially low and unpredictable rainfall amounts, are so acute that ecosystem recovery through the process of natural secondary succession is likely to be very slow, thus would require some external input such as reseeding of native grass species to accelerate the rehabilitation process. Range reseeding involves reseeding of denuded land by the seeds of superior plants, or the establishment of completely new pastures, with or without the aid of irrigation (Bogdan and Pratt, 1967). Native grasses are more successful in reseeding degraded rangelands (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. These rangeland rehabilitation methods have been tried in many parts of Kenyan rangelands. It was observed that the chance of establishment depends much on site conditions, soil type and rainfall amount (Opiyo, 2007).

Rangelands reseeding in most cases require soil disturbances. This help in replenishing deficient plant species or introducing new ones by allowing seed penetration to the ground through provision of conditions suitable for germination, emergence and subsequent establishment of the species (Singh, 1987). Different methods are used to prepare a degraded range area for reseeding. Some of these methods include seed bed preparation and soil disturbance. All of these methods involve some form of rain water harvesting or the building of micro-catchments. This ensures that all available moisture is utilised effectively to increase water penetration and slow run-off. 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. 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).

For the many attempts made in Kenya to restore grass cover through seeding, it has been learned that the fundamental requirements of success are:

- An appreciation of the ecological potential of the site.
- Grasses suitable for reseeding purposes and sufficient seed of adequate quality.
- The integration of the seeding operation into an overall land-management policy, embracing grazing and bush control where necessary.
- Some form of seedbed preparation and a degree of seed protection in keeping with site requirements.
- A period of complete rest from grazing after reseeding.
- Reasonable rains during the establishment season (Opiyo, 2007).

2.4 RANGE GRASSES FOR RESEEDING

Range grasses have evolved adaptive mechanisms for survival (Opiyo, 2007). According to Bogdan (1958), local grasses should always be used for reseeding in preference to introduced, exotic species. The grasses that have given best results in East Africa are all

local grasses (Pratt and Gwynne, 1977). Only local species have proven to be the most successful (De Groot *et al.* 1992; Opiyo, 2007). Perennial grasses are preferable to all other plants, except in eco-climate zone VI, where the rainfall is mostly too low to support perennials and where annual grasses are favoured (Pratt and Gwynne, 1977). Perennial grasses have the ability to survive dry seasons and regenerate with each rain to produce fresh growth from the original rootstock. According to Mnene (2005), perennial grasses have good self-seeding ability so that with proper management, they can establish and spread quickly to give good cover. Although perennials may produce seed every season, they leave for a few to several years.

The choice of grass for reseeding should be based on the following: it must be sufficiently drought tolerant to survive and perpetuate itself, and provide a good quantity of herbage of fair or good grazing value (Mnene, 2005). It should also produce adequate amount of viable seed, which can be easily harvested, and easy to establish (Mnene, 2005; Opiyo, 2007). In addition to these characteristics, tolerance to grazing and the ability to establish fast during spells of favourable climatic conditions are very important traits in choosing grass species for reseeding (Jordan, 1957). According to Pratt and Gwynne (1977), six grass species which have been useful in reseeding include: *Cenchrus ciliaris*, *Chloris gayana*, *Chloris roxburghiana*, *Cynodon dactylon*, *Enteropogon macrostachyus* and *Eragrostis superba*. Others grass species which have been tried for reseeding grazing rangelands in Kenya are: *Eragrostis trichodes*, *Eragrostis bicolor*, *Chloris virgata*, *Cymbopogon caesius*, *Dactyloctenium aegyptium*, *Panicum coloratum*, *Sorghum sudanensis* and *Sporobolus pyramidalis*. The grasses selected for this study are discussed below.

2.4.1 *Cenchrus ciliaris* L.

Cenchrus ciliaris is a persistent tufted perennial which occurs in a wide variety of types, some of which have become reputed cultivars (strains or varieties in cultivation) (Pratt and Gwynne, 1977). Numerous cultivars have been created in order to improve productivity and vigor in extreme conditions of drought, disease, frequent fire and other factors (Duke, 1983). This species has a variety of common names depending on where

it is found. For example, the grass is referred to as Buffel grass (Australia), African foxtail (USA, Kenya) and Anjan grass, Koluk katai, Dhaman (India). It belongs to the C₄ photosynthesis type (Bogdan, 1977).

It 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. Leaf blades are linear, 2-13mm wide and 3-30cm long; green, blue green to grey green in colour, scabrous, mostly glabrous and sometimes hairy at the base. Panicle is erect or nodding, straw normally grey or purple coloured, bristly, false spike, 2-15cm wide, with seed units or fascicles inserted along a zigzag axis. Each bur-like fascicle comprises a single spikelet or cluster of 2-4 spikelets, 3.5-5mm long, surrounded by an involucre of bristles of various lengths up to 16mm long. The bristles are barbed and hairy, giving the fascicle an adhesive quality. Seeds disperse profusely by clinging to animal fur, similar to other *Cenchrus* species, i.e. *C. longispinus*, which have spiny seeds. *C. ciliaris* seed is lighter than the sand burs, has barbed bristles and may disperse by wind as well (Morisawa, 2000). *Cenchrus ciliaris* has a deep strong fibrous root system that exceeds 2m. It is a particularly aggressive grass, by virtue of its extensive root system competing with associated species for water and nutrients. It also appears to be allelopathic (suppression of other species by exudation of phytotoxic chemicals that inhibit germination and growth of other plants).

The grass is native to tropical and sub-tropical Africa (Bogdan, 1977). The species is well adapted to the hotter regions and enjoys wide distribution over the drier parts of India, Pakistan and South Africa. It is one of the most drought-tolerant of perennial grasses (Pratt and Gwynne, 1977). In Australia, it is considered among the best drought resistant grasses (Opiyo, 2007). According to Duke (1983), the grass species was probably introduced in Western Australia about 1870-1880. Currently, it has been widely naturalised in sub-humid and semi-arid tropics and sub-tropics. Though rare, it is possible for a free-seeding species to become a major pasture component simply by

spreading into relatively undisturbed native pasture from nucleus areas established by more traditional methods (Cameron, 1980). This is a very long-term undertaking in semi-arid areas as significant spread occurs only in very favourable seasons. *Cenchrus ciliaris* has this enviable ability on fertile, friable soils in inland Australia and is therefore widely sown, without cultivation, after pulling scrubs (Silcock, 1986).

Cenchrus ciliaris has been recommended for reseeding areas receiving 350-900mm of rain 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. It is a palatable and nutritious grass species (Farooq *et al.* 2003). *Cenchrus ciliaris* is preferred because it is highly nutritious forage for livestock and recovers well from grazing (Morisawa, 2000). It produces reasonable-quality hay when cut in the early flowering stage, yielding up to 2 500 kg/ha per cut with a protein content of 6-10% of dry matter. Dry matter yields depend greatly on soil fertility and growing conditions but is mostly in the range of 2-9 tonnes/ha and under ideal conditions upto 24 tonnes/ha. Seed yield ranges between 10-60 kg/ha of clean seed per harvest.

The species often occurs in the wild on sandy soils, but is also well adapted to deep, freely draining sandy loams, loams, clay loams and red earth soils. It requires good soil fertility, particularly with respect to Nitrogen, Phosphorus and Calcium. Phosphorus (P) levels should be > 10mg/kg and total Nitrogen (N) levels > 0.1%. The optimum soil reaction is pH 7-8, but grows on soils with pH as low as 5.5. It is very sensitive to high levels of soil Aluminium and Manganese. Apart from soil depth, rooting depth is also limited by high sub-soil salinity or sodicity and low pH of <5. However, it has a moderate tolerance of salinity. The grass has adaptation is limited to elevations of less than 2000 m throughout the tropics (Bogdan, 1977; Boonman, 1993). *Cenchrus ciliaris* occurs naturally in areas with average annual rainfall from as low as 100 mm upto about

1000 mm, but mostly between 300 mm and 750 mm. It does not survive prolonged water logging particularly in the cold season. In Australia, *Cenchrus ciliaris*, withstood 5-day flooding without any loss of plants and 20-day flooding with losses of 20–85%, depending on the cultivar (Anderson, 1970). For greater flood tolerance, Anderson (1970) recommends selecting taller varieties of *C. ciliaris*, and leaving the plants uncut/ungrazed shortly before the highest flooding period. In Kenya, the seeds are often destroyed by attacks of smut in wetter areas (Bogdan and Pratt, 1967). It occurs in areas with average annual temperatures ranging between 12-28° C. Optimum temperatures for photosynthesis in varieties measured is 35° C and minimum between 5-16° C.

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

Enteropogon macrostachyus is a widely distributed graminaceous species very common in arid areas where it grows in bush, in forest edges and to a lesser extent in open grassland (Jordan, 1957; Kitalyi *et al.* 2002; Opiyo, 2007). This grass species is well distributed throughout tropical Africa. In Kenya, it is abundant between Sultan Hamud and Voi (Bogdan and Pratt, 1967). It is a tufted annual or perennial. It is particularly suitable for reseeding rock slopes or bushland (Pratt and Gwynne, 1977). It has proved an excellent grass for reseeding the rangelands of Kenya under moderately dry conditions, as has been demonstrated in Baringo District, Kenya (Bogdan and Pratt, 1967). This species has been tried with moderate success for reseeding denuded pastoral land in Kenya (Kitalyi *et al.* 2002) under annual rainfall of 550-800mm. *Enteropogon macrostachyus* is a good grass for arid and semi-arid ecosystems because it is drought resistant. In Kenya, it is commonly referred to as bush rye, whereas in Zimbabwe it is commonly known as mopane grass.

This species has erected 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. Although stemmy, it is drought resistant and provides useful grazing for herbivores. The inflorescence is composed of racemes. Fertile

spikelets are sessile comprising of fertile florets, with diminished florets at the apex. Spikelets are elliptic, dorsally compressed, 7-10mm long.

Enteropogon macrostachyus occurs naturally in grasslands and rocky outcrops in semi-arid environments. It occurs from 300-1600m above sea levels in semi-arid areas of tropical Africa. The species occurs in areas receiving around 575mm of rainfall per annum. It is a very good seeder and seed can be collected rapidly by cutting the seed-heads or stripping the heads by hand (Bogdan and Pratt, 1967). It should lend itself easily to mechanical harvesting. The seeds germinate readily and grow vigorously. It is palatable thus its re-introduction in degenerated swards is of obvious value to grazers (Opiyo, 2007).

2.4.3 *Eragrostis superba* Peyr.

Eragrostis comes from the Greek words *Eros* meaning love and this possibly refers to the heart shaped spikelets; and *Agrostis* meaning grass. The species name *superba* is the Latin for splendid and is probably descriptive of the spikelets. *Eragrostis* is a cosmopolitan genus occurring mainly in the tropics and subtropics with over 350 species of which about 90 occur in southern Africa.

Locally, *Eragrostis superba* is commonly referred to as Maasai love grass. Its other common names are saw-tooth love grass (South Africa), Wilmann love grass (U.S.A) and Flat-seed love grass. This species occurs naturally in South Africa and northwards throughout East Africa to Sudan. 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. Also, it occurs in rocky and sandy grounds (Bogdan, 1958). It has been introduced into the USA, India and Australia.

This is a tufted perennial 20-120cm high (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 5-16mm 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 is advantaged by 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). It is a moderate tiller and its regrowth ability is poor when compared to *Cenchrus ciliaris* (L) and *Chloris roxburghiana* (Schult).

Eragrostis superba grows in disturbed places and thus has been used successfully for reseeding denuded lands (Bogdan, 1958). It has also been used for reseeding denuded pastoral land in Kenya (Pratt and Gwynne, 1977). The grass has excellent establishment characteristics. This species has also been used in soil erosion control. It has been successful in the semi-arid areas of East Africa particularly in eco-climatic zone VI where mean annual rainfall is about 500-900mm. The grass occurs from 0-2000m above sea level and doesn't grow below -11°C. *Eragrostis superba*, along with *Cenchrus ciliaris* have been the basis of the seed mixtures used for large-scale reseeding in Kitui, Machakos and Baringo in Kenya (Bogdan and Pratt, 1967). It is quick growing, shows green vegetative growth almost throughout the year and has good drought tolerance. It is very palatable when young. Chemical and digestibility analyses indicate that the grass has 12% crude protein (%CP) in the dry matter at an early-flowering stage with 30-35% crude fibre (%CF) (Bogdan and Pratt, 1967). Wasonga *et al.* (2003) reported that the Pokot community in Kenya has identified *Eragrostis superba* as one of the grass species suitable for fattening and improving the condition of their livestock herd. Depending on the management, it can give high yields. A dry matter of more than 24000 kg/ha per year under an eight-week cutting interval was obtained by Strickland (1973) at Stamford, Queensland. Under a four-week cutting regime the yield was approximately one-half. In Gujarat, India, 3104 kg green matter per hectare was recorded (Srinivasan *et al.* 1962).

The grass grows very easily from seed. The seeds of this species are in the form of a small, plump grain, which are particularly susceptible to insect damage. It can be grown in gravelly, sandy, loamy or clay soils. However, it prefers sandy soils but occurs also on

clay loams and clays. *Eragrostis superba* can also be found on termite mounds common in the arid and semi-arid areas. A medium-textured deep soil neither strongly acid nor strongly alkaline is preferred. It has a high tolerance to salinity and alkalinity and the seed will germinate well (Ryan *et al.* 1975). The grass seeds can be collected easily from open grassland or at roadsides by stripping the ripe panicles. Mature spikelets, each with numerous florets, detach easily with the caryopses enclosed.

2.5 METHODS OF ESTABLISHING SEEDED STANDS FOR RANGE REHABILITATION

2.5.1 RAINFED

Rainfall shows variability within the Eastern African region in both space and time (Herlocker, 1999). Pratt and Gwynne (1977) reckon that rainfall in Eastern Africa is highly erratic and unreliable in terms of amount, time and space. Rainfall variability from year to year causes significant differences in primary production. Therefore, reliance on rainfed establishment is risky and costly. However, with effective rainfall and water harvesting techniques, successful rehabilitation is possible.

2.5.2 IRRIGATING PASTURES: SPRINKLER IRRIGATION

Irrigated pastures can provide forage for livestock, be useful in breeding and calving time and conserve and improve soil and provide an alternative to rangeland (Young *et al.* 1994). Irrigation for grass stand establishment must be done cautiously until the seed has germinated and the seedling emerged. Any sealing or crusting of the soil surface prior to emergence will result in failure or poor stand establishment. Once irrigation is started, the soil surface must be kept moist by frequent light irrigations until the seedlings have emerged (Holzworth and Wiesner, 2006). The key to irrigating land is to fill the soil profile to a depth of four feet. Four feet of soil will hold approximately four inches of water and the plant will be able to extract 50% of the water in the soil before stressing. 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 of water per growing season (Young *et al.* 1994). However, the use of grass species that have a combination of traits for drought resistance

and persistence with reduced water may increase chances for survival during periods when irrigation may be restricted (Da Costa and Huang, 2004).

Sprinkler irrigation, also referred to as spray irrigation, is a method of applying irrigation water which is similar to natural rainfall. The main objective of a sprinkler system is to apply water as uniformly as possible to 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 so that it breaks up into small water drops which fall to the ground similar to rain drops. Friction between the air and the stream of water causes the stream to break apart into water droplets that fall to the surface, similar to rainfall (Smajstrla and Zazueta, 2003). Sprinkler irrigation systems are best suited to sandy soils with high infiltration rates although they are adaptable to most soils. Sprinklers also work better for shallow soils that require more frequent irrigation. According to Young *et al.* (1994), sprinkler irrigation has an advantage where the water supply is limited or expensive, the soil is shallow or sandy or the terrain is rough or steep. Different soil types require different irrigation schedules. However, for soils which easily form crusts, then a light fine spray is recommended. The irrigation interval for sands or sandy loams is much shorter than for fine textured soils (Young *et al.* 1994). Sprinklers systems are currently being used for a variety of crops such as fruit trees, vines and vegetables, broad acre crops and pasture, on a wide variety of soil types and topography (Qassim, 2003). The average application rate from the sprinklers (in mm/hr) is always chosen to be less than the basic infiltration rate of the soil so that surface ponding and runoff can be avoided.

2.5.3 ROLE OF MICROCATCHMENTS

Soil disturbance plays an important role in the success rate of restoration attempts (van den Berg and Kellner, 2005). This intervention has a number of ultimate effects: it promotes better root growth; enhance germination of seeds and establishment of seedlings; increase the soils water retaining capacity (Visser *et al.* 2007). These micro-catchments ensure that the grass seeds trapped enough water for a prolonged period of time thus improving the chances of the grass seeds to germinate and establish. Factors affecting germination and early seedling growth are often the primary determinants of the

distribution of adult plants (Snyman, 2004). Of the environmental factors, soil-water is the key limiting factor to seedling establishment in the semi-arid rangelands (Schellenberg, 1999).

2.6 THE SITUATION IN THE STUDY AREA

The Kambas are predominately agropastoralists. Agropastoralism is an example of a land-based livelihood. A large number of farmers in the study area favour mixed farming, that is, crop-livestock production systems. Most people in the study area are still dependant on land for their daily livelihood. The prospect for depletion of land and water resources will be amplified as long as the people remain dependant on land (LUCID, 2006). According to Diagana (2003), a central question to the sustainable agricultural debate in Sub Saharan Africa (SSA) is why many African farmers unsustainably exploit soils and water and why many do not adapt or adopt other seemingly superior and available technologies, but instead continue using practices that degrade water and soil resources.

Whereas people formerly concentrated around permanent groundwater sources or along perennial streams, widespread deforestation and soil compaction have led to the transformation of many permanent groundwater sources to seasonal supplies and have reduced perennial streams to intermittent flow. This has changed water quantity and quality and has radically altered the timing and terms of water availability for agriculture, livestock, and domestic use. Moreover, the changes in use pattern engendered by these effects have in turn caused further damage and disruption in watershed systems. For example, one of the rehabilitation sites in the study area, in Silanga Ngomano used to provide water for people, domestic animals and wildlife for many months has deteriorated due to silting of the natural water holes. Nyangito *et al.* (2008) attributes such land degradation to inappropriate land use practices especially overgrazing and debilitating droughts. Overgrazing, which leaves the soil unprotected from the disastrous impact of the sun and wind leads to accelerated land degradation (Lang, 1995). This problem is assumed to partly stem from the Tragedy of Commons (Hardin, 1968), prevailing aridity (Ellis *et al.* 1993) and the Cattle Complex phenomenon. Droughts are

recurrent in Arid and Semi-arid Lands (ASALs), occurring every 10-15 years (LUCID, 2006). The potential impact of these recurrent droughts has increased as the number of residents has increased, making the access to key resources become more competitive. On a more regular basis, the degradation of soil, water, forest, and range resources has reduced the supply and the quality of these resources to fulfill basic needs. Environmental degradation has also diminished the productive capacity of many local land-use systems, both for subsistence and for commercial purposes.

The three major problems in ASALs of Kenya are; land degradation, poverty and food insecurity. The land degradation problem has reduced the supply of range resources needed to fulfill the basic household needs of the Kamba agropastoralist community living in Kibwezi district. This study investigates the role of grass reseeded in improving the supply of range resources and subsequently fulfilling the basic household requirements of the Kamba community in Kibwezi district.

CHAPTER THREE

MATERIALS AND METHODS

3.1 STUDY AREA

This study was carried out in Kibwezi District, Kenya. Kibwezi district is a typical semi-arid district in Kenya mainly inhabited by the Kamba agropastoral community.

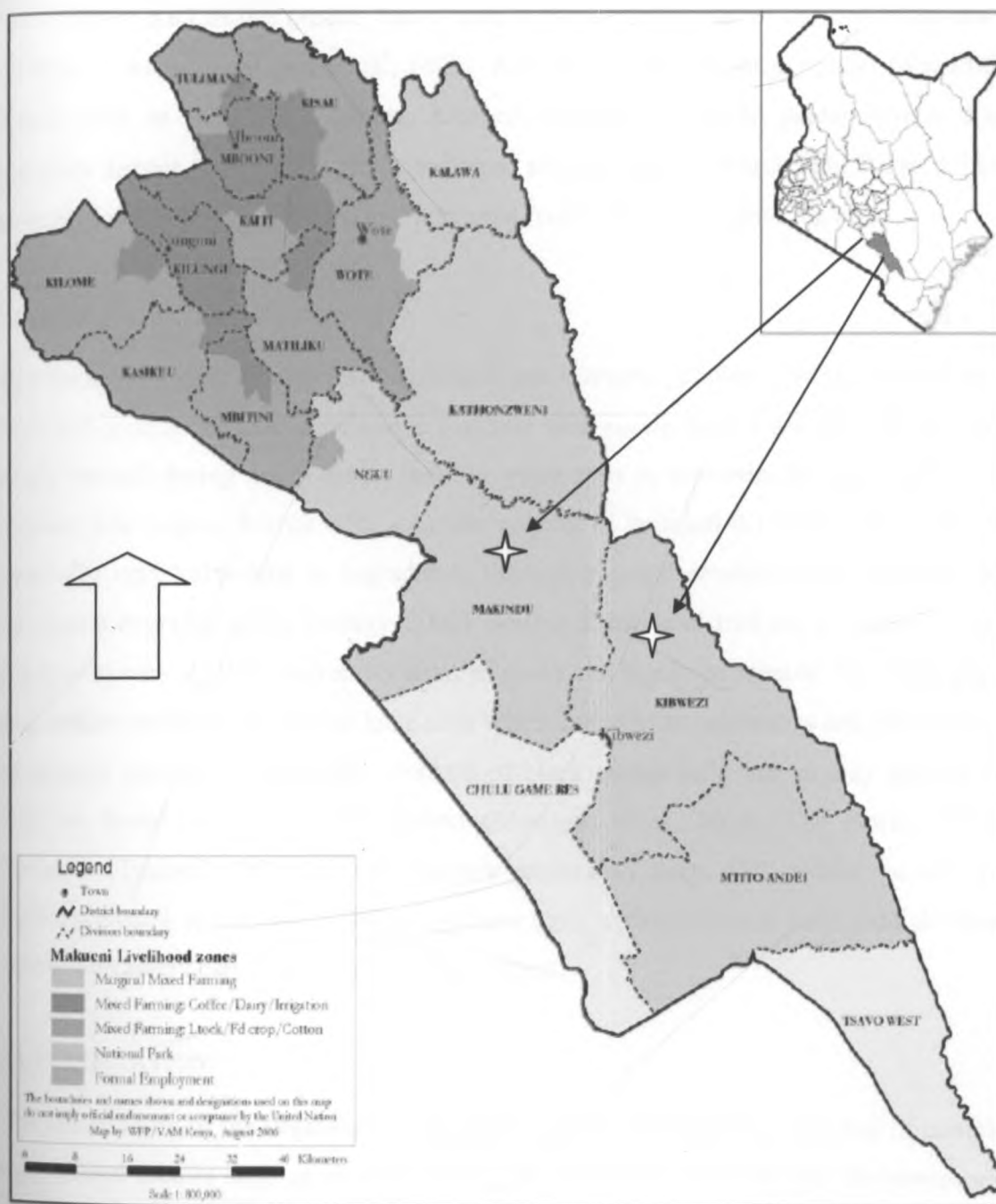
3.1.1 LOCATION AND SIZE

Kibwezi district was carved out from Makueni District in 2007 and is one of the 26 districts that form Eastern Province, in Kenya. Kibwezi District is located about 200 Km South East of Nairobi. It lies between the latitudes 2° 6'S and 3°S, and longitude 37° 36'E and 38° 30'E respectively. Kibwezi District borders Taita District to the South, Kajiado District to the West, Kitui District to the East and Makueni District to the North (Figure 3.1). The district has a total area of 3400 Km² (CBS, 2000).

3.1.2 GEOLOGY

The geology of Kibwezi District is characterised by recent volcanic rocks under the basement complex system. Granite rocks are found around the Chyulu Hills which is a major water catchment area in the district. The rest of the area is almost entirely built up of recent lava flows and some volcanic cones. The flood plains and bottom lands occupy only minor portions. The rocks present in the district can broadly be subdivided into basement system rocks, volcanic and superficial deposits (Tucker, 1983). Volcanic activity significantly enriched large areas of basement system rocks with volcanic material. This enrichment coincided with major volcanic activities in pleistocene and recent times (Musimba *et al.* 2004). Recent volcanic rocks are represented by the string of ash and cinder cones of the Chyulu range and its surrounding lava flows, which consists of various olivine basalts, partly covered by ash deposits of various texture and thickness. Volcanic ash is evident upto today as witnessed in the recent lava flows, popularly known as *Shamba la Mashetani*, the devils farm, in the Tsavo West National Park.

Figure 3.1: Map of Kenya and study area



Source: Makueni District report, 2008

3.1.3 TOPOGRAPHY

The altitude of the study area varies from 600m to 1100m. The land rises slightly below 600m a.s.l in the greater Tsavo area at the southern end of the district to about 1,100m in the northern part (GoK, 2002). Athi River is the major perennial river in the district and its tributaries- Kambu, Kibwezi, Kiboko and Mtito Andei Rivers, drain Kibwezi district. Low lying, gently eastward sloping plains towards Athi River, broken by occasional hills and seasonal and perennial rivers also characterise the area.

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 Kibwezi contain low organic matter with a carbon content of between 0.1-0.5%. Such soils are generally very vulnerable to degradation through physical erosion and to chemical and biological degradation (El Beltagy, 2002). Soils in Kibwezi district are of volcanic origin, shallow to very shallow, extremely stony to rocky and highly permeable. The flood plains and bottom lands in the district have soils which range from calcareous and non-saline to extremely calcareous and saline. Pockets of black cotton soils rich in clay content can also be found scattered in the district (Musimba *et al.* 2004). The Ferral-Chromic Luvisols (Touber, 1983) are well drained, moderately deep, dark reddish brown with well-developed A-horizons. The A-horizons have a characteristic dark reddish brown colour and sandy clay loam to sandy clay texture.

3.1.5 VEGETATION

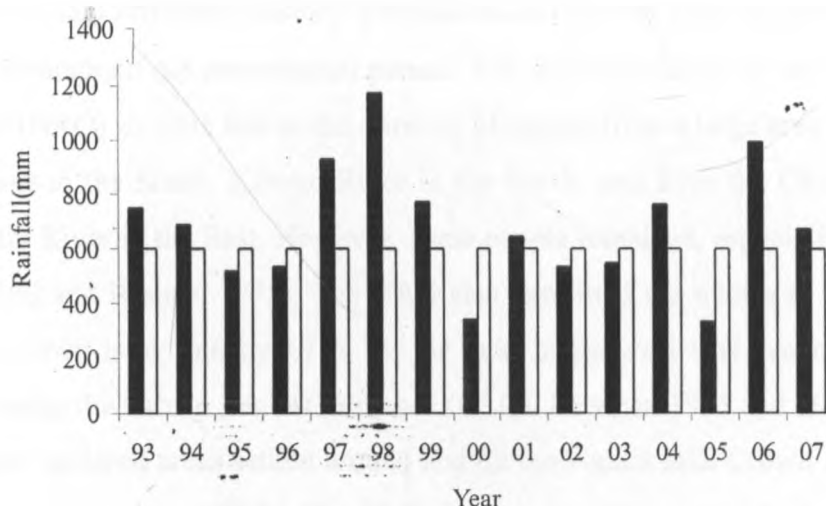
The distribution of the vegetation in the study area is controlled by a number of complex interrelated factors such as climate, geological formation, soil type and the presence or absence of ground water (Gachimbi, 1990). The vegetation in the study area has evolved under pressure from both periodic droughts and large herds of wild herbivores including the agro-pastoral herds. Kibwezi is a typical semi-arid rangeland district dominated by *Commiphora*, *Acacia* and allied genera, mainly of shrubby habitat. The Baobab tree,

Adansonia digitata are also common (Musimba *et al.* 2004). Perennial grasses such as *Cenchrus ciliaris*, *Enteropogon macrostachyus* and *Chloris roxburghiana* can dominate but many succumb to continuous abuse over long periods. *Eragrostis superba* is also commonly found in the district. Bottom lands dominated by Vertisols are characterised by *Pennisetum mezianum* at the lower storey and *Acacia drepanolobium* at the middle storey.

3.1.6 CLIMATE

The climate is typical semi-arid and the district is representative of many other zones with similar ecological conditions throughout Kenya, 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 low Inter-Tropical Convergence Zone (ITCZ) (Biamah, 2005). The average annual rainfall, evaporation and temperatures are 600mm, 2000mm and 23°C respectively (Michieka and van der Pouw, 1977). The rainfall is characterised by small total amounts, strong seasonal and bimodal distribution (Nyangito *et al.* 2008), with long rains from March to May and short rains from November to December. The short rains are more reliable in time than long rains and are therefore more important. Results from Gichuki (2000) show that 60% of the annual rainfall in the study area is received during the short rains, with the long and dry season rains contributing 37% and 3% of the annual rainfall, respectively. According to Braunn (1978), there is a concentration of rainfall at the beginning of the long or short rains. Rainfall intensities are usually very high. There is a lot of variability in rainfall amounts both in time and space and its reliability is low.

Figure 3.2 Annual rainfall (mm) and long-term average annual rainfall



■ Total annual rainfall □ Long-term average annual rainfall for Kibwezi district

Notes: Data Source: DWA Station

Kibwezi is a typical semi-arid district in Kenya, and generally lies in two agro-climatic zones (ACZ), IV and V (Table 1), on the basis of the ratio of rainfall to open water evaporation (R/E_o).

Table 1: Agro-climatic zones of Kenya, excluding areas above 3000m altitude (Biamah, 2005)

Zone	R/E_o^* (%)	Classification	R^* (mm)	E_o^* (mm)
I	> 80	Humid	1100-2700	1200-2000
II	65-80	Sub-humid	1000-1600	1300-2100
III	50-65	Semi-humid	800-1400	1450-2200
IV	40-50	S.humid - S.arid	600-1100	1500-2200
V	25-40	Semi-arid	450-900	1650-2300
VI	15-25	Arid	300-560	1900-2400
VII	< 15	Very arid	150-350	2100-2500

Notes: * R – Average rainfall; E_o - Average annual evaporation

3.1.7 DEMOGRAPHIC AND SETTLEMENT PATTERNS

The largest ethnic group in the study area is the agro-pastoral Kamba community. Their mainstream economic activity is raising livestock and cultivating cereals and pulses. The production system is largely geared to subsistence production (Nyangito *et al.* 2008).

Kibwezi has a human population density of 85 persons per km² (GoK, 2002). The district has a complicated settlement history. 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). The NRO also permitted the whites to secure 88 years leases on crown land, and by 1915, all the land in Kibwezi was declared government property under the Crown Lands Ordinance (CLO). Between 1925 and 1936, the colonial government declared areas settled around and on the Ngulia hills Crown Land, under the Crown Lands Ordinance (CLO). The CLO also increased lease periods from the initial 88 years to 999 years. Shortly before independence, around 1961, efforts were made to relieve population pressure on the Akamba farms in the area around Machakos town (Murton, 1999). The best land was found in the Chyulu hills in Kibwezi District. The wave of settlement brought 20% of the area under cultivation. In the same period (1961-1978), bush encroachment increased from 52-62% and the amount of forest decreased by 62% (Tiffen, 1991). According to Mbithi and Barnes (1975), the unorganized settlement immediately after independence, in 1964, into the area between Mtito Andei and Kibwezi, that was declared and designated for settlement, has led to the present land deterioration prevalent in the area. The newly opened settlement schemes in Kibwezi District (Kibwezi, Masongaleni, Kiboko and Nguu Ranch), have further caused a large influx of people from other districts and increased the population density.

3.2 RESEEDING MATERIALS AND PREPARATIONS METHODS

A number of methods were applied to evaluate various attributes for grass reseeded in the study area. These methods are detailed below.

3.2.1 SEED VIABILITY TESTING BY GERMINATION

Seeds of the 3 grass species were used in the experiment; *Enteropogon macrostachyus*, *Eragrostis superba* and *Cenchrus ciliaris*, were purchased from the local farmers in the study area. The germination capacity of the grass seeds as a measure of seed quality was

tested in the laboratory. The seed viability tests were carried out in two laboratories; The Animal Nutrition Laboratory, Department of LARMAT, in Kabete, under controlled conditions in the incubator (20°C) and at the Kibwezi Field Station Laboratory, under room temperatures.

Random samples of 100 seeds of each grass species obtained from the bags of collected seeds were put on a wet Whitman filter in standard laboratory petri-dishes. Each petri-dish contained 25 grass seeds replicated four (4) times to make 100 seeds per grass species. The grass seeds were arranged in five straight lines each containing five seeds to make 25 grass seeds per petri-dish. The petri-dishes were then placed in an incubator at 20°C or in open air at room temperature. The filter paper was moistened with a few drops of water when it appeared dry. The grass seeds that germinated everyday were counted and removed from the petri-dishes. Germination was considered to have occurred when a clearly identifiable radicle emerged from the seed in the petri-dish (Opiyo, 2007). At the end of 14 days, all germinated seeds were expressed as a percentage of total number of seeds.

The same procedure was repeated again after nine months, at the Range Animal Nutrition Laboratory alone, with the same seeds used previously and mature seeds of the three grass species harvested during the study period.

Percent Germination was calculated using the following formula:

$$\% \text{ Seed Germination} = \frac{\text{Total number of seeds germinated}}{\text{Seeds per petri-dish} \times \text{Replicates}} \times 100$$

3.2.2 SLOPE CHARACTERISTICS OF EXPERIMENTAL SITES

Slope characteristics are important to soil management because they influence soil hydrological properties namely infiltration capacity, run-off, drainage and sediment production. In addition, slope characteristics influence the choice of crops to be grown and the use of machinery.

The slope characteristics of the sites were estimated using a line level, a thick cotton string, a marker pen and two thin poles of equal length measuring 50 inches as follows. The two poles were marked using a marker pen at intervals of 1 inch from the top to the bottom. The cotton string was then tied to run in between the poles. An adjustable loop was made at one end and fixed at the other end, 1 inch from the top of each pole. One person was made to stand down slope holding one pole and another person up slope holding the other pole ensuring that the string running in between is as turgid as possible. The line level was suspended on the string, roughly at the center, between the two poles. A third person was made to stand at the centre to observe the movement of the mercury in the line level to indicate a level setting. The person at the top of the slope moved the string to the different marks on his pole until the level suspended at the centre of the string showed a level setting.

The slope was calculated by measuring the distance from the mark where the string was placed initially to where the level suspended showed a level setting. Slope is a percentage, meaning the number of unit falls or rises in 100 units of horizontal distance. Every inch from the top of the 50 inch pole equals 2% of slope. The lower the string must be on the pole to be level, the higher the percent of the slope.

The % Slope was calculated using the following formula:

$$\% \text{ Slope} = \text{Inches Drop to a Level Setting} \times 2\%$$

3.3 EXPERIMENTAL DESIGNS AND LAND PREPARATIONS

Climate variability, especially low and erratic rainfall necessitated the setting up of experimental plots to make site specific evaluations. The experimental plots set up under rainfed and irrigation is described below.

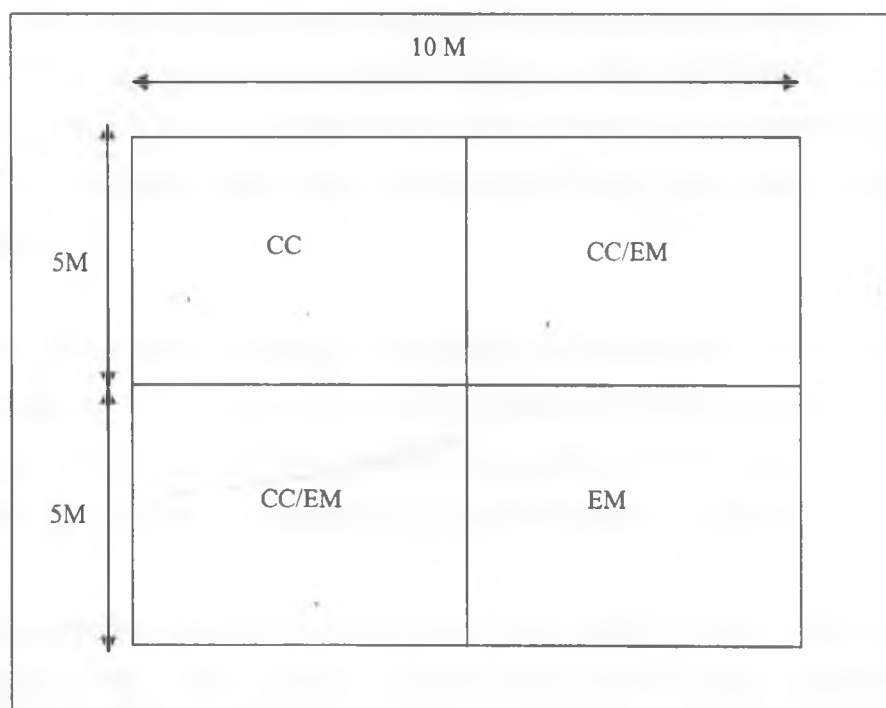
3.3.1 RAINFED EXPERIMENTAL PLOTS

Site 1 (Local farmer's farm) and site 2 (Silanga Ngomano Community water reservoir site) experimental plots, each measuring 10m X 10m were laid out as shown in figure 3.3. The land preparation method involved the use of ox-driven plough to disturb the bare

ground with shallow plough lines to provide the necessary micro-catchments. These micro-catchments ensure that the grass seeds trapped enough water for a prolonged period of time thus improving the chances of the grass seeds to germinate and establish. The experimental plots were prepared during the dry season just before the onset of the long rains of April-May, 2008.

Four sub-plots measuring 5m X 5m were laid out. The grass seeds were hand sown along the micro-catchments and covered with some light amount of soil on 29th March, 2008. The experimental sites were fenced using locally available branches of *Acacia* to exclude both livestock and wild herbivores from grazing on the reseeded plots.

Figure 3.3 Experimental layout of plots under rainfall



Notes: CC – *Cenchrus ciliaris*, EM – *Enteropogon macrostachyus*, CC/EM – *Cenchrus ciliaris*-*Enteropogon macrostachyus*

3.3.2 IRRIGATION EXPERIMENTAL PLOTS

Three (3) experimental plots each measuring 15m X 10m were set up horizontally. Another large plot, measuring 55m X 10m running parallel to the three plots was also laid out. The spacing between these two plots was 2m. The three plots measuring 15m X 10m

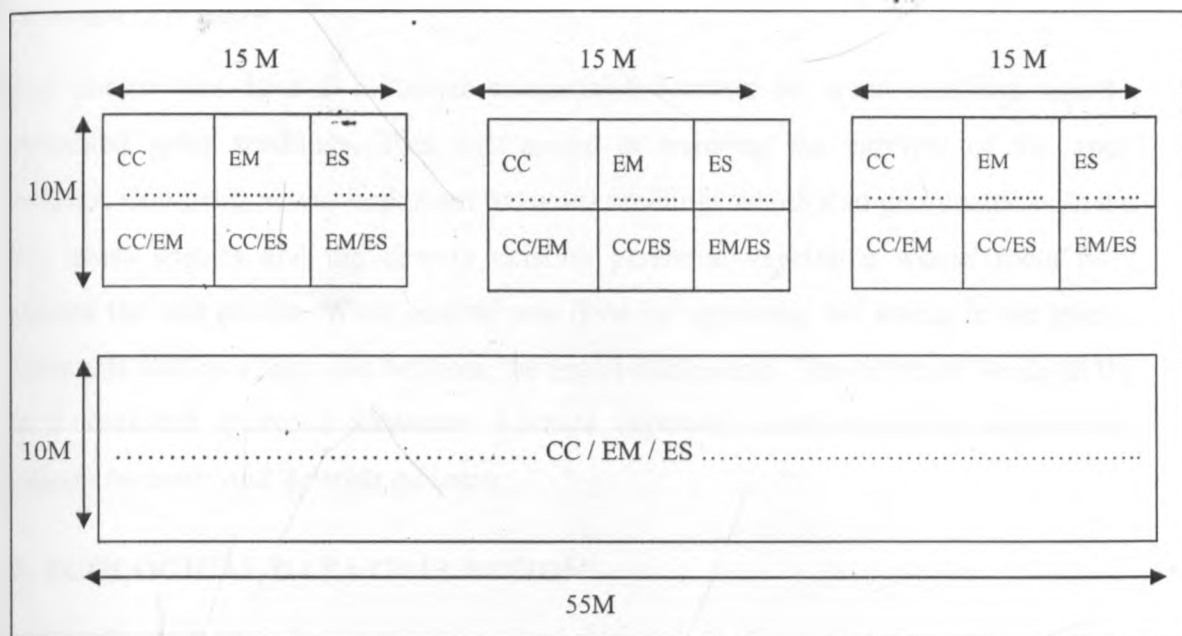
were laid out horizontally next to each other with a spacing of 5m in between them. These experimental plots were set up at the Chemistry Department Irrigation farm in Kibwezi dryland field station (Site 3). The land preparation method involved the clearing of the bush, ploughing and setting up the irrigation laterals and sprinklers. Fire breakers of 5m width were made around the area to be ploughed. The fire-breaks were made using hand hoes. A total area of 1 acre was ploughed using a disc plough to create micro-catchments running horizontally across the plots. The 3 plots were placed at the center of a portion of the ploughed area and marked.

Six sub-plots measuring 5m X 5m each were laid out in all the 3 plots. The plots were then tagged to correspond with the grass species to be sown, either as pure stands or mixtures. The tags were labelled as follows; CC – *Cenchrus ciliaris*, ES – *Eragrostis superba*, EM – *Enteropogon macrostachyus* to represent pure stands and CC/ES, CC/EM and ES/EM to represent 2 grass mixtures. One tag labelled CC/ES/EM was placed in the larger plot (60m X 10m) to represent the 3 grass mixture. A single lateral running through the centre of the plots with a total of 9 sprinklers evenly spaced along the length was set up (Figure 3.4).

The grass seeds were hand sown along the micro-catchments in the three experimental plots measuring 15m X 10m. Seeds in the experimental plot measuring 55m X 10m were broadcasted. Before sowing the mixtures, the seeds were thoroughly mixed and sown using the recommended sowing rates for the area (see outlay in Figure 3.4).

Larger experimental plots (15m X 10m) were used under simulated rainfall compared to those under rainfed (10m X 10m) to accommodate the third grass species *Eragrostis superba* which was not available when setting up the plots under natural rainfall.

Figure 3.4 Experimental layouts of irrigation plots



Notes

CC – *Cenchrus ciliaris* EM – *Enteropogon macrostachyus* ES – *Eragrostis superba*

CC/EM – *Cenchrus ciliaris* - *Enteropogon macrostachyus* Mixture

CC/ES – *Cenchrus ciliaris* – *Eragrostis superba* Mixture

EM/ES – *Enteropogon macrostachyus* – *Eragrostis superba* Mixture

CC/EM/ES – *Cenchrus ciliaris* – *Enteropogon macrostachyus* – *Eragrostis superba* Mixture

..... – Sprinkler lateral arrangement

3.3.3 APPLICATION RATE OF THE SPRINKLER IRRIGATION SYSTEM

Six cylindrical containers of the same diameter were spaced at even intervals and in a line running away from the sprinkler. The last container was placed near the edge of the area of coverage. The plots were then irrigated for an hour. The water depths in all the containers were then added up and divided by the number of cans used to find the amount of water applied per hour.

The Application Rate was calculated from the following formula;

$$\text{Application Rate} = \frac{\text{Total Amount of Water Collected in all Containers}}{\text{Number of Containers}}$$

To ensure that the soil was maintained at near field capacity, the duration of application was constantly adjusted.

3.3.4 WEED CONTROL

Weed control was done to minimize competition between the weed seedlings and the germinated grass seedlings. This was aimed at ensuring the survival of the grass seedlings. Competition was both from the weed seedlings which also germinated with the sown grass species and the already existing perennial vegetation whose roots fully explored the soil profile. Weed control was done by uprooting the weeds in the micro-catchments and by a hand hoe between the micro-catchments. The common weeds in the site 3 included *Ipomoea kituensis*, *Lactuca capensis*, *Dactyloctenium aegypticum*, *Solanum incanum* and *Aristida adoensis*.

3.4 ECOLOGICAL DATA COLLECTION

3.4.1 RAINFALL DATA

Rainfall data was collected and analysed to determine the effects of rainfall totals and distribution on the germination percentages, survival rates and establishment of the seeds. A rain-gauge was set up approximately in between the two plots under rainfed. The amount of water collected was measured every morning between 8-9am using a measuring cylinder and recorded as rainfall received for the previous day in the rainfall data entry sheet. The water was then discarded and the rain-gauge was put back in place. Additional rainfall data for the previous seasons and years was obtained from the DWA Sisal plantation weather station in Kibwezi district.

3.4.2 SOIL DATA

Disturbed soil samples were taken from the top soil of 0-20cm to determine soil moisture, soil texture, soil organic matter and soil fertility in all the three sites. Soil moisture content was determined by the gravimetric method (Rowell, 1994). Soil texture was determined following the hydrometer method as described by Gee and Baunder (1986). The fine fraction of soil passing through a 2mm sieve was taken for texture analysis using the Buoyoucos hydrometer. The textural class was determined using the standard USDA

Triangle (USDA, 1975). Disturbed soil samples were taken only once at the beginning of the experiment.

Undisturbed soil core samples taken to depths of 0-5cm were used to determine soil bulk density and saturated hydraulic conductivity. Bulk density was determined by the core method (Blake and Hartge, 1986). Constant head permeameter as described by Klute and Dirksen (1986) was used to determine saturated hydraulic conductivity (K_{sat}). Undisturbed soil samples were taken at the beginning of the experiment and again at the end of the experiment when the grasses had set seed. Soil chemical analysis for nitrogen, phosphorus, potassium, carbon and cation exchange capacity (CEC) were done using standard soil laboratory analysis procedures as described by Miller and Keeney (1982)

3.4.3 VEGETATION DATA

Aboveground biomass production, basal cover, frequency, plant density, tiller density estimates were only taken in plots under irrigation. Vegetation measurements in plots under rainfed were not taken due to poor grass establishments in the plots due to low rainfall totals received during the study period in the study area.

3.4.3.1 Aboveground biomass production

Above ground standing biomass from the plots was determined by the quadrat method. Three 0.5m X 0.5m (0.25m²) quadrats were systematically placed in each sub-plot and clipped to 2.5cm stubble height. For the larger plot, six such quadrats were harvested. All the harvested material from each quadrat was placed in labeled collection bags, separated into grass and weeds. The harvested material was oven dried at 80°C for 96 hrs. The oven dry weights were determined using a digital balance. The weeds and desired grass species of each sample were recorded separately and expressed as a percentage of the total dry weight. The average dry matter production per sub-plot was calculated. Above ground biomass production was determined at different grass heights at 15cm, 30cm and 60cm.

3.4.3.2 Percentage basal cover, frequency and plant density

The percentage basal cover was estimated using the step-point method (Evans and Love, 1957). Four line transects were used in each of the six sub-plots in all the three plots in the irrigation site. Ten line transects were used in the 55m X 10m plot under the three grass mixture. Plant densities and frequencies were estimated using the quadrat method. Six quadrats were placed systematically in each of the six sub-plots, while twelve quadrats were used in the three grass mixture plot. Percentage basal cover, frequency and plant density estimates were taken once, after three months of sowing.

3.4.3.3 Tiller density

Tillers are shoots that grow from buds at the base of the plant. Tiller density was determined by placing a quadrat and counting the tillers at the reproductive stage of development of the plants. Each tiller consisted of a leaf, stem node, stem inter-node and a bud.

3.4.4 HYDROLOGICAL RESPONSES AND SEDIMENT PRODUCTION UNDER THE GRASSES

Simulated rainfall (Kamphorst, 1987) was used to study soil hydrological responses and sediment production in site 3. Infiltration capacity in the site at different plant stubble heights (0cm, 20cm and 40cm) were measured using the Kamphorst Rainfall Simulator (Kamphorst, 1987). Each simulation consisted of a rain shower of 5 minutes with an intensity of 375 ml/min (6mm/min) (Rietkerk *et al.* 2000). The simulations were done in triplicate in the site. Run-off was collected, decanted and weighed. The infiltration capacity was calculated by subtracting the runoff from the amount of simulated rainfall applied.

$$\text{Infiltration Capacity (mm)} = \text{Amount of Simulated Rainfall} - \text{Total Runoff Collected}$$

The sediment produced was washed into storage bottles and later filtered off and dried at 105°C for 24 hrs. Sediment production was also estimated at different grass stubble heights of 0cm, 20cm and 40cm. The amount produced was converted to sediment yield in kg/ha. This was used as an index of sheet erosion as given in the equation below.

$$\text{Sediment Production (kg/ha)} = \frac{\text{Sediment Produced X Area}}{\text{Plot Area}}$$

3.5 SOCIAL DATA COLLECTION

Interviews were used to obtain information on grass reseeding technology and its role in rehabilitating degraded rangelands in the study area. Focus Group Discussions (FGD's) were also carried out to get additional information on the same.

3.5.1 PREPARATION OF THE QUESTIONNAIRE

A draft questionnaire taking into account the objectives of the study was constructed before setting out to the field. Questions were dichotomous, multi-choice and open ended to allow ease of capture of the diverse issues that were being investigated, with necessary detail. The questionnaire was pre-tested in a pilot survey involving 20 households, before it was used in the main survey. The households belonged to the same area of study but were not included in the actual survey. Pre-testing ensured the final questionnaire had relevant and appropriate phrased questions for the interviews.

3.5.2 TRAINING FIELD ENUMERATORS

Two enumerators with secondary level of education and experience in field survey were recruited and trained. The enumerators were selected from the local community and were fluent in the local Kamba language and English. Furthermore, the enumerators were selected based on their field experience and knowledge on the issues to be addressed in the questionnaire. These enumerators had participated in field interviews as agropastoral development agents (ADPs) for development programs in the recent past in the study area.

3.5.3 SAMPLING PROCEDURE

The sample involved 50 households distributed in 2 Divisions (Kibwezi and Makindu) out of 5 divisions, 5 locations and 12 sub-locations of the study area. Statistically, a sample size of 30 is large enough. Kibwezi division has a human population of 80,236

whereas Makindu division has a human population of 34,522 (Makueni district development plan, 1996). The 12 sub-locations were selected for sampling to give the study a wide scope. The households were selected systematically while in the field. A group of farmers who participated in the Dryland Husbandry Project (DHP) in the study area were targeted.

3.5.4 STATISTICAL ANALYSIS

Statistical analyses were done using Statistical Package for Social Sciences (SPSS) packages (Einstein and Abernethy, 2000). Differences in vegetation and soil measurements were analysed by ANOVA and means separation. Social data was analysed using descriptive statistics.

3.5.5 REGRESSION ANALYSIS, SELECTION AND MEASUREMENT OF VARIABLES

Secondary data covering a period of 35 years (1973-2007) on the area under grassland cover, woodland and cultivation, and human population, livestock populations, rainfall and drought occurrences obtained from the annual district reports and the DWA Sisal plantation weather station, were used to create time-series data for the period.

A time-series regression analysis was carried out to establish the link between land degradation and human activity among other factors in the study area. The rate of change in the vegetation component and land use pattern was also determined using a Log-lin regression analysis. Five-year moving averages of the data set were plotted to show the trends of the variables over the period of study.

In formulating the model, variables were selected *a priori* based on the knowledge gained from literature and then carrying out preliminary test runs, including unit root tests of stationarity. A correlation analysis was carried out and an appropriate choice was made between those variables that were found to be highly correlated (Appendix II). The variables used in the final regression were grassland cover, woodland cover, cultivated land area, rainfall, human population, livestock population and a shift dummy.

Grassland and woodland: Grasslands form an important vegetation type in the rangelands. Savanna ecosystems provide an important forage resource for both livestock and wildlife. However, this type of ecosystem has come under increased pressure leading to its degradation. The arid and semi-arid lands (ASALs) of Kenya have undergone increasing land use pressure within the last 15 years, largely due to various factors that have caused a decline in grass cover and an increase in woody vegetation. This situation is particularly pronounced in Kibwezi district.

Cultivated area: Dryland ecosystems, in which Kibwezi district forms part, are very vulnerable to over-exploitation and inappropriate land use. Over-cultivation exhausts the soil, destroying its structure and fertility. The semi-arid to weakly aridic areas in developing countries in Africa are particularly vulnerable as they have fragile soils, localized high population densities and generally a low input form of agriculture. Increased pressure from the expanding patterns of cropping in the district has resulted in grazing area per household becoming smaller and more exclusive (Nyangito, 2005).

Rainfall: Rainfall, together with soil moisture balance, has an overwhelming effect on vegetation structure, composition and productivity. The rains in the southern rangelands of Kenya are usually low, erratic and unpredictable in nature. Rangeland vegetation dynamics are highly influenced by the rainfall amounts received. In this analysis, rainfall totals received over the years were included because of their influence on changes in the distribution and occurrence of vegetation types in the area. It may be useful to note that annual rainfall totals for a period of 35 years were appropriate in the regression because, according to Biamah (2005), a period of about 30 years is considered as the absolute minimum for any rainfall event analysis.

Human population: Human population in the study area has been on the increase, with an influx of people from the neighbouring more fertile and productive areas to these marginal lands. Continuous population growth exacerbates land degradation and hastens the conversion of ecosystems such as forests and rangelands into less productive, resulting in land degradation and loss of valuable land (Farahpour, 2003).

Shift dummy: The influence of drought patterns on vegetation dynamics necessitated the use of a shift dummy. In this analysis total annual rainfall of less than 450mm was considered a drought spell. Previous studies have used different rainfall amounts to represent a drought. For example, Nyariki (2008) used a rainfall amount of 300mm/year to represent a drought in a study carried out in Laikipia district, Kenya, which receives an annual rainfall of as low as 400mm in the north-east. Kibwezi district receives a much higher annual rainfall of 600mm (Michieka and van der Pouw, 1977).

$$D_{0t} = \begin{cases} 0 & \text{if observed } t \text{ is a drought} \\ 1 & \text{otherwise} \end{cases}$$

$$D_{1t} = \begin{cases} 1 & \text{if observed } t \text{ is 'good' weather} \\ 0 & \text{otherwise} \end{cases}$$

Where D is the dummy and t is the year of observation.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 SEED VIABILITY TESTS UNDER DIFFERENT AMBIENT TEMPERATURES

Figure 4.1 illustrates the seed germination of the three grasses at controlled ambient temperature (20°C). Seeds of *Enteropogon macrostachyus* gave the highest percentage germination (46%), while *Cenchrus ciliaris* and *Eragrostis superba* recorded zero germination. Under uncontrolled daily ambient temperatures averaging 30°C (Figure 4.2), *Enteropogon macrostachyus* had the highest germination percentage of 53%, followed by *Cenchrus ciliaris* (12%) and *Eragrostis superba* (10%).

Figure 4.3 illustrates the results of a repeat of the same experiment under controlled laboratory conditions, at 20°C after 9 months. There were differences in seed germination between the three grasses. Seeds of *Enteropogon macrostachyus* had the highest germination of 85%. The percent seed germination for *Cenchrus ciliaris* was 40% while *Eragrostis superba* had the lowest percent germination of 21%. Freshly harvested mature seeds of the three grass species after 9 months of the experiment in the study site at 20°C, showed no germination after the 14 days period.

The differences observed among the grass species in terms of percent seed germination may be explained by the intrinsic properties of the seeds such as dormancy and integumental hardness, and climatic factors especially ambient temperatures. Poor initial germination percentages may be attributed to the high hygroscopic nature of most seeds of range grasses. Dry seeds, particularly those of rangeland grasses are known to be highly hygroscopic (Veenendaal, 1991; Opiyo, 2007), and exposure of dry seeds to moisture has been reported to worsen the dormancy and often leads to fungal infection (Chin and Hanson, 1999; Tweddle *et al.* 2003). For *Cenchrus ciliaris* and *Eragrostis superba*, their hygroscopic nature may have been made worse as at 20°C, compared to high (30°C) ambient temperatures.

Higher percent seed germination of *Enteropogon macrostachyus* may be explained by its dormancy mechanism which involves only the integument while the other two species may have both the embryo and/or the integument related dormancy (Mnene, 2005). The hairy bristle coat of the *Cenchrus ciliaris* fascicles is likely to have also aided its germination by maintaining a high humidity within the fascicle and thereby help reduce water loss from the caryopsis thus enhancing a higher germination (Sharif-Zadeh and Murdoch, 2001), as compared to that of *Eragrostis superba*. However, individual grass seed species ability to withstand moisture stress varies between species (Veenendaal, 1991; Opiyo, 2007).

All the freshly harvested grass seeds did not germinate within the 14 days period. This suggests that the seeds were still dormant. Therefore, older seeds gave better germination percentage compared to fresh seeds. In this study, fungal growth was evident although no data was collected on grass seeds infection.

Figure 4.1: Daily percentage seed germination of *Enteropogon macrostachyus*, *Eragrostis superba* and *Cenchrus ciliaris* under controlled conditions, 20°C.

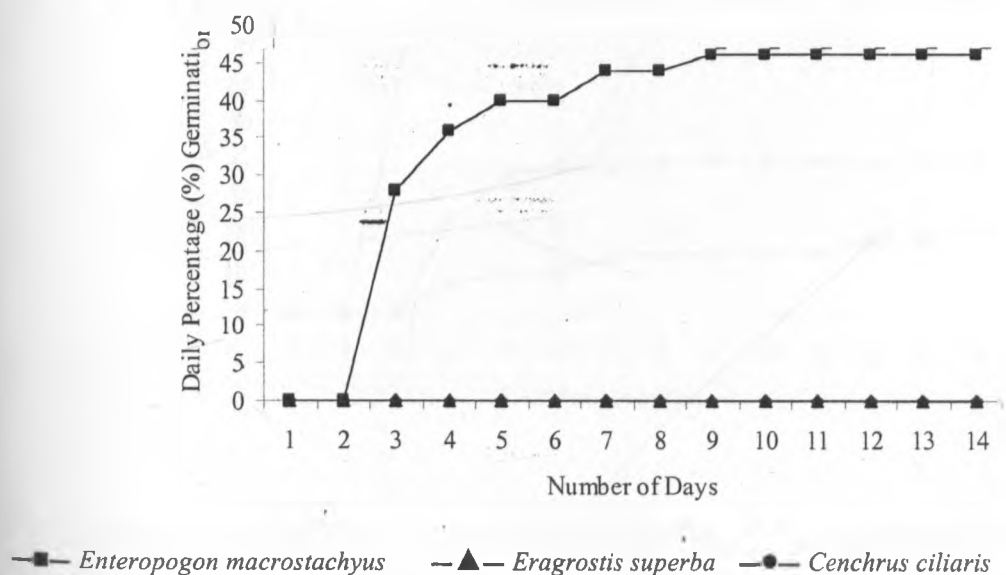


Figure 4.2: Daily percentage seed germination of *Enteropogon macrostachyus*, *Eragrostis superba* and *Cenchrus ciliaris*, under room conditions, 30° C in the study area.

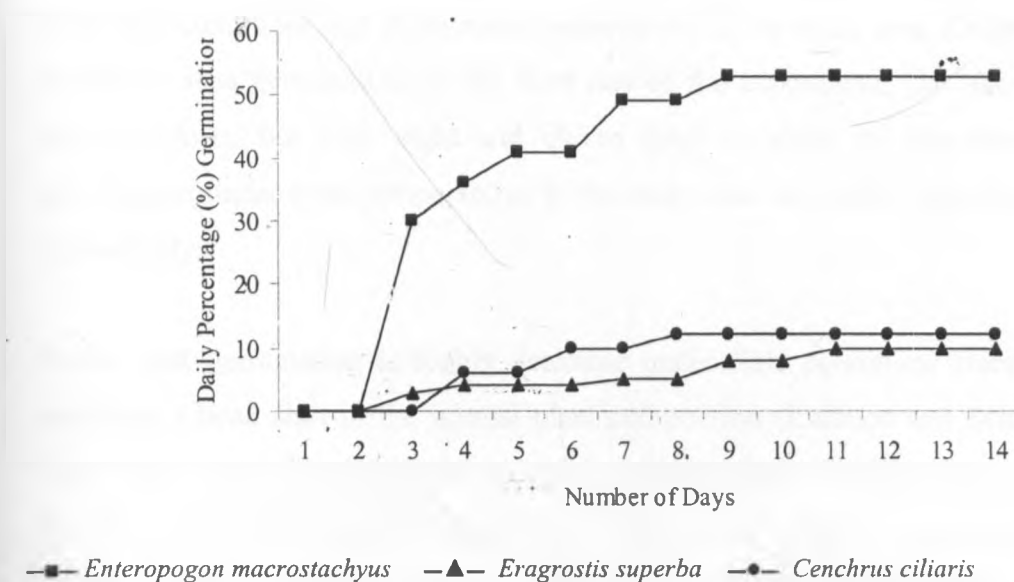
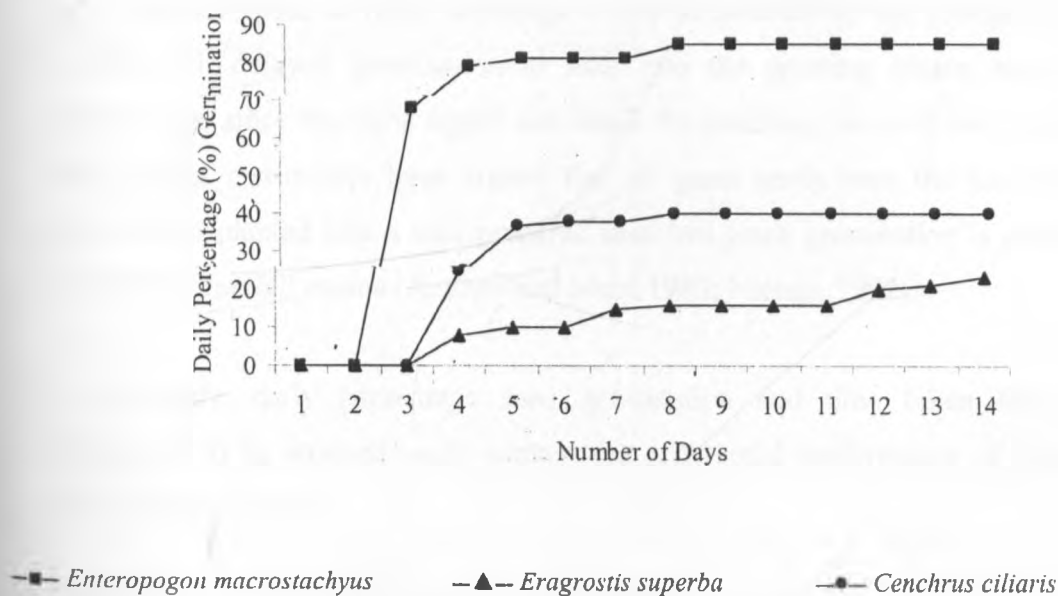


Figure 4.3: Daily percentage seed germination of *Enteropogon macrostachyus*, *Eragrostis superba* and *Cenchrus ciliaris* under controlled conditions, 20°C (After 9 months).



From figure 4.3, *Enteropogon macrostachyus* is a fast-germinating tufted perennial grass compared to *Eragrostis superba* and *Cenchrus ciliaris*. Although the seed germination of *Cenchrus ciliaris* started a day after that of *Enteropogon macrostachyus*, it attained its

maximum germination percentage after five days as compared to *Enteropogon macrostachyus* which attained its highest germination percentage after six days in both controlled conditions and under room temperatures in the study area. *Eragrostis superba* started its seed germination on the third day of the experiment, just like *Enteropogon macrostachyus*, but took eight and eleven days to attain its maximum percentage germination under room temperatures in the study area and under controlled conditions, respectively.

Faster seed germination is highly desirable under field conditions since it gives the seedlings a head start in the normal plant competition (Kadmon and Schimida, 1990). The faster a seed moves from the seed and seedling stages, the higher the chances for its survival and subsequent establishment if there is no selective predation (Ernest and Tolsma, 1988; Chin and Hanson, 1999). It is therefore expected that *Enteropogon macrostachyus* could have the best seedling survival and establishment compared to *Cenchrus ciliaris* and *Eragrostis superba*. However, delay in seed imbibition is also advantageous in areas where rainfall patterns are such that the initial storms are followed by a long dry spell, as fewer seedlings would be affected by the drought. In contrast, species with delayed germination to later into the growing season would be at a disadvantage since the rains would end while the seedlings are still too young (Mnene, 2005). Other researchers have argued that all grass seeds have the best germination results when planted into a well prepared seed-bed since germination is usually spread over several rainfall events (Andrew and Mott, 1983; Njenga, 1992).

In this study, daily percentage seed germination and time taken for maximum germination to be attained could explain the differential performance of these grasses under field conditions.

4.2 SLOPE CHARACTERISTICS OF EXPERIMENTAL SITES

The slope of a site is important to soil formation and management because of its influence on runoff, drainage, soil erosion, use of machinery, and choice of crops to grow. Slope is the incline or gradient of a surface and is commonly expressed in percent

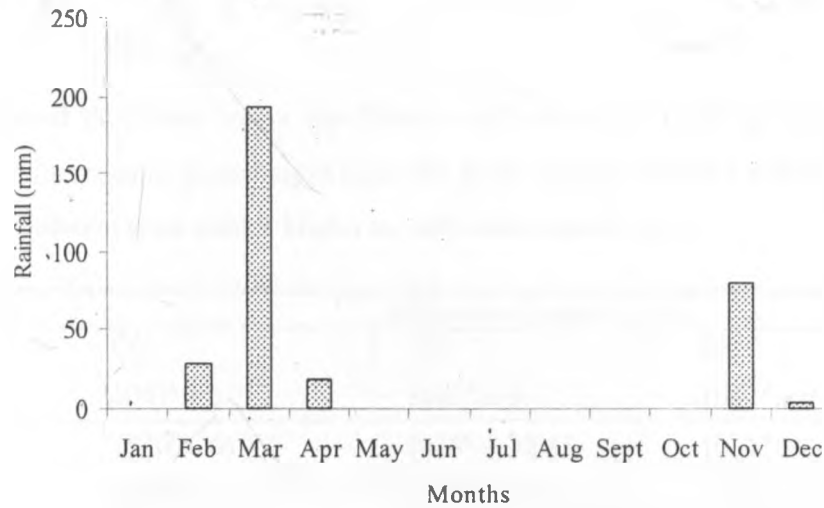
(Scherer *et al.* 1996). Results from site 1 gave a 6.5 inches drop to a level setting, which translated to a 13% slope. Sites 2 and 3 were located on a relatively flat area, which gave < 1 inch drop to a level setting, which translated to a slope of < 2%. In addition to the percent of slope, the shape of the slope is another important characteristic. A convex slope curves outward like the outside surface of a ball, a concave slope curves inward like the inside surface of a saucer, and a plane slope is like a tilted flat surface. Convex slopes were the most common in the study area. Results from the survey carried out showed that 36% of the farmers interviewed practice grass reseeding technology on a relatively flat area, whereas, 62% of the farmers interviewed, practice grass reseeding on areas with a relatively gentle slope. This suggests that reseeded areas are not prone to erosion hazards.

4.3 APPLICATION RATE OF THE SPRINKLER IRRIGATION SYSTEM

The total amount of volume collected from all the six containers in a period of one hour was 1260mls. The application rate of the irrigation system was 230mls/hr (0.638mls/sec). This was the average rate at which water was sprayed onto the grasses. The application rate depends on the size of sprinkler nozzles, the operating pressure and the distance between sprinklers. The applied rate of the sprinkler system was effective as it was less than the basic infiltration rate of the soil (3.49mls/sec).

4.4 RAINFALL

Figure 4.4: Monthly rainfall totals for 2008 in the study area.



Rainfall total in the study area for the year 2008 was 324.35mm. This rainfall totals received in the year 2008 were much less compared to the average annual rainfall totals of 600mm, for the study area as described by Michieka and van der Pouw (1977) and Braunn (1977). The long rains recorded the highest total amount of 240.45mm as compared to the short rains of 83.9mm. The wettest month of the year was March, which received a total of 192.85mm. However, most of the rain came as short lived flushes, which lasted for a maximum of 10 days at the beginning of the month, followed by long spells of dry periods for the remaining days of the month. The area received a total of 39 rainy days in the whole year (2008).

Rainfall together with soil moisture balance has an overwhelming effect on vegetation structure, composition and productivity. Rainfall regime witnessed during the study period further justifies that the rains in the eastern rangelands are usually low, erratic and unpredictable in nature and highly variable. The variability in rainfall amounts and distribution are common characteristics of the semi-arid rangelands (Pratt and Gwynne, 1977; Ekaya *et al.* 2001). Low amounts of rainfall received during the study period were reflected by the soil moisture deficits, which hindered seed germination and the growth of

the sown grasses. Thus, explaining the poor rates of establishment in site 1 and site 2 under rainfed conditions.

4.5 SOIL HYDROLOGICAL RESPONSES AND SEDIMENT PRODUCTION

4.5.1 INFILTRATION CAPACITY

The results showed that there was a significance difference ($p < 0.05$) in the infiltration capacity with an increase in grass height in all the grass species (Table 2 below).

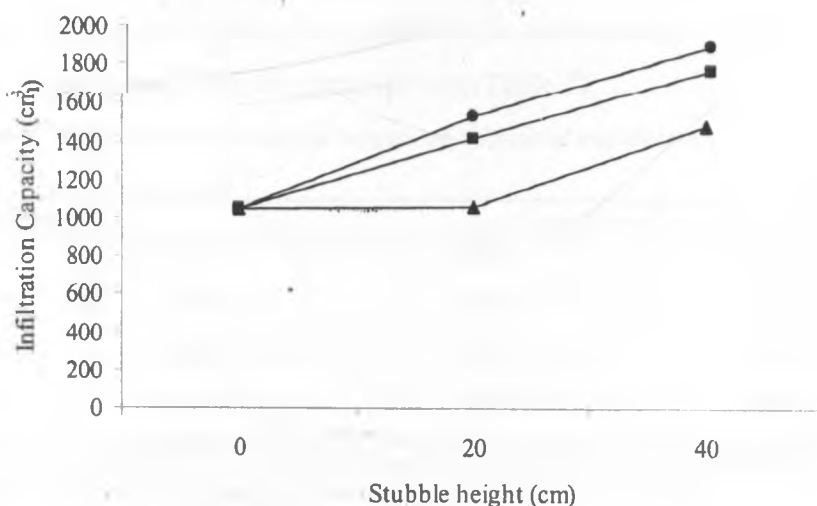
Table 2: Effect of different grass stubble heights on Infiltration capacity (cm^3)

Height (cm)	Infiltration Capacity (cm^3)		
	CC	EM	ES
0	$1047^a \pm 0$	$1047^a \pm 0$	$1047^a \pm 0$
20	$1530^b \pm 65.57$	$1413^b \pm 32.15$	$1067^a \pm 30.55$
40	$1883^c \pm 25.17$	$1760^c \pm 55.68$	$1513^b \pm 70.95$

Notes: CC—*Cenchrus ciliaris*, EM—*Enteropogon macrostachyus*, ES—*Eragrostis superba*
Column means with different superscripts are significantly different at $p < 0.05$

The infiltration capacities (cm^3) of site 3 at various grass stubble heights are illustrated in figure 4.5 below.

Figure 4.5 Infiltration capacity curves of the three grass species at different heights



—▲— *Eragrostis superba* —■— *Enteropogon macrostachyus* —●— *Cenchrus ciliaris*

Results show a general increase in the infiltration capacity with an increase in the grass stubble height. *Cenchrus ciliaris* maintained a higher infiltration capacity of 1530cm³ and 1883cm³ at stubble heights of 20cm and 40cm respectively. *Enteropogon macrostachyus* had 1413cm³ and 1760cm³, and *Eragrostis superba* recorded 1067cm³ and 1513cm³ within the same stubble height range. Previous studies have demonstrated that perennial vegetation can increase infiltration (Seobi *et al.* 2005). Nyangito, 2005 and Nyangito *et al.* 2009 also observed higher infiltration capacity in sites dominated by *Enteropogon macrostachyus* than those dominated by *Eragrostis superba*, while working with the same grasses in Kibwezi district.

Observed differences in infiltration capacity could be attributed to the growth and morphological characteristics of the grasses. *Cenchrus ciliaris* is densely leafed with branching culms arranged in a funnel shape. The grass is also relatively broad leafed. These characteristics presents a greater surface area for collecting water and rain drops that is concentrated more into its rhizosphere. *Enteropogon macrostachyus*, though narrow leafed, tends to be leafy than stemmy especially at its base and therefore, closely compares with *Cenchrus ciliaris* in trapping rain water. In contrast, *Eragrostis superba* is stemmier and thus less effective in concentrating rainwater into their rhizosphere.

4.5.2 RUNOFF

The results showed that there was a significance difference ($p < 0.05$) in runoff with an increase in grass height in all the grass species (Table 3).

Table 3: Effect of different grass stubble heights on volume of runoff (cm³)

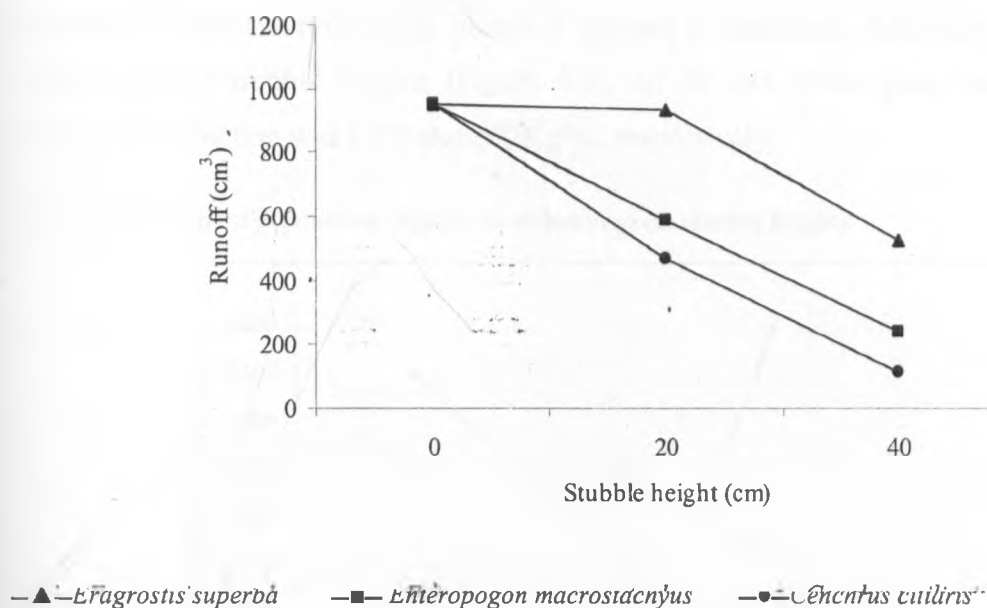
Height (cm)	Runoff (cm ³)		
	CC	EM	ES
0	953 ^a ± 0	953 ^a ± 0	953 ^a ± 0
20	470 ^b ± 65.57	587 ^b ± 32.15	933 ^a ± 30.55
40	117 ^c ± 25.17	240 ^c ± 55.68	487 ^b ± 70.95

Notes: CC–*Cenchrus ciliaris*, EM –*Enteropogon macrostachyus*, ES –*Eragrostis superba*
Column means with different superscripts are significantly different at $p < 0.05$

Runoffs in site 3 at various grass heights are illustrated in figure 4.6 below. Grasses with higher and lower infiltration capacities gave lower and higher runoffs respectively.

Cenchrus ciliaris yielded lower run-off of 470 and 117cm³ at 20 and 40cm grass stubble heights, respectively. *Enteropogon macrostachyus* yielded 587 and 240cm³ while *Eragrostis superba* recorded run-offs of 933cm³ and 487cm³ respectively at the same range of grass stubble heights.

Figure 4.6 Runoff curves of the three grass species at different heights



4.5.3 SEDIMENT PRODUCTION

Table 4: Sediment production (Kg/ha) in the three study sites at bare ground condition

Site	Sediment Production (Kg/ha)
1	4894 ^a ± 470.9
2	2535 ^a ± 78.5
3	3476 ^a ± 1966

Column means with different superscripts are significantly different at $p < 0.05$

The results from the experiments showed that there was no significant difference ($p > 0.05$) in sediment production in the three sites under bare ground conditions (Table 4). Site 1 had the highest sediment production of 4894 Kg/ha. Sites 1 and 3 had sediment productions of 2535 Kg/ha and 3476 Kg/ha, respectively.

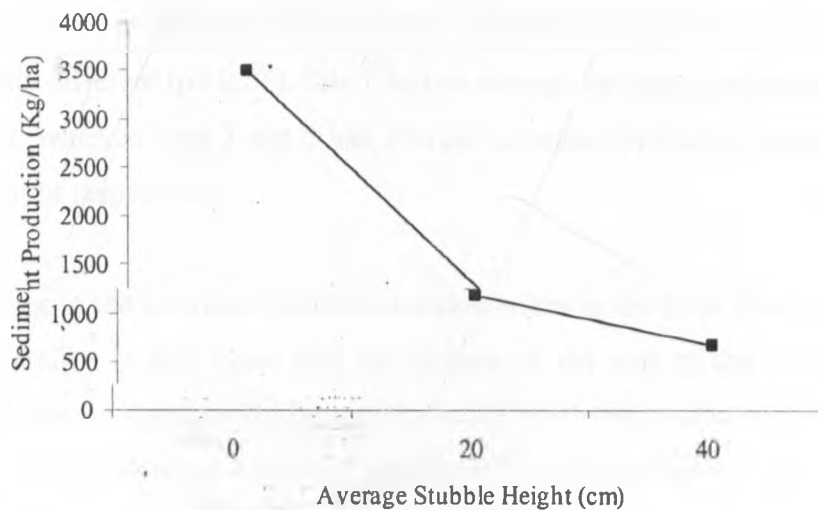
Table 5: Effect of different grass stubble heights on sediment production (Kg/ha) (Site 3)

Grass stubble height (cm)	Sediment Production (Kg/ha)
0	3476 ^a ± 1996
20	1178 ^b ± 1010
40	652 ^b ± 957

Column means with different superscripts are significantly different at $p < 0.05$

Results of sediment production in site 3 showed a significant difference ($p < 0.05$) at different grass stubble heights (Figure 4.7). At 20 and 40cm grass stubble heights, sediment production was 1178 and 652Kg/ha, respectively.

Figure 4.7 Sediment production (Kg/ha) at different grass stubble heights



There was a general decline in sediment production with an increase in grass stubble height. This can be attributed to the reduction of the force of water drops hitting and destabilising the soil structure. Generally, vegetation cover intercepts rainfall kinetic energy and thereby decreases the mobilization of soil particles. The taller grass traps more water drops and funnels it down its crown thus concentrating more water around the rhizosphere compared to the shorter grass. The larger leaf blades also reduce the force of the water drops directly hitting the ground. This improves infiltration capacity, reduces run-off and thus less sediment production.

4.6 SOIL PHYSICAL PROPERTIES

Results of the soil physical properties of the three sites are summarized in table 6.

Table 6: Some soil physical properties in the study sites

Site	K Sat cm/hr	Texture	Moisture %	Bulk density g/cm ³ *
1	2.84 ^a ± 1.31	Sandy Clay	6.87 ^a ± 0.88	1.29 ^a ± 0.09
2	1.94 ^{ab} ± 1.39	Sandy Clay	7.37 ^a ± 1.69	1.36 ^a ± 0.11
3	4.93 ^b ± 3.64	Sandy Clay Loam	2.47 ^b ± 0.82	1.33 ^a ± 0.07

Notes: *Bulk density at first soil sampling

Column means with different superscripts are significantly different at $p < 0.05$

4.6.1 SATURATED HYDRAULIC CONDUCTIVITY (Ksat) AND SOIL TEXTURE

Results showed that the saturated hydraulic conductivity of the three sites (Table 6) were significantly different ($p < 0.05$). Site 1 had an average saturated hydraulic conductivity of 2.84 cm/hr, whereas sites 2 and 3 had average saturated hydraulic conductivities of 1.94 and 4.93cm/hr respectively.

The difference in the saturated hydraulic conductivities in the three sites can be explained by the difference in soil types and the texture of the soil in the three sites. Higher saturated hydraulic conductivity in site 3 can be attributed to the soil and soil texture, sandy clay loam. Saturated hydraulic conductivity is influenced by grain size, which is reflected in the texture of the soil. Soils in site 3 had a higher percentage of sand, which has larger soil grains, thus higher hydraulic conductivity. Sites 1 and 2 had lower hydraulic conductivities due to a higher percentage of clay, which has smaller grains. Both sites 1 and 2 had a sandy clay texture. Results of this present study concur with that of Clapp and Hornberger (1978) which showed sandy clay loam soils to have a higher saturated hydraulic conductivity than sandy clay soils (Table 7).

Table 7: Representative values of saturated hydraulic conductivity of different soil textures

Soil Texture	K Sat (m/yr)
Sand	5.55×10^3
Loamy Sand	4.93×10^3
Sandy Loam	1.09×10^3
Silty Loam	2.27×10^2
Loam	2.19×10^2
Sandy Clay Loam	1.99×10^2
Silty Clay Loam	5.36×10^1
Clay Loam	7.73×10^1
Sandy Clay	6.84×10^1
Silty clay	3.21×10^1
Clay	4.05×10^1

Source: Clapp and Hornberger, 1978.

4.6.2 BULK DENSITY

The results showed a no significant difference ($p > 0.05$) in bulk densities in the three sites under bare ground conditions. Site 1 had a bulk density of 1.29g/cm^3 . Sites 2 and 3 had bulk densities of 1.36 and 1.33g/cm^3 , respectively. There was an increase in bulk densities in site 3 after the grasses had set seed at 60cm grass stubble height. Undisturbed soil samples in site 3 collected near the crown of *Enteropogon macrostachyus* stands had the highest bulk density of 1.44g/cm^3 . Undisturbed soil samples collected near the crowns of *Cenchrus ciliaris* and *Eragrostis superba* had bulk densities of 1.41g/cm^3 and 1.40g/cm^3 respectively. Similar soil samples collected from an adjacent area which had not been ploughed for four years had different results. Undisturbed soil samples collected near the crown of *Eragrostis superba* had the highest bulk density of 1.48g/cm^3 . Under the same conditions, *Cenchrus ciliaris* and *Enteropogon macrostachyus* had bulk densities of 1.43 and 1.36g/cm^3 respectively. Results of this study agree with those of Nyangito (2005) and Nyangito *et al.* (2009), which showed that ungrazed areas under stands of *Eragrostis superba* and *Enteropogon macrostachyus* had soil bulk densities of 1.499 and 1.343g/cm^3 , respectively.

The difference in bulk densities under bare ground conditions in the three sites could be attributed to the prevailing management practices. Higher bulk density in site 2 as compared to sites 1 and 3 could have resulted from the long term soil compaction caused by the grazing cattle, compared to sites 1 and 3 which are excluded from grazing animals. Also, bulk density is a function of root thinning and the root mass that occupies a soil column. An increase in soil bulk densities in established grass stands could be attributed to the root mass and root thinning at the root crown near the rhizosphere. Higher soil bulk densities of plots under pure stands of *Enteropogon macrostachyus* can be attributed to its faster rate of growth and development compared to the other grass species in the first season of planting. Higher soil bulk densities of older grass stands of *Eragrostis superba* can be attributed to its higher concentration of the root mass in the soil profile (Opiyo, 2007).

4.6.3 SOIL MOISTURE CONTENT

Results showed that the soil moisture content of the three sites were significantly different ($p < 0.05$). Site 2 had the highest average soil moisture content of 7.37%. Site 1 and site 3 followed with 6.87 and 2.47% soil moisture content, respectively. Differences in soil moisture contents in the three sites could be attributed to soil types. Higher soil moisture content in sites 1 and 2 can be attributed to soil texture and lower soil hydraulic conductivity. These characteristics in both sites restrict rapid penetration of water into the lower horizons leading to higher moisture content in the upper soil profile.

The general low levels of soil moisture contents in all the sites could be attributed to the low amounts and distribution of rainfall received during the study period. This partly explains the poor rates of establishment in the sites under rainfed reseeding. Available soil moisture within the root zone and the actual evapo-transpiration, which responds to the changes in soil moisture content, are the two parameters of the soil water balance that will influence the occurrence of water stress in rainfed production systems. These results further justify the fact that moisture plays a key role in herbage production especially in arid and semi-arid environments.

4.7 SOIL CHEMICAL PROPERTIES

Results of the soil chemical properties are summarized in table 8.

Table 8: Some soil chemical properties in the study sites

Site	C %	N %	P ppm	CEC me/100g	K me/100g
1	1.56 ^a ± 2.02	0.37 ^{ab} ± 0.06	13.90 ^a ± 8.42	13.88 ^a ± 7.45	2.03 ^a ± 0.31
2	0.75 ^a ± 0.12	0.32 ^a ± 0.04	15.38 ^a ± 4.63	19.59 ^a ± 3.63	2.21 ^a ± 0.78
3	0.92 ^a ± 2.20	0.43 ^b ± 0.04	13.72 ^a ± 5.47	6.40 ^b ± 6.91	1.92 ^a ± 0.45

Column means with different superscripts are significantly different at $p < 0.05$

Results show that the cation exchange capacity (CEC) and percent nitrogen were significantly different ($p < 0.05$) whereas phosphorus, percent carbon and potassium were not significantly different between the sites (Table 8). Higher CEC values in sites 1 and 2 can be attributed to the soil texture. Sandy clay soils have a higher clay content compared to sandy clay loams. Soils with higher clay content tend to have higher CEC. These results suggest that sites 1 and 2 have greater water holding capacity thus a higher capacity to hold cations compared to site 3. This can further be explained by the lower hydraulic conductivities of sites 1 and 2 as compared to site 3. The soils in all three sites have low organic matter content, thus are generally very vulnerable to degradation through physical erosion and to chemical and biological degradation (El Beltagy, 2002). Higher amounts of phosphorus in site 2 can be attributed to the addition of animal manure by the free grazing livestock common in the site. Site 1 and 2 are excluded from the free grazing livestock. Animal manures and contain significant amounts of phosphorus in organic forms. Low levels of nitrogen in all the sites can be attributed to nitrogen losses due to number of factors namely; low levels of organic matter, runoff and soil erosion. Soil erosion is the most visible form of land degradation in the area. Higher amounts of potassium in sites 1 and 2 can also be attributed to higher clay mineral content in the soil. As the clays weather, the potassium ions sandwiched between the layers are released. Furthermore, the amount of this exchangeable potassium in a soil depends on the cation exchange capacity (CEC) of the soil.

4.8 VEGETATION CHARACTERISTICS

A summary of some of the vegetation attributes are summarized in table 9.

Table 9: Some vegetation attributes

	Plant Frequency (%)	Plant Density (Plants m ⁻²)	Basal Cover (%)	Seed Production (Kg/ha)
CC	44.4 ^a ± 19.63	7 ^a ± 5.23	30 ^c ± 26.44	145 ^{ab} ± 113
EM	72.3 ^a ± 25.43	36 ^b ± 21.79	54 ^{ab} ± 19.29	56 ^b ± 25
ES	38.7 ^a ± 9.82	5 ^a ± 6.25	23 ^c ± 15.44	191 ^a ± 117
CC/EM	38.9 ^a ± 25.53	28 ^b ± 23.06	34 ^{bc} ± 22.75	63 ^b ± 45
CC/ES	38.9 ^a ± 25.53	6 ^a ± 6.08	33 ^{bc} ± 16.03	168 ^{ab} ± 274
EM/ES	55.5 ^a ± 25.42	34 ^b ± 35.77	58 ^a ± 20.06	134 ^{ab} ± 43
CC/EM/ES	50.0 ^a ± 0	31 ^b ± 16.91	24 ^c ± 9.28	99 ^b ± 39

Notes: CC- *Cenchrus ciliaris*, EM- *Enteropogon macrostachyus*, ES- *Eragrostis superba*
Column means with different superscripts are significantly different at $p < 0.05$

4.8.1 PLANT FREQUENCY

Results showed no significant difference in plant frequency of the grasses as pure stands and mixtures. The differences observed in terms of frequency may be explained by the difference in morphology of the grass seeds and seed size which enhanced a higher germination percentage, thus percentage frequency. Seed size has an effect on seedling emergence. Higher frequency of occurrence of *Enteropogon macrostachyus* could be attributed to this, since it has a bigger seed size. In addition to this, *Enteropogon macrostachyus*'s dormancy mechanism which involves only the integument would explain its rapid imbibitions and germination relative to the other two grass species. The seed morphology of *Cenchrus ciliaris*, characterised by the hairy bristle coat, is likely to have aided germination by maintaining a high humidity within the fascicle and thereby helps reduce water loss from the caryopsis thus enhancing germination (Sharif-Zadeh and Murdoch, 2001) as compared to those of *Eragrostis superba*. In addition, these fascicles are known to contain more than one caryopsis (Daehler and Georgen, 2005).

4.8.2 PLANT POPULATION DENSITY

Results showed a significant difference ($p < 0.05$) in plant densities. On average, the grass mixtures had higher plant densities as compared to pure stands. The differences in plant densities among the pure grass stands can also be attributed to the seed morphology and seed size as discussed under plant frequency. However, the higher plant densities in the *Cenchrus ciliaris*-*Enteropogon macrostachyus* and *Eragrostis superba*-*Enteropogon macrostachyus* mixtures as compared to the *Cenchrus ciliaris*-*Eragrostis superba* mixture can be attributed to the presence of *Enteropogon macrostachyus* grass species in the two mixtures. This is also true for the *Cenchrus ciliaris*-*Enteropogon macrostachyus*-*Eragrostis superba* mixture. Similar results were obtained by Musimba *et al.* (2004) while working with the same grasses in the same study area.

4.8.3 PERCENTAGE BASAL COVER

Results showed a significant difference ($p < 0.05$) in percentage basal cover. On average the two grass mixture plots had a higher basal cover percentage of 42%, compared to plots under pure stands which had an average basal cover of 35%. Higher percentage basal cover of *Enteropogon macrostachyus* can be explained by the faster germination of the grass species giving it a head start in the normal plant competition. Lower basal covers of *Cenchrus ciliaris* and *Eragrostis superba* can be explained by their delay in germination. Higher percent basal cover in the plots with the *Enteropogon macrostachyus*-*Eragrostis superba* mixture can also be attributed to the faster germination of *Enteropogon macrostachyus* in the mixture, whereas the lower percentage basal cover in plots under *Cenchrus ciliaris*-*Enteropogon macrostachyus* and *Cenchrus ciliaris*-*Eragrostis superba* can be explained by the allelopathic nature of *Cenchrus ciliaris* in the mixture which suppresses the growth and establishment of the other grass species in the mixture.

4.8.4 SEED PRODUCTION

Results showed a significant difference ($p < 0.05$) in seed production. *Eragrostis superba* had the highest seed production in all the plots. *Cenchrus ciliaris* and *Enteropogon macrostachyus* were ranked second and third respectively in plots under pure grass

stands. Two grass mixtures with *Eragrostis superba* had higher seed yields than those without it.

The differences in seed production among the grass species can be attributed to the morphological characteristics of the grasses and the seeds. *Eragrostis superba* has much bigger spikelets of 6-16mm long and 3-10mm wide compared to *Cenchrus ciliaris* and *Enteropogon macrostachyus* which have spikelets measuring 3.5-5mm long and 7-10mm long respectively. In addition, *Eragrostis superba* has a higher spikelet density per inflorescence compared to the other two grasses thus a higher seed production.

4.8.5 BIOMASS PRODUCTION

Biomass production on dry matter basis of the grass species and weeds at different grass heights and is shown in table 10 and illustrated in figures 4.8, 4.9 and 4.10. Percentage biomass yield of the grass species and weeds is shown in table 11. The inverse relationship between biomass yields of planted grasses and weeds is illustrated in figure 4.11.

Table 10: Biomass yields on dry matter basis (Kg/ha) at different stubble heights

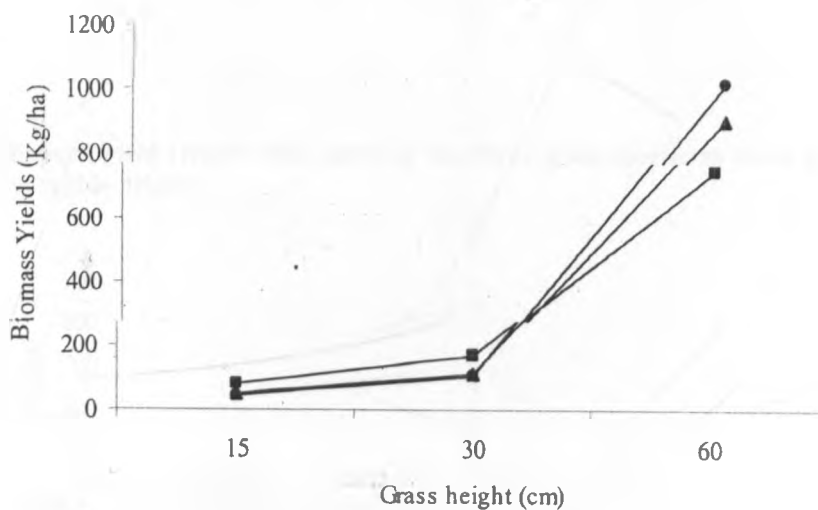
Plot	Biomass Kg/ha (DM)					
	15cm		30cm		60cm	
	Grass	Weeds	Grass	Weeds	Grass	Weeds
CC	44.2 ^a ± 35.1	360.8	104.2 ^a ± 44.6	85.56	1026.6 ^b ± 557.9	37.16
EM	83.9 ^a ± 43.5	662.4	168.0 ^a ± 88.6	70.04	744.0 ^b ± 289.0	52.92
ES	47.0 ^a ± 24.2	386.4	109.8 ^a ± 56.8	66.36	896.5 ^b ± 447.0	58.60
CC/EM	32.0 ^a ± 22.1	308.4	144.0 ^a ± 36.7	63.12	780.9 ^b ± 511.2	49.72
CC/ES	43.4 ^a ± 29.6	309.5	169.2 ^a ± 77.6	71.16	808.3 ^b ± 617.7	39.64
EM/ES	59.0 ^a ± 56.3	398.8	164.8 ^a ± 90.5	62.36	709.3 ^b ± 183.5	53.04
CC/EM/ES	100.6 ^a ± 42.8	375.3	281.9 ^b ± 99.4	64.28	792.2 ^c ± 166.9	138.36

Notes: CC- *Cenchrus ciliaris*, EM- *Enteropogon macrostachyus*, ES- *Eragrostis superba*
Row means with different superscripts are significantly different at p < 0.05

Table 11: Percentages of the total biomass yield of the grasses and weeds at different heights

Plot	Percentage (%)					
	15cm		30cm		60cm	
	Grass	Weeds	Grass	Weeds	Grass	Weeds
CC	11%	89%	55%	45%	96%	4%
EM	11%	89%	71%	29%	93%	7%
ES	6%	94%	62%	38%	94%	6%
CC/EM	9%	91%	70%	30%	94%	6%
CC/ES	12%	88%	70%	30%	95%	5%
EM/ES	16%	84%	73%	27%	93%	7%
CC/EM/ES	21%	79%	75%	25%	86%	14%

Figure 4.8 Biomass yield (Kg/ha DM) curves of the three grass species as pure stands at different heights



—▲— *Eragrostis superba* —■— *Enteropogon macrostachyus* —●— *Cenchrus ciliaris*

Figure 4.9 Biomass yield (Kg/ha DM) curves of the three grass species as two grass mixtures at different grass stubble heights

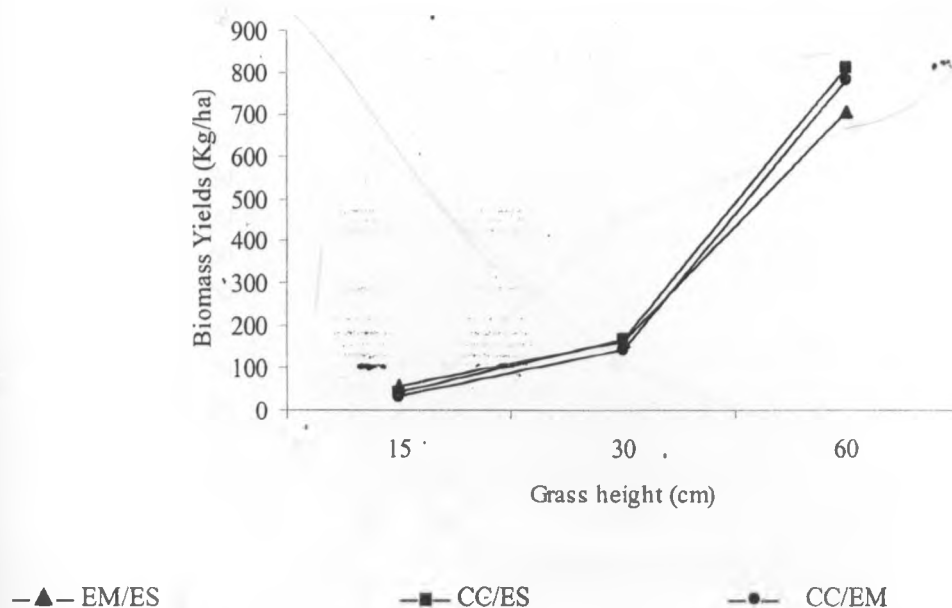


Figure 4.10 Biomass yield (Kg/ha DM) curve of the three grass species as three grass mixtures at different grass stubble heights

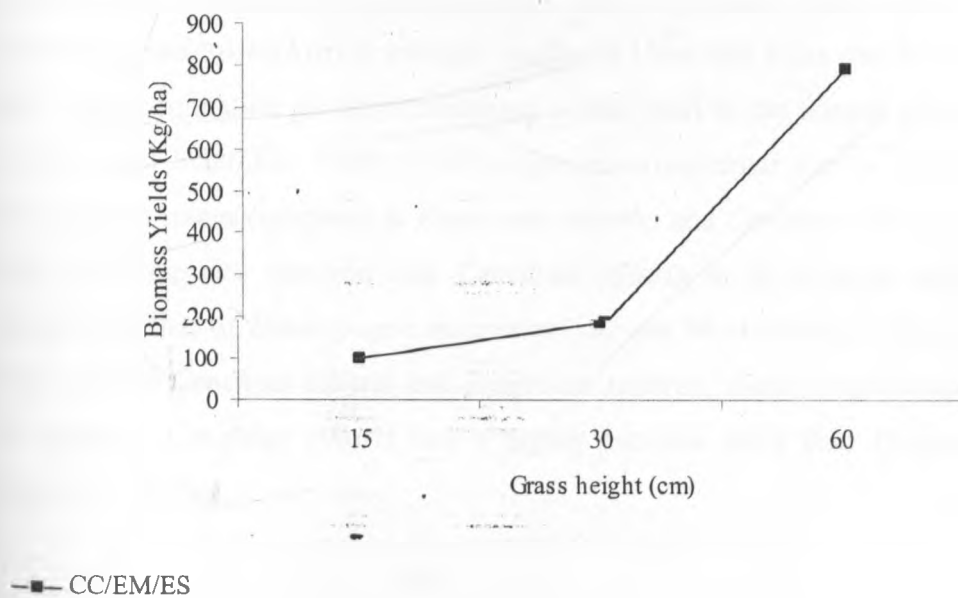
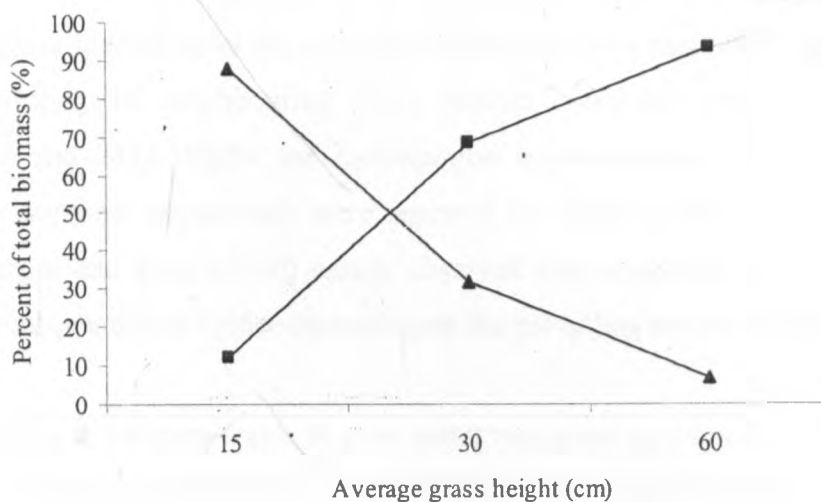


Figure 4.11 Inverse relationship curve of percent total biomass yields (Kg/ha) between planted grasses and weeds



—■— Percent Grass —▲— Percent Weeds

Results showed that there was a significant difference ($p < 0.05$) in biomass yields at different grass heights in all the grasses. The difference in biomass yields in plots under pure grass stands across the different grass stubble heights can be attributed to the growth characteristics and morphological properties of the grasses. Higher biomass yields of *Enteropogon macrostachyus* at average heights of 15cm and 30cm can be attributed to its faster seed germination giving its seedlings a head start in the normal plant competition (Kadmon and Shimida, 1990). *Enteropogon macrostachyus* moves faster through the initial growth stages compared to *Eragrostis superba* and *Cenchrus ciliaris*. Higher grass yields of *Eragrostis superba* and *Cenchrus ciliaris* at an average height of 60cm compared to that of *Enteropogon macrostachyus* can be attributed to the more stemmy nature of both *Cenchrus ciliaris* and *Eragrostis superba*. *Enteropogon macrostachyus* is less stemmy. *Cenchrus ciliaris* had a higher biomass yield than *Eragrostis superba* because it is leafier.

The results showed that aboveground biomass production of the three grass species used were different. This is comparable to the results of Chelishie and Kitanyi (2002) who reported that these grass species have different aboveground biomass yields. These results of biomass yields in site 3 were however much lower compared to the biomass yields of the same grass species under the same land treatment under rainfall as reported by Opiyo (2007) working in neighbouring Kitui district. Biomass yields of 4908.5Kg/ha, 3734Kg/ha and 2434.5Kg/ha for *Enteropogon macrostachyus*, *Cenchrus ciliaris* and *Eragrostis superba* respectively were reported by Opiyo (2007). This confirms what Reichenberger and Pyke (1990) earlier observed that rangeland grasses are known to yield various quantity of fodder depending on the prevailing environmental conditions.

The difference in biomass yields in plots under two grass mixtures can also be attributed to their growth characteristics, morphological and physiological properties and competitive advantage of the grass species. Higher biomass yields of the plots under *Enteropogon macrostachyus*-*Eragrostis superba* at an average grass height of 15cm can be attributed to the faster germination and growth of grass seedlings of *Enteropogon macrostachyus* in the mixture. Lower biomass yields at a height of 15cm of plots under *Cenchrus ciliaris*-*Eragrostis superba* and *Cenchrus ciliaris*-*Enteropogon macrostachyus* can be explained by the allelopathic nature of *Cenchrus ciliaris* which suppresses other species by exuding phytotoxic chemicals that inhibit germination and growth of other plants.

At an average grass height of 30cm, higher biomass yields of plots under *Cenchrus ciliaris*-*Eragrostis superba* mixture can be attributed to the initial development steeper culms of these two grasses. Lower yields of *Cenchrus ciliaris*-*Enteropogon macrostachyus* mixture can still be attributed to the allelopathic nature of *Cenchrus ciliaris*. Results show therefore that *Enteropogon macrostachyus* is less competitive compared to *Eragrostis superba* when planted with *Cenchrus ciliaris*. Higher biomass yields in plots under *Cenchrus ciliaris*-*Eragrostis superba* at an average height of 60cm can be explained by the steeper nature of the two grass species. Higher biomass yields of plots under *Cenchrus ciliaris*-*Enteropogon macrostachyus* compared to plots under

Eragrostis superba-*Enteropogon macrostachyus* can be explained by the higher biomass yields of *Cenchrus ciliaris* than *Eragrostis superba* in the mixtures since *Enteropogon macrostachyus* is less competitive than these two grass species, thus cannot suppress either.

The inverse relationship in biomass yields between the grasses planted and the weeds can be explained by the longevity of the planted grasses and weeds. The planted grasses are perennials compared to the weeds in the area which are mostly annuals. The annuals have a competitive advantage at the early stages of development but are out competed by the perennial grasses at later stages. The perennials have a deeper root system compared to the annuals thus out-compete the weeds for water and nutrients from the soil.

4.8.6 TILLER DENSITY

A summary of the results of tiller densities are summarized in table 12 below.

Table 12: Tiller densities of the three grass species

Grass species	Tiller density (tillers per shoot)	
	Pure stands	Two grass mixture
CC	14 ^a ± 3.21	9 ^b ± 2.31
EM	17 ^a ± 3.7	7 ^b ± 1.36
ES	13 ^a ± 5.9	6 ^b ± 2.95

Notes: CC- *Cenchrus ciliaris*, EM- *Enteropogon macrostachyus*, ES- *Eragrostis superba*

Row means with different superscripts (c,d) are significantly different at $p < 0.05$

Results showed that there was a significant difference ($p < 0.05$) in tiller densities in all the three grasses in pure stands and in two grass mixtures. In this study, *Enteropogon macrostachyus* would be at an advantage than *Cenchrus ciliaris* and *Eragrostis superba*. Further, large numbers of tillers and leaves produced by some grasses such as *Panicum maximum* and *Digitaria microblephara* allow the grasses to attain maximum growth rate at an earlier age and recover soon after defoliation (Woie, 1986; Skerman and Riveros, 1990). Studies by Hacker (1989), Skerman and Riveros (1990) and Laidlaw (2005) showed that tillers are known to increase plants chances of survival and amount of foliage cover. This agrees with the findings of this study, that grass species with highest number of tillers had the highest percent foliage cover. Lower tiller density in the grass mixtures

could be attributed to competition among the grass species for water and nutrients in the soil and space. *Eragrostis superba* maintained a relatively low number of tillers both in pure stands and as two grass mixtures.

Tillering is important in forage plants because of its influence on leaf-area production and dry matter yield. A high rate of tillering would be beneficial in attaining high yields and maintaining a grass stand under defoliation.

4.9 DESCRIPTIVE STATISTICS

4.9.1 GRASS RESEEDING TECHNOLOGY UPTAKE

The survey conducted showed that 76% of the total farmers interviewed practice grass reseeding technology in their individual farms. The farmers mentioned a number of ways in which they came to learn about the technology namely; radio, extension officers in the area, neighbours and friends, local informal forums and development projects and research institutes like Kenya Agricultural Research Institute, K.A.R.I. and Kenya Forestry Research Institute, K.E.F.R.I. Results showed that development projects in the area like the Drylands Husbandry Project, D.H.P. and research institutes like K.A.R.I. and K.E.F.R.I. had the largest influence in educating and informing the farmers about the reseeding technology. The survey showed that 58% of the farmers interviewed got the knowledge of grass reseeding technology from such development projects and research institutes in the area of study. This can be attributed to the proximity of research institutes like K.A.R.I. Kiboko to the area residents. Open field days and field demonstrations in collaboration with the farmers was cited as one of the channels of disseminating the reseeding knowledge.

The survey results also showed that 92% of all the farmers who practice grass reseeding got their initial seeds from the development projects and research institutes. None of the farmers paid for these seeds. Only 13% of the farmers had their own initial seeds harvested from their farms or in the open bushland where they naturally grow. However, currently, 85% of the farmers source their seeds from their own individual farms and only

13% still depend on developments projects and research institutes. The local farmers currently harvest and store their own seeds in readiness for sowing and/or selling.

4.9.2 GRASSES USED FOR RESEEDING AND THEIR USES

Results showed that four grasses are commonly used in Kibwezi district for reseeded namely *Eragrostis superba*, *Enteropogon macrostachyus*, *Cenchrus ciliaris* and *Chloris roxburghiana*. *Eragrostis superba* is the most popular, and was ranked first among the four grass species used for reseeded. Out of all the farmers who practice grass reseeded technology, 97% of them plant *Eragrostis superba*. *Cenchrus ciliaris*, *Chloris roxburghiana* and *Enteropogon macrostachyus* were ranked second, third and fourth with 63%, 39% and 37% respectively. Higher preference of *Eragrostis superba* to the other grasses was primarily attributed to its role in milk production and fattening in cattle. In addition, as a result of its good taste to cattle, the local farmers have also observed that when all the grass species are available for grazing, the cattle will first feed on *Eragrostis superba* and later on the other grasses. This can also be attributed to its high levels of crude protein. Bogdan and Pratt (1967) reported a 12% C.P. in dry matter at an early-flowering stage with 30-35% percent crude fibre (%C.F.). Wasonga *et al.* (2003) also reported that the Pokot community of Kenya has identified *Eragrostis superba* as one of the grass species suitable for fattening and improving the condition of their livestock herd. Furthermore, the farmers also noted that due to its big sized spikelets, it's easy to harvest the grass seeds.

Although the local grasses are known to rehabilitate degraded rangelands, most of the farmers have planted the grasses primarily to satisfy their household needs, particularly as:

- Source of animal feed
- Source of income through the sale of grass seeds, milk and hay
- Raw materials for thatching their houses and granaries

The local farmers prefer these grasses due to their grazing resistance, drought tolerance, seed availability and soil conservation. *Cenchrus ciliaris* was noted to be good in soil conservation and is normally planted in the farms to stabilize the terraces. In addition, during the rains when the soil is moist, *Cenchrus ciliaris* is normally uprooted from other

places and planted near terraces for soil conservation. This can be attributed to its deep and strong fibrous root system to $> 2\text{m}$. *Enteropogon macrostachyus* is least preferred since it produces less leafy biomass and can be easily be uprooted by the grazing cattle especially during the rains when the soils are moist. In addition, *Enteropogon macrostachyus* is highly susceptible to termite attacks.

4.9.3 GRASS RESEEDING TECHNOLOGY

Kibwezi district receives a bimodal type of rainfall pattern (Nyangito *et al.* 2008) with the long rains coming between March and May and the short rains coming in November and December. The results from the survey showed that 95% of the farmers who practice the technology, rely on rainfall as a source of water for their reseeded areas, while only 5% rely on nearby rivers. All the farmers who practice reseeding sow their grass seeds during the short rains which are more reliable compared to the long rains. This is because of the higher rainfall totals and that the short rains have a shorter dry spell of about three months compared to six months after the long rains. Descriptive statistics showed that 76% of the farmers who practice reseeding sow their seeds prior to the short rains. Proper timing is critical in any successful rehabilitation. Most of the farmers sow the seeds prior to the rains in preparation of the coming rains. This agrees with the findings of Biamah (2005), that most farmers in the semi-arid environments prefer early tillage operations and dry planting before the onset of the rains. Local farmers also prefer this period because there is plenty of time compared to when they are busy cultivating their farms. 11% sow their seeds just after the start of the rains while 13% sow both during and just after the start of the rains. The farmers who sow their seeds just after the rains do so to avoid seed wastage, by ensuring that the seedlings will have enough moisture for growth and minimise destruction by pests and rodents common during dry planting. *Quelea quelea* birds common in the study area were cited to feed on the sowed grass seeds especially those of *Eragrostis superba*. This results in reduced germination. However, those who plant grass seeds prior to the rains cited poor establishment when seeds are planted in wet conditions since the small grass seeds will be deeply covered by the mud.

Previous attempts to restore cover in Kenya using reseedling has shown that some form of seed bed preparation and a degree of seedling protection in keeping with site requirements are some of the fundamental requirements for successful rehabilitation (Opiyo, 2007). Descriptive statistics show that 82% of the farmers use hand held hoes, 71% use an ox-driven ploughs and 3% use a tractor, for seed bed preparation. Seed bed preparation involves minimal soil disturbance to create micro-catchments to trap enough moisture. This is done to break the hard soil crust in the upper soil horizons thus improve water infiltration and root penetration after establishment. In addition to this, 95% of the farmers who practice the technology have put up fences using locally available materials, for example, *Acacia* branches around the reseeded plots. This is primarily done to exclude livestock from trampling on the grass seedlings. 5% of the farmers who had not put a fence around their reseeded plots cited no disturbance from grazing livestock from their neighbours.

4.9.4 METHODS AND PATTERNS OF SOWING

The results show that there are basically two methods of sowing grass seed among the agropastoral Kamba community in Kibwezi district namely; hand-sowing along created micro-catchments and broadcasting. Descriptive statistics show that 52% of the farmers who reseed do so along created micro-catchments. 26% of the farmers prefer broadcasting whereas 22% use both the hand sowing and broadcasting. Higher preference to the hand sowing method along microcatchments was highly influenced by the development projects and research institutions in the area which proposed the method for better germination and establishment of the sown grasses. The seeds are sown along created micro-catchments to ensure that the seed bed retains enough moisture to trigger germination and sustain growth of the grass seedlings and reduce soil loss through runoff. The farmers who use broadcasting method of sowing prefer this method because it is quick, time saving, requires less expertise and the farmer can cover a larger area of land within a short duration of time.

The survey results also showed that the farmers practice different patterns of sowing. 55% of the farmers sow their seeds as pure stands, whereas 18% and 26% sow the grass

seeds as mixtures and both pure stands and mixtures, respectively. Most of the farmers prefer sowing the grass seeds as pure stands because of the following reasons;

- Easy to harvest grass seeds
- Easy to work on in the farm
- Better biomass yields compared to mixtures
- Maintain the variety of every grass species

However, the farmers who plant the grasses in mixtures also cited the following advantages of mixtures over pure stands;

- Spread the risks in case one particular grass species fails to establish.
- Enjoy the multiple benefits of all the grasses planted
- Reduce diet selectivity among the cattle during grazing.
- Ensure a wider diet variety for the grazing animals.
- Have the seeds of all the grasses.

Results also showed that the farmers who planted grass seed both as pure stands and mixtures do so to compare results to see which among the two methods gives better results. Among the farmers who plant grass in mixture, *Cenchrus ciliaris-Chloris roxburghiana* mixture is the most common type of grass mixture, with 86% of the farmers practicing it in their farms. *Cenchrus ciliaris-Eragrostis superba* and *Cenchrus ciliaris-Enteropogon macrostachyus* mixtures were jointly ranked second with 57% followed by *Eragrostis superba-Enteropogon macrostachyus* mixture with 29%.

From these results, the following are some of the factors contributing to successful rehabilitation of degraded lands using the grass reseeding technology in the study area:

- Use of the indigenous grass seeds for reseeding
- Soil disturbance and creation of micro-catchments for water harvesting and retention
- Fencing of rehabilitation plots to keep of livestock
- Proper sowing time

4.9.5 REHABILITATION FAILURES

Rehabilitating degraded rangelands in the arid and semi-arid environments is a risky and costly. 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. Results from the survey showed that 92% of all the farmers who practice grass reseeding have experienced rehabilitation failures in more than one occasion. Reasons for rehabilitation failures in order of significance include;

- Recurrent droughts
- Low amounts of rainfall
- Destruction by livestock
- Poor sowing time
- Poor skills and lack of knowledge
- Poor quality seeds
- Soil erosion through flash floods
- Destruction by pests and rodents

Climatic factors appear to be the main contributor of rehabilitation failures in the study area. An increased frequency of the occurrence of droughts from once in every ten years to once in every five years and low amounts of rainfall below the long-term average annual rainfall of the study area were cited to be the main contributors of rehabilitation failures. Only 8% of the farmers have never experienced failures. They attributed it primarily on good timing and use of fencing.

4.9.6 LAND DEGRADATION

The results from the survey show that all the farmers interviewed agree that land degradation is a problem facing them, citing a change in vegetation cover from the more preferred grasslands to a more bushy vegetation type. The causes of land degradation in the arid, semi-arid and sub-humid climate are many and varied (IFAD, 1998). Some researchers consider climate to be the major contributor to the degradation processes, with human factors playing a relatively minor supporting role. Other researchers reverse the significance of these two factors. A third group of researchers blame climate and man more or less equally (Glantz and Orlovsky, 1983). The causes of land degradation in the

study area can also be divided into climatic factors and human factors. 96% of all the farmers interviewed cited climatic factors namely recurrent droughts and low amounts of rainfall as the greatest contributor of land degradation in the area. Human factors included overgrazing as a result of overstocking, charcoal burning, poor agricultural practices and lack of government support, increase in human population and private land ownership.

4.10 FACTORS INFLUENCING CHANGE IN GRASSLAND COVER

4.10.1 DESCRIPTIVE DATA OF THE ANALYSIS

Before discussing the results of the regression analysis, perhaps it would be interesting to present some of the descriptive data of the analysis. Table 13 shows values of variables used over the 35 year period, using five-year moving averages. The mean annual rainfall over the period was 70.67cm. The data indicate that the annual rainfall in the study area ranged between 89.68cm (in 1981) and 54.42cm (in 1987). The plot in figure 4.12 shows the cyclic pattern of rainfall common in the study area. Low amounts of rainfall (dry spells) were recorded at an interval of approximately five years throughout the period, the reason behind using the five-year moving averages in this descriptive analysis. High annual rainfall totals recorded in the years 1981, 1992 and 1999 were followed by periods of low annual rainfall in the years 1986, 1997 and 2004 respectively over the whole period.

Table 13 shows a general increase in human population, livestock population and area under cultivation. An increase in livestock numbers and area under cultivation can be attributed to the general increase in the human population. The wide range in human population during the 35 year period suggests a high rate of population growth. Increased human populations in the semi-arid environments relative to what the land can support leads to attempts to grow too many crops and keep too many livestock. As a result, grazing lands are being converted to farmlands, thus reducing the area available for the free grazing animals. This increases grazing pressure, which consequently leads to a reduction of the area under grass cover. This gives woody species a competitive

advantage over grasses. Grassland cover had a wider range of 7.56%, compared to the woodland cover which had a range of 0.77%. This suggests that the area under grass cover has been declining at a faster rate than the invasion of woody species. Woody species take a longer period to colonize an area. The data in Table 13 show a steady decline in the area under grass cover and a general upward trend in area under woody species. Figures 4.12 and 4.13 clearly illustrates these trends.

Table 13: Sample means and ranges of variables over the period 1973-2007 (5-year moving averages)

Year	Rainfall (cm)	Livestock Numbers (‘000)	Grassland Cover (%)	Human Popn (‘000)	Woodland Cover (%)	Cultivated land (%)
1977	59.50	172.60	41.55	91.81	51.54	3.52
1978	67.85	173.75	41.38	92.74	51.55	3.55
1979	80.46	176.03	41.21	93.84	51.57	3.61
1980	85.14	179.58	41.04	95.39	51.59	3.70
1981	89.68	183.27	40.99	97.77	51.60	3.76
1982	87.86	186.11	40.79	99.84	51.62	3.89
1983	76.42	189.30	40.55	103.33	51.65	4.05
1984	65.24	191.22	40.37	106.34	51.68	4.19
1985	66.92	192.39	40.19	111.01	51.71	4.34
1986	66.52	193.82	39.90	116.67	51.74	4.57
1987	54.42	195.33	39.60	123.31	51.76	4.78
1988	66.88	196.49	39.38	128.52	51.79	4.94
1989	69.26	197.76	39.17	133.74	51.82	5.17
1990	78.86	198.50	38.80	138.45	51.85	5.35
1991	76.44	198.88	38.55	141.04	51.88	5.56
1992	81.36	199.40	38.35	145.89	51.92	5.77
1993	75.54	199.86	38.15	151.24	51.95	5.98
1994	74.00	200.27	37.80	156.58	51.98	6.19
1995	62.40	200.58	37.55	161.04	52.00	6.40
1996	61.46	201.22	37.35	166.26	52.04	6.71
1997	68.26	198.09	37.15	169.92	52.08	6.77
1998	76.74	198.50	36.80	174.77	52.11	7.01
1999	78.36	197.30	36.55	181.30	52.13	7.21
2000	74.86	196.00	36.30	193.21	52.16	7.47
2001	77.18	195.96	36.00	210.51	52.19	7.72
2002	69.32	199.92	35.64	232.23	52.22	7.95
2003	56.80	202.32	35.37	256.18	52.26	8.14
2004	56.70	217.86	35.03	278.44	52.28	8.32
2005	56.54	222.06	34.68	300.44	52.32	8.46
2006	63.50	231.98	34.32	322.15	52.35	8.54
2007	66.20	246.38	33.99	337.73	52.38	8.59
Mean	70.67±9.48	197.89±15.62	38.21±2.31	164.89±70.61	51.93±0.27	5.88±1.73
Range	35.26	75.78	7.56	245.94	0.77	5.07

Figure 4.12: Trends in rainfall, woodland cover, grassland cover and cultivated land area, 1973-2007 (5 year moving averages)

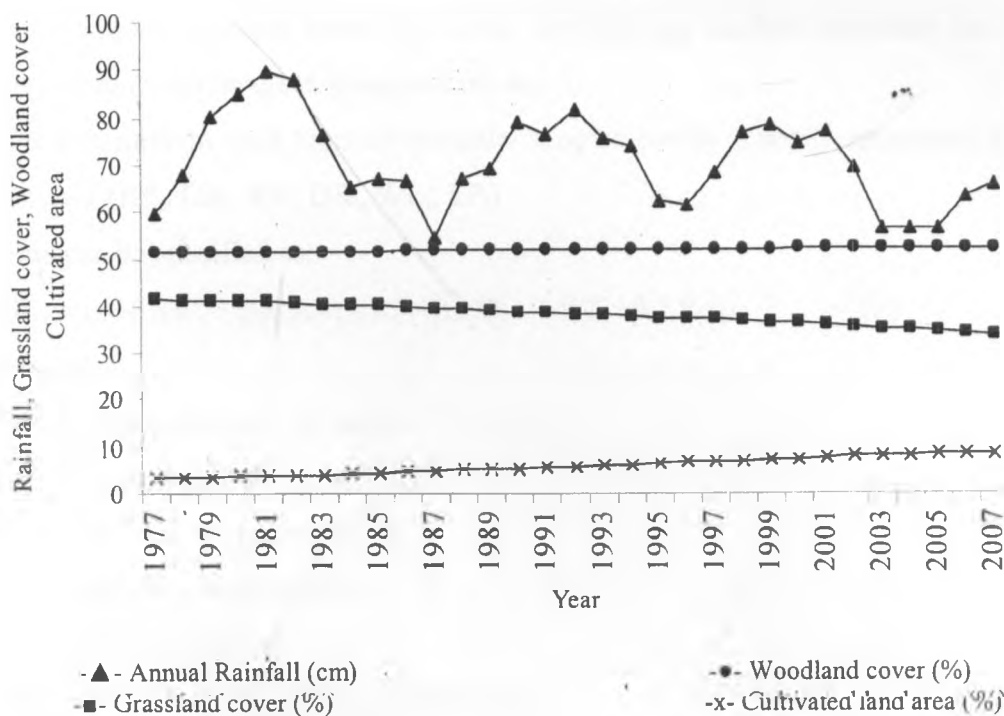
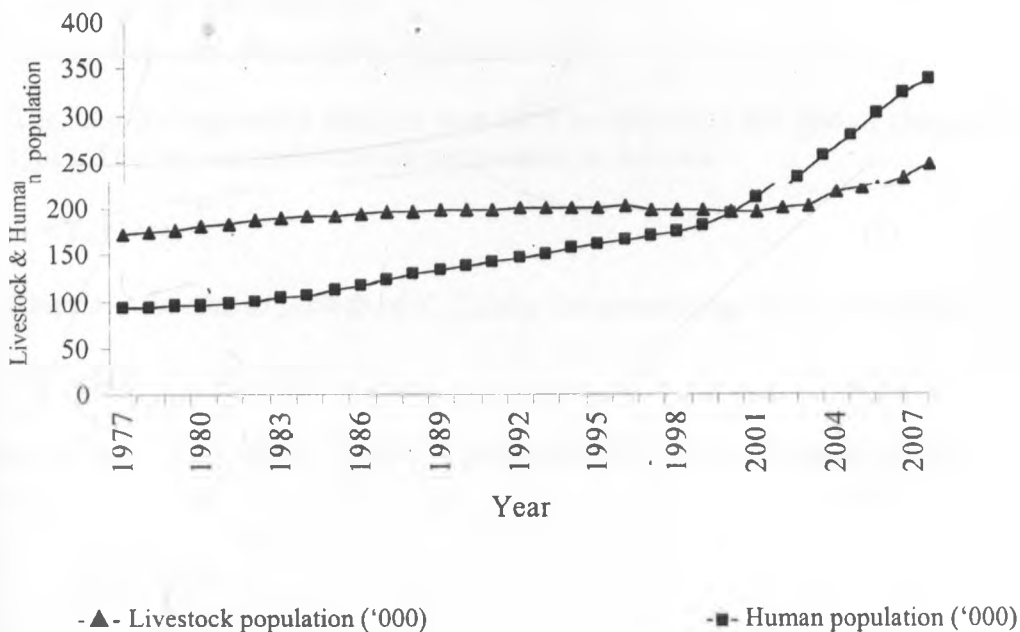


Figure 4.13: Trends in human and livestock populations, 1973-2007 (5 year moving averages)



4.10.2 REGRESSION ANALYSIS

A time-series multiple linear regression analysis was used to determine the factors that are influencing change in grassland cover.

The non-random walk time-series model adopted can be generally expressed as:

$$GC_t = f(HP_t, CA_t, RF_t, DR_t, WL_t, LP_t)$$

This can be specified as:

$$GC_t = \alpha + \beta_1 HP_t + \beta_2 CA_t + \beta_3 RF_t + \beta_4 DR_t + \beta_5 WL_t + \beta_6 LP_t + \mu_t \quad (1)$$

Where:

GC_t = Grassland cover at time t

HP_t = Human population at time t

CA_t = Cultivated area at time t

RF_t = Rainfall totals at time t

DR_t = Drought at time t

WL_t = Woodland vegetation cover at time t

LP_t = Livestock population at time t

α = constant

$\beta_1, \beta_2, \dots, \beta_7$ = regression parameter estimators

μ_t = error term at time t

4.10.2.1 *The rate of change of vegetation types*

The Log-lin regression analysis was used to determine the rate of change in vegetation types. The log-lin model can be represented as follows:

$$Y_t = Y_0 (1+r)^t \quad (2)$$

Where r is the rate of growth of Y . Taking the natural logs of (2), we obtain:

$$\ln Y_t = \ln Y_0 + t \ln (1+r) \quad (3)$$

Assuming $\alpha = \ln Y_0$ and $\beta = \ln (1+r)$, then equation (3) can be expressed as:

$$\ln Y_t = \alpha + \beta t + \mu_t \quad (4)$$

$$\beta = \frac{\text{Relative } \Delta \text{ in } Y_t}{\text{Absolute } \Delta \text{ in time } (t)}$$

The interpretation of the regression results of equation (4) in the present case is that over the period 1973-2007, Y_t increased or decreased at a rate given by $\beta \times 100$ percent per year.

Table 14 presents the results of the time-series regression analysis to determine the factors influencing change in grassland vegetation. Time-series data are known to exhibit the problem of random walk, which leads to misleading parameter estimates. This necessitated the unit root test of stationarity of the variables before estimating equation (1). The test showed that the variables represented stationary time-series at 5% level of significance. To illustrate with livestock numbers, which are expected to rise alongside grazing land since there would be need for more grazing resources as the livestock population expands, the following equation was used:

$$\Delta LP_t = \alpha_1 + \delta LP_{t-1} + \mu_t$$

Where: ΔLP_t is the first-difference of livestock numbers, and the null hypothesis is set at $\delta=0$. The presence of a unit root problem in the data would lead to δ being equal to zero.

The results were as follows:

$$\begin{aligned} \Delta LP_t &= 1.846 - 0.079 LP_{t-1} \\ t &= (0.911) \quad (-3.432) \\ r^2 &= 0.195 \quad d = (2.103) \end{aligned} \quad (5)$$

Since the results in equation (5) suggest that the error term is not autocorrelated—based on the Durbin-Watson (d) test—the stationarity of livestock numbers can be proved by the Dickey-Fuller (DF) test, using the t -value (τ statistic). Since the computed τ value is 3.432, in absolute terms, which is greater than the 5% critical (DF) value of -2.895, the data did not exhibit random walk.

Table 14: The factors influencing change in grassland vegetation cover

Variables	β	SE	t-value
Constant	2.90315×10^2	81.486	3.563*
Rainfall, RT_t	-2.51×10^{-4}	.000	-1.305
Drought, DR_t	2.74×10^{-1}	.135	2.026
Livestock popn., LP_t	-1.15×10^{-5}	.000	-3.818*
Human popn., HP_t	9.995×10^{-7}	.000	1.086
Cultivated area, CA_t	-4.752	1.604	-2.964*
Woodland, WL_t	-5.62	.246	-2.281*

Notes: * Significant at 5%, $F = 834.214^*$, $R^2 = 0.994$, Adj. $R^2 = 0.993$, DW = 1.932

The rates of change of the various factors using the Log-lin regression model are presented below:

Grassland cover

$$\begin{aligned}
 \ln Y_t &= \alpha + \beta_t + \mu_t & r^2 &= 0.980 \\
 \ln Y_t &= 3.76 - 0.00669_t \\
 se &= (0.003) \quad (.000) \\
 t &= (1083.046) \quad (-39.793) \\
 P \text{ value} &= (.000)^* \quad (.000)^* & & \text{*Significant at 5\%} \\
 \beta &= -6.69 \times 10^{-3} \\
 \% \beta &= -0.669\%
 \end{aligned}$$

Woodland cover

$$\begin{aligned}
 \ln Y_t &= \alpha + \beta_t + \mu_t & r^2 &= 0.982 \\
 \ln Y_t &= 2.637 + 0.181_t \\
 se &= (0.088) \quad (.004) \\
 t &= (30.112) \quad (42.639) \\
 P \text{ value} &= (.000)^* \quad (.000)^* & & \text{*Significant at 5\%} \\
 \beta &= 0.181 \\
 \% \beta &= 18.1\%
 \end{aligned}$$

Cultivated land

$$\begin{aligned}
 \ln Y_t &= \alpha + \beta_t + \mu_t & r^2 &= 0.992 \\
 \ln Y_t &= 51.413 + 0.02875_t
 \end{aligned}$$

se	= (0.009)	(.000)	
t	= (5625.142)	(64.925)	
P value	= (.000)*	(.000)*	*Significant at 5%

β	= 2.875×10^{-2}
$\% \beta$	= 2.875%

The results in Table 14 show that livestock population has a significant and negative effect on grassland vegetation cover. Previous studies have shown that continuous grazing is apt to have a negative impact on soil, forage production and plant diversity. Overgrazing by large livestock herds reduces the forage production and plant diversity of an area by reducing grass cover. Increased livestock numbers decrease the grazing land available per livestock. Continuous grazing reduces the quality and quantity of available grass.

The log-lin regression results on grassland cover reveal that there has been an annual rate of decrease in grassland cover by 0.669% over the period of 35 years (between 1973 and 2007). This confirms the Walter's two-layer model which maintains that if the grass layer is overutilised, e.g. by overgrazing, it loses its competitive advantage and can no longer use water and nutrients efficiently. The two layer theory is still widely accepted (Skarpe, 1990). Increased livestock numbers also suppress the establishment of new grass seedlings through the trampling effect.

Higher livestock numbers lead to competition which results in the over-exploitation of available forage resources. Increased livestock numbers grazing on the newly established grass seedlings at the early vegetative growth before seed setting deprive the soil of its seed bank. This finally causes a reduction of grass cover over a period of time. In managing Kenya's arid and semi-arid environments, grazing plans must allow for adequate residual plant material in the stubble during the growing season to support livestock maintenance during the dry season and to assure sufficient leaf tissue for subsequent regrowth.

Continuous grazing, common in the study area, removes most of the photosynthetic area of the grass, which in turn affects the root growth. According to Tueller (1973), heavy grazing removes especially the leaves of grasses and forbs to such an extent that photosynthesis can be severely curtailed. Such extended periods of use result in permanent damage to the pastures. These results—an increase in the woody and shrub component at the expense of grasses—are in agreement with established principles of range management and most community ecology literature regarding the impact of herbivory on plant community structure (Stoddart *et al.*, 1975; McNaughton, 1979).

The regression results in Table 14 indicate that the area under cultivation has a significant and negative effect on the area under grass, while the results of the log-lin regression indicate that land under cultivation has been increasing at an annual rate of 2.875%. This can be attributed to changes in land tenure policy, both officially and customary, which has led to privatization and fragmentation of former communal holdings which were used as grazing lands. Land formerly under a natural grass cover is increasingly being converted to farmland to provide food for the increasing human population. Encroachment of farmlands on former grazing lands has greatly reduced access to dry-season grazing resources. Conversion of formerly grazing areas to cultivated areas not only shrinks the grazing resource base but also exposes the land to agents of erosion, namely water and wind, since arid and semi-arid ecosystems are fragile and susceptible to land degradation.

Most research has focused on the effect of woody plants on grass production (Archer *et al.*, 2002). The results in the current study (Table 14) showed that woodland vegetation has a significant and negative effect on the area covered by grass. Despite the recognition of woody plant encroachment as a worldwide rangeland management problem, little is known about the rates and dynamics of the phenomenon or its impact on fundamental ecological processes related to energy flow, nutrient cycling and its effect on biodiversity (Archer *et al.*, 2002). Ecological changes are manifested by a progressive growth in bush encroachment, which is a common cause of herbaceous vegetation loss in dry savannas and is responsible for the decline in range condition (Oba *et al.*, 2000; Angassa, 2005).

In this study, the log-lin regression gave an annual rate of increase of 18.1% of woodland over the period of 35 years. According to Roques *et al.* (2001), the proximate causes of woody plant encroachment are still poorly understood, but land use practices, including heavy grazing and anthropogenic reduction in fire regimes, are suspected to facilitate the process. Over-exploitation of grasses through overgrazing gives woody species a competitive advantage over the grasses. Woody species tap on the available moisture and nutrients available in the sub-soil which are inaccessible to the shallower roots of grasses. Continued growth of woody species also suppresses the growth of grasses through the shading effect. These woody species greatly reduce the amount of ultra-violet radiation reaching the herbaceous grass layer, which in turn affects its physiological processes.

Although the amount of rainfall, droughts and an increase in human population were expected to have an impact on the change in grassland cover, the results showed that these variables had no significant effect on the area under grass cover. Drought periods (rainfall of less than 450mm per year) were less frequent occurring only five times during the 35 year period. These long intervals of drought occurrences allowed the grasses to recover with the coming of the consecutive rains. The annual rainfall totals over the period of 35 years were generally over 450mm, which was sufficient for the survival of the grasses which are mostly drought tolerant. An increase in human population has led to the reduction in farm sizes and as a result one of the local community's options has been eliminated. Therefore, income generation must now come from greater intensification on already small farms or the development of new occupations, for example, in the processing and services sectors of the economy. Most of the inhabitants have opted to seek alternative sources of income in nearby towns, and thus have helped reduce over-reliance on the land resource as their source of income.

From the regression results and discussion above, it is clear that increased livestock numbers, increase in woodland vegetation and the encroachment of grazing areas by cultivators have a significant negative effect on grass cover. These results agree with those of Too *et al.* (1986) who attributed the general decline in range productivity to

overgrazing, invasion of brush species and encroachment of better grazing areas by cultivators. The results show that human activity rather than climatic factors are the more important contributors to land degradation in the study area.

CHAPTER FIVE

GENERAL DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

5.1 GENERAL DISCUSSIONS

The results from this ecological study in the semi-arid district of Kibwezi have significant implications for dryland rehabilitation using indigenous grasses. Generally, seed viability of *Enteropogon macrostachyus* was greater than that of *Cenchrus ciliaris* while *Cenchrus ciliaris* had higher percent seed germination than *Eragrostis superba*. The seeds showed a higher viability under different ambient temperatures and after breaking their seed dormancy. These differences are attributed to both the intrinsic properties of the seeds such as dormancy and tegumental hardness and the prevailing environmental conditions, especially ambient temperatures. Therefore, to ensure successful reseeding in this dryland ecosystem, it is necessary to determine whether the grass seeds being used are viable for range rehabilitation.

This study also shows that even though other fundamental requirements namely; seedbed preparation, soil disturbance, fencing, seed protection, and the use of appropriate grass seed were necessary for successful rehabilitation, reasonable amount of rain during the establishment season was the most important. Poor establishment in sites 1 and 2 under rainfall, despite relatively good initial germination with the first rains, was attributed to the general low amounts of rainfall received during the study period. This relationship was further demonstrated by the use of a control site (site 3) kept under sprinkler irrigation. Good germination and establishment of the same grass seeds used in site 3 indicated that with sufficient amount of moisture in the soil, range rehabilitation using grass reseeding technology is possible in the rangelands.

Rehabilitation of degraded rangelands using grass reseeding technology plays an important role in improving soil physical, hydrological and chemical properties and thus, soil conservation and fertility. Generally, established grass stands increase the infiltration capacity of the soils thus reducing run-off and sediment production, and consequently soil erosion. The established grasses reduce the impact of rain drops hitting the soil by

reducing the force and momentum of the water drops and concentrating the water into their rhizosphere. This leads to less disintegration of the soil surface leading to less soil loss. Roots of established grass stand also improve the soil bulk density. This reduces the soils vulnerability to agents of erosion namely water and wind. Increased levels of organic matter to the soil as a result of leaf blade fall, culms breakage and root thinning influences the long term chemical and physical properties of the soil. Organic matter releases many plant nutrients, including nitrogen (N), phosphorus (P) and Sulphur (S), as it is broken down in the soil. As a source of cation exchange capacity (CEC) in the soil, organic matter increases the sites in the soil that can hold positively charged nutrients like Calcium (Ca^{2+}), Magnesium (Mg^{2+}) and Pottasium (K^{+}). Increased levels of CEC with an increased level of organic matter leads to an increased capacity of the soil to hold more nutrients and release them for plant growth. Organic matter also loosens the soil, which increases the amount of pore space, which increases the soils ability to hold more water and more air. This minimises water logging, runoff and sedimentation as water percolates into the soil from the surface more quickly. Increased porosity of the soil assist the plant roots penetrate through the soil structure more easily and thus get enough soil moisture and nutrients necessary for plant growth.

Plots under *Enteropogon macrostachyus* had the best percentage ground cover followed by *Cenchrus ciliaris* and *Eragrostis superba*, respectively. These results mirrored those of the seed viability tests in the laboratories. However, in general terms, two grass mixtures had a higher percentage ground cover compared to plots under pure stands. Biomass yields of *Cenchrus ciliaris* at an average height of 60cm were ranked first followed by *Eragrostis superba* and *Enteropogon macrostachyus*. This can be attributed to the stemmier and leafier nature of *Cenchrus ciliaris* compared to the other grass species. Results showed that plots under pure stands yielded higher biomass yields on dry matter basis followed by a three grass mixture and two grass mixture. This can be attributed to less competition between the same grass species as compared to mixtures. Grasses such as *Cenchrus ciliaris* are known to be allelopathic in nature thus hinder growth of other grass species. Further more a higher percentage of *Eragrostis superba* roots are located within the upper soil horizon thus maximizing on the available moisture

in the upper horizons before it percolates to the lower horizons. There was a general inverse relationship of biomass between the planted grasses and weeds over time and at different heights. The percentage contribution of weeds to the total biomass yield decreased as that of the planted grasses increased with increased height and time. This relationship can be explained by the longevity and competitiveness of the grasses and weeds. The planted grasses were perennials and the majority of the weeds were annuals and the weeds thus, were out competed with time. *Eragrostis superba* had the highest amount seed production followed *Cenchrus ciliaris* and *Eragrostis superba*. This could be attributed to the size, density and mass of the seeds. *Eragrostis superba* has larger and heavier seeds compared to the other grass species.

The survey carried out showed that the local farmers are aware that land degradation is a problem facing them. Indicators of land degradation among the farmers include change in vegetation type from the preferred grasslands to more bushy vegetation, soil erosion leading to reduction in crop yields in their farms and loss of plant biodiversity. Although human factors namely overgrazing, poor agricultural practices, deforestation, charcoal burning and change in land ownership all contribute to land degradation, recurrent droughts as a result of low amounts of rainfall was cited to be the most contributing factor to land degradation in the area.

Local farmers have adopted the rehabilitation technology in their individual farms because in addition to it improving their individual farms, they can also derive additional benefits from the planted grasses. Local farmers are now using the planted grasses to thatch their houses and granaries, harvesting both grass seed and hay for sale as a source of income and as a source of livestock feed. Furthermore, the farmers also use the milk produced by the livestock as a source of a balanced diet through consumption and as a source of income through sales. *Eragrostis superba* is highly preferred among the three grass species followed by *Cenchrus ciliaris* and *Enteropogon macrostachyus*. This was mainly attributed to its role in milk production among the indigenous zebu cattle in the study area.

The most common and important form of land degradation in the study area is the change in vegetation cover from the preferred grassland to a more woody vegetation. The most significant factors which have contributed to this change are overgrazing through an increase in livestock numbers, increase in woodland cover and area under cultivation. Increase in area under cultivation is directly related to an increase in human population. Results show grass cover to have declined at a rate of 0.669% annually between the period 1973 and 2007, and that area under woodland and cultivation to have increased at annual rate of 18.1% and 2.875%, respectively, over the same period. Thus, land degradation in the study area can be attributed primarily to human factors rather than climatic factors.

5.2 CONCLUSIONS

From this study, the following are the main conclusions:

- Moisture (rainfall) is the most critical ecological factor which contributes to successful reseeding in the study area.
- Pure stands of the grass species give higher biomass yields compared to mixtures, but mixtures give a greater percentage ground cover compared to pure grass stands.
- Established grass stands improve soil physical, hydrological and chemical properties.
- Human factors as opposed to climatic factors are more important contributors to land degradation in the study area.

5.3 RECOMMENDATIONS

Generally this study tried to validate the use of grass reseeding technology as a means of rehabilitating degraded rangelands in Kibwezi district as a case study of semi-arid environments, using indigenous local grasses namely *Cenchrus ciliaris*, *Eragrostis superba* and *Enteropogon macrostachyus*. Since most of the data collected was under controlled conditions, where moisture was generally not limiting, the findings of this study therefore only act as a pointer on the expected performance and establishment of pastures in the eastern rangelands of Kenya under natural conditions. However, the

results obtained here are comparable to those of other similar studies within the East African rangelands.

Based on the research findings of this study, the main recommendations are as follows:

- Rainfall (moisture) is the most critical for any successful rangeland rehabilitation using grass reseeding technology. Under natural environments in the eastern rangelands of Kenya, individual farmers should sow grass seed prior to the short rains of October-December rather than prior to the long rains, since the dry spell is much shorter (4months) after the short rains compared to the long dry spell (6months) after the long rains (April-May). This gives the grass seedlings sufficient moisture for establishment.
- Individual farmers need to engage in some form of seed bed preparation through minimal soil disturbance and creation of micro-catchments prior to planting to ensure that the soil can trap enough moisture and reduce runoff during the rains, thus ensuring that the grass seedlings get enough moisture.
- Most of the rangeland grass seeds stay dormant for a very long time, thus need to use mature but older seeds (3-4 yrs old), which have broken dormancy, to ensure good germination and establishment. Freshly harvested seeds are usually dormant, and thus should not be used for reseeding immediately. However, they can remain viable within the soil for many years and sprout later under favorable conditions. More research is needed on ways of reducing the seed dormancy period of perennial range grasses.
- Individual farmers need to fence of the rehabilitation plots to keep off livestock mainly cattle. This will ensure successful rehabilitation since the grass seedlings will be protected from the trampling effect and of the grazing livestock.
- Extension workers and field officers need to promote indigenous grasses for reseeding since they are tolerant to drought, resistant to grazing, good seeders, produce sufficient amount of biomass yields and are adapted to the local environment.
- Extension workers and field officers need to promote the sowing of the indigenous grass species as mixtures as opposed to pure stands since they give better ground cover, thus better rehabilitation.

- Researchers need to develop and introduce multi-faceted technologies to combat land degradation in the arid and semi-arid environments. Individual farmers will easily adopt such technologies since they can derive other benefits in addition to the primary purpose to which the technology will be introduced.
- Extension officers and field officers need to educate and create awareness among the community members in semi-arid environments on the sustainable utilisation of range resources, for example, proper livestock husbandry and grazing management, in order to reverse the land degradation problem.

LIST OF REFERENCES

- Anderson, E. 1970.** Effect of flooding on tropical grasses. Sect. 6(a) pp 591-594 In: Norman, M.J.T. (Ed); Proceedings of the 11th International Grassland Congress, Surfers Paradise, Queensland, Australia.
- Andrew, M.H. and J.J. Mott. 1983.** Annuals with transient seed banks: the population biology of indigenous *Sorghum* species of tropical north-west Australia. *Australian Journal of Ecology* 24:265-276.
- Angassa, A. 2005.** The ecological impact of bush encroachment on the yield of grasses in Borana rangeland ecosystem. *African Journal of Ecology* 43:14-20.
- Archer, S., T.W. Boutton and K.A. Hibbard. 2002.** Trees in grasslands: biogeochemical consequences of woody plant expansion. In: Global biogeochemical cycles in the climate.
- Bakker, J.P., P. Poschlod, R.J. Strydstra, R.M. Bekker and K. Thompson. 1996.** Seed banks and seed dispersal: important topics in restoration ecology. *Acta Botanica Neerlandica* 45:461-490.
- Bekure, S., P.N. de Leeuw, B.E. Grandin and P.J.H. Neate. 1991.** Maasai herding. ILCA system study 4. International Livestock Research Center, Addis Ababa, Ethiopia.
- Biamah, E.K. 2005.** Coping with drought: Options for soil and water management in semi-arid Kenya. Tropical Resource Management Papers, No.58. Wageningen University and Research Centre (Wageningen UR).
- Blake, G.R. and K.H. Hartge. 1986.** Bulk density. In: Kiule, A (ed) Methods of soil analysis. Agron No.9. Amer. Soc. Agron. Inc. and Soil Sci. Amer. Inc. Madison, Wisconsin, U.S.A.
- Bogdan A.V. 1958.** A revised list of Kenya grasses. Government Printers, Nairobi.
- Bogdan A.V. 1977.** Tropical Pasture and Fodder Plants (Grasses and Legumes) pp. 66-74. Longman, London and New York.
- Bogdan, A.V. and D.J. Pratt. 1967.** Reseeding denuded pastoral land in Kenya. Republic of Kenya, Ministry of Agriculture and Animal Husbandry, Government Printers. pp. 1-46
- Boonman, J.G. 1993.** East African grasses and Fodder: Their ecology and husbandry. Kluwer Academic Publishers: Dordrecht, The Netherlands.

- Bradshaw, Y.W. 1990.** Perpetuating underdevelopment in Kenya: The link between agriculture, class and state. *African Studies Review* 33 (1): 1-28.
- Braunn, H.M.H. 1978.** "Climate." In Michieka, D.O., Vlee Shouwer, J.J. and Van der Pouw B.J.A. Eds., Soils of the Kwale-Mombasa-Lunga Lungu area. Report No. R3 Kenya Soil Survey, Nairobi, pp. 11-22.
- Braunn, H.M.H. 1977:** Average monthly rainfall as a percentage of the annual rainfall in Kenya and Tanzania, with particular reference to the Kenya coast, Misc. paper No.M14, Kenya Soil Survey, Nairobi, pp.1-5.
- Bull, L. and R. Allison. 2001.** Geomorphology of drylands. Lecture notes by Dr. Louise Bull. www.dur.ac.uk/l.j.bracken
- Cameron, D.G. 1980.** Criteria of merit for pasture species with particular reference to legumes. *Tropical Grasslands* 14:130-135
- Central Bureau of Statistics, CBS. 2000.** Republic of Kenya, Ministry of Economic Planning and Development, Nairobi.
- Chelische, E.C. and A. Kitalyi. 2002.** Management of rangelands. Use of natural grazing resources in southern province, Zambia. Regional Land Management Unit-RELMA, Technical Handbook No. 28, Nairobi.
- Chin, H.F. and J. Hanson. 1999.** Seed storage. Pp 303-315. In: Loch D.S and Ferguson J.E. (Eds) Forage seed production. 2. Tropical and subtropical species. CAB International Publishing, Wallingford, Axon, UK.
- Clapp, R.B. and G.M. Hornberger. 1978.** Empirical equations for some soil hydraulic properties. *Water Resource Research* 14:601-604.
- Da Costa, M. and B. Huang. 2004.** Evaluation of irrigation requirements and water use characteristics among three bentgrass species. 2004 Rutgers Turfgrass Proceedings of the New Jersey Turfgrass Expo, December 7-9, 2004, Trump Taj Mahal, Atlantic City, New Jersey, USA.
- Daehler, C. and E.M. Georgen. 2005.** Experimental restoration of an indigenous Hawaiian grassland after invasion by buffel grass (*Cenchrus ciliaris*). *Restoration Ecology* 13:380-389.
- De Groot P., A.F. Juma and D.O. Hall. 1992.** Taking root: revegetation in semi-arid Kenya. African Centre for Technology Studies, Nairobi, Kenya.
- Diagana, B. 2003.** Land Degradation in sub-saharan Africa. What explains the widespread adoption of unsuitable farming practices?

- Duke, J.A. 1983.** Handbook of Energy Crops. Purdue University, Center for New Crops and Plant Products. www.hort.purdue.edu/newcrop/duke_energy/dukeindex.html
- Einstein, G. and K. Abernethy. 2000.** Statistical package for the social sciences (SPSS) Version 12.0. Furrnan University.
- Ekaya, W.N., J.I. Kinyamario and C.N. Karue. 2001.** Abiotic and herbaceous vegetational characteristics of an arid rangeland in Kenya. *African Journal of Range and Forage Science* 18:125-129.
- El Beltagy, A. 2002.** ICARDA' Experience in the Rehabilitation of Degraded Drylands of Central and Western Asia and Northern Africa: In the proceedings of the International Workshop on Combating Desertification. Rehabilitation of Degraded Drylands and Biosphere Reserves, Aleppo, Syria, May 2-3, 2002.
- Ellis, E., M.B. Coughenour and D.M. Swift. 1993.** Climate variability, ecosystem stability, and the implications for range and livestock development, pp. 31-41. Range Ecology at disequilibrium. New models of Natural Variability and Pastoral Adaptation in African savannas. R.H. Behnke, I. Scoones and C. Kerven (Eds.). ODI, London (1993).
- Ernest, W.H.O. and D.J. Tolsma. 1988.** Dormancy and germination of semi-arid annual plant species, *Tragus berteroniannus* and *Tribulus terrestris*. *Flora* 181: 243-251.
- Evans, R.A. and R.M. Love. 1957.** The step-point method of sampling- A practical tool in range research. *Journal of Range Management* 10:208-212.
- Farahpour, M. 2003.** A combination of traditional methods and modern technologies for rangeland management.
- Farooq, M.U., R. Saleem and A. Razzaq. 2003.** Estimation of root and shoot biomass of *Cenchrus ciliaris* (Dhaman) under Barani conditions. *Pakistan Journal of Biological Sciences* 6(21):1808-1813.
- Gachimbi, L.N. 1990.** Land degradation and its control in the Kibwezi area, Kenya. *MSc Thesis, University of Nairobi, Nairobi, Kenya.*
- Gee, G.W. and J.W. Bauder. 1986.** Particle size analysis. In: Kiule, A (Ed). Methods of soil analysis. Part 1. 2nd Edition. Agron. No.9. Amer. Soc. Agron. Inc. and Soil Sci. Amer. Inc. Madison, Wisconsin, U.S.A.
- GEF/IFAD. 2002.** Tackling Land Degradation and Desertification. Global Environmental Facility-International Fund for Agricultural Development (IFAD) Partnership, Rome, Italy.

- Gichuki, F.N. 2000.** Makueni District Profile: Rainfall Variability, 1950-1997. Drylands Research, Working Paper 2. Drylands Research, Crowkerne, Somerset, UK.
- Glantz, M.H. and N.S. Orlovsky. 1983.** Desertification: A review of the concept. *Desertification Control Bulletin* 9:15-22.
- GoK. 2002.** Makueni District Development Plan for the period 2002-2008. Government Printers, Nairobi.
- GoK/NAP. 2002.** National Action Programme: Framework for combating desertification in Kenya, in the context of the United Nations Convention to Combat Desertification (UNCCD). National Environment Secretariat, Nairobi, Kenya.
- Hacker, J.B. 1989.** The potential for buffel grass renewal from seed in 16 years-old buffel grass-siratro pastures in south-east Queensland. *Journal of Applied Ecology* 26:213-222.
- Hardin, G. 1968.** Tragedy of commons. *Science* 162:1243-1248.
- Harker, K.M. and D. Napper. 1960.** An illustrated guide to the grasses of Uganda. Government Printers, Entebbe.
- Herlocker, D. 1999.** Rangeland resources in eastern Africa: their ecology and development. German Technical Cooperation, Nairobi, Kenya: GTZ.
- Holzworth, L.K. and L.E. Wiesner. 2006.** Management of seedlings – Principles of Establishment and Seedling Year Management. www.animalrangeextension.montana.edu/Articles/Forage/Chpt3/3-mgt-dry.htm
- Hussey, A.M. and Bashaw E.C. 1996.** Performance of buffel grass germplasm with improved winter survival. *Agronomy Journal* 88:944-946.
- IFAD. 2001.** Desertification as a global problem. International Fund for Agricultural Development (IFAD), Rome Italy. Produced on the occasion of the Conference of Parties, COP-V, UNCCD, Geneva, Switzerland.
- IFAD. 1998.** Drylands. A Call for Action. Building on IFAD's Experience: Lessons from Sub-Saharan Africa. International Fund for Agricultural Development (IFAD), Rome, Italy.
- IFAD. 2007.** IFAD's Exhibit: Fighting land degradation and poverty. www.ifad.org/events/cop/exhibit
- Johansson, J. and Svensson, J. 2002.** Land degradation in semi-arid catchment of Lake Baringo, Kenya – A minor field study of physical and socio-economic aspect. Department of Physical Geography, Göteborg.

- Jordan, S.M. 1957.** Reclamation and pasture management in the semiarid areas of Kitui district, Kenya. *East African Agricultural and Forestry Journal* 25:18-22.
- Kadmon, R. and A. Schimida. 1990.** Patterns of spatial variation in the reproductive success of a desert annual. *Oecologia* 83:139-144.
- Kamphorst, A. 1987.** A small rainfall simulator for the determination of soil erodibility. *Netherlands Journal of Agricultural Science* 35:407-415.
- Kassahun, A., H.A. Snyman and G.N. Smit. 2008.** Livestock grazing behaviour along a degradation gradient in the Somali region of eastern Ethiopia. *African Journal of Range and Forage Science* 25(1):1-9.
- Keya, G.A. 1991.** Alternative Policies and Models for Arid and semi-arid lands in Kenya: When the grass is gone. Development Interventions in African Arid Lands. Seminar Proceedings No. 25, pp 73-81. The Scandinavian Institute of African Studies.
- Keya, G.A. 1998.** Impact of land use patterns and climate on the vegetation ecology of arid and semi-arid nomadic pastoral ecosystems of northern Kenya. *PhD Thesis, Trier University, Trier, Germany.*
- Kitalyi, A., J. Suazo and F. Ogutu. 2002.** Enclosures to protect and conserve. For better livelihood of the West Pokot community. *Technical Pamphlet No. 2. RELMA, Nairobi.*
- Klute, A. and C. Dirksen. 1986.** Hydraulic conductivity and diffusivity: Laboratory methods, pp. 687-734. In: *Methods of soil analysis. Part 1. 2nd Edition.* Klute, A. (Eds). *Agrop. Ser. No.9. Amer. Soc. Agron. Inc., Madison, Wisconsin.*
- Krugmann, H. 1996.** Towards improved indicators to measure desertification and monitor the implementation of the Desertification Convention. In: Hambly, H. and T.O. Angura (Ed) *Grassroots Indicators for Desertification: Experience and Perspectives from Eastern and Southern Africa.* International Development Research Centre (IDRC)
- Laidlaw, A.S. 2005.** The relationship between tiller appearance in spring and contribution of dry-matter yield in perennial ryegrass (*Lolium perenne* L.) cultivars differing in heading date. *Grass and Forage Science* 60:200-209.
- Lang, C. 1995.** Environmental degradation in Kenya as a cause of political conflict, social stress and ethnic tensions. ENCOP Occasional paper No. 12. Center for Security Policy and Conflict Research Zurich. Swiss Foundation, Berne. Zurich/Berne.

- LUCID. 2006.** Arid and semi-arid agro-pastoral systems in transition. LUCID Working Policy Brief No. 2. Land Use Change, Impacts and Dynamics.
- Makokha, W., S. Lonyakou, M. Nyang and K.K. Kareko. 1999.** We work together. Land rehabilitation and household dynamics in Chapeseria division, West Pokot district, Kenya. *Technical Report No. 22. RELMA, Nairobi.*
- Makueni district development plan, 1997-2001. 1996.** Office of the President and Ministry of Planning and National Development, Nairobi, Kenya.
- Maze, K.M., T.B. Koen and L.A. Watt. 1993.** Factors influencing the germination of six perennial grasses of central New South Wales. *Australian Journal of Botany* 41:79-80.
- Mbithi, P.M. and C. Barnes. 1975.** The spontaneous settlement in Kenya. East Africa Literature Bureau, Nairobi, pp. 128-167.
- McNaughton, S.J. 1979.** Grazing as an optimization process: Grass-ungulate relationships in Serengeti. *American Naturalist* 113:691-703.
- Michieka, D.O. and B.J.A. van der Pouw. 1977.** Soils and vegetation of the Kiboko range research station. A semi-detailed report No. 53, Nairobi.
- Miller, R.H. and D.R. Keeney. 1982.** Methods of soil analysis. Chemical and microbiological properties (2nd Edition). *Agron. Ser. No.9. Amer. Soc. Agron. Inc.,* Madison, Wisconsin.
- Mnene, W.N. 2005.** Strategies to increase success rates in natural pasture development through reseeding degraded rangelands of Kenya. *PhD Thesis, University of Nairobi, Nairobi, Nairobi, Kenya.*
- Morisawa, T.L. 2000.** Wildlands Invasive Species Program. The Nature Conservancy: Weed Alert! *Cenchrus ciliaris* L. www.tncweeds.ucdavis.edu/alert/alrtcenc.html
- Murton, J. 1999.** Population growth and poverty in Machakos district, Kenya. *Geographical Journal* 105(1):37-46
- Musimba, N.K.R., D.M. Nyariki, C.N. Ikutwa and T. Teka. 2004.** Dryland Husbandry for sustainable development in the southern rangelands of Kenya. OSSREA, Addis Ababa, 2004.
- Njenga, F.M. 1992.** The effect of land treatment and seeding methods on establishment of three range grasses in the semi arid rangelands of Makueni district, Kenya. *MSc Thesis, University of Nairobi, Nairobi, Kenya.*

- Nyangito, M.M. 2005.** Grazing patterns, energy extraction and livestock productivity in agropastoral production systems in Kibwezi, southeastern Kenya. *PhD Thesis, University of Nairobi, Nairobi, Kenya.*
- Nyangito, M.M., N.K.R. Musimba and D.M. Nyariki. 2008.** Range use and dynamics in the agropastoral system of southeastern Kenya. *African Journal of Environmental Science and Technology* 2(8): 220-230.
- Nyangito, M.M., N.K.R. Musimba and D.M. Nyariki. 2009.** Hydrological properties of grazed perennial swards in semiarid southeastern Kenya. *African Journal of Environmental Science and Technology* 3(2): 226-233.
- Nyariki, D.M. 2008.** Price response of herd off-take under market liberalization in a developing cattle sector: panel analysis applied to Kenya's ranching. *Environmental and Development Economics* 14(2):263-280.
- Oba, G., E. Post, P.O. Syvertsen and N.C. Stenseth. 2000.** Bush cover and range condition assessments in relation to landscapes and grazing in Southern Ethiopia. *Landscape Ecology* 15: 535-546.
- Okoth-Ogendo, H.W.O. 1991.** Tenants of the crown: Evolution of agrarian law and institutions in Kenya. ACTS Legal Studies Series no. 2. Nairobi: African Centre for Technology Studies (ACTS).
- Opiyo, F.O. 2007.** Land treatment effects on morphometric characteristics of three grass species and economic returns from reseeding in Kitui district, Kenya. *MSc Thesis, University of Nairobi, Nairobi, Kenya.*
- Pratt, D.J and M.D. Gwynne. 1977.** Rangeland management and ecology in East Africa. Hodder and Stoughton, London.
- Qassim, A. 2003.** Sprinkler Irrigation: A Situation Analysis. Institute of Sustainable Irrigated Agriculture (ISIA), at Tatura, Australia, for the International Programme for Technology and Research in Irrigation and Drainage (IPTRID).
- RAE. 2007.** Land Reclamation. The Rehabilitation of Arid Environments (RAE) Charitable Trust. www.raetrust.org/act_land_rec
- Reichenberger, G. and D.A. Pyke. 1990.** Impact of early root competition on fitness components of four semi-arid species. *Oecologia* 85:159-166.
- Rietkerk, M., P. Ketner, J. Burger, B. Hoorens and H. Olff. 2000.** Multiscale soil and vegetation patchiness along a gradient of herbivore impact in a semi-arid grazing system in West Africa. *Plant Ecology*, 148:207-224.

- Roques, K.G., T.J. O'Conner and A.R. Watkinson. 2001.** Dynamics of shrub encroachment in an African savanna: relative influences of fire, herbivory, rainfall and density dependence. *Journal of Applied Ecology* 38:268-280.
- Rowell, D.R. 1994.** Soil science methods and application. Longman Group, UK.
- Ryan, J., S. Miyamoto and J.L. Strohlein. 1975.** Salt and specific ion effects on germination of four grasses. *Journal of Range Management* 28:61-64.
- Schellenberg, M.P. 1999.** Grass, forb and shrub requirements for soil water for emergence. Proceedings for the VIth International Rangeland Congress, Townsville, Australia. pp 232-233.
- Scherer, T. 1996.** Selecting a sprinkler irrigation system. North Dakota State University. www.wca-infonet.org/id/17463
- Seobi, T., S.H. Anderson, R.P. Udawatta and C.J. Gantzer. 2005.** Influence of grass and agroforestry buffer strips on soil hydraulic properties for an Albaqualf. *Soil Science Society of America Journal* 69:893-901.
- Sharif-Zadeh, F. and A.J. Murdoch. 2001.** The effects of temperature and moisture on after-ripening *Cenchrus ciliaris* seeds. *Journal of Arid Environments* 49:823-831.
- Silcock, R.G. 1986.** Strategies for plant introduction and reseeding of semi-arid pastoral lands. In: Joss, P.J., P.W. Lynch and O.B. Williams (Eds): *Rangelands: A resource under siege*. Proceedings of the second International Rangeland Congress. Cambridge University Press, pp 268-274.
- Singh, R.P. 1987.** Pasture development in Bhutan In: Panjab S and Pothak P.S. (Eds.) *Rangeland resources and management*. Proceedings of the National range resource and management. IGFRI Jhansi. November 9-12, 1987.
- Sinha, R.K., S. Bhatia and R. Vishnoi. 1997.** Desertification control and range management in the Thar desert of India. *RALA REPORT No. 200*. Desertification and Rangeland Management in India.
- Skarpe, C. 1990.** Shrub layer dynamics under different herbivore density in an arid savanna, Botswana. *Journal of Applied Ecology* 27:873-885.
- Skerman, P.J. and F. Riveros. 1990.** Tropical grasses. Food and Agriculture Organization of the United Nations, Rome.
- Smajstrla, A.G. and F.S. Zazueta. 2003.** Evaporation loss during sprinkler irrigation. Agricultural and Biological Engineering Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. *Bulletin No. 290*.

- Snel, M. and A. Bot. 2005.** Properties and management of drylands: Proposed indicators for land degradation assessment of drylands. www.fao.org
- Snyman, H.A. 2004.** Soil seed bank evaluation and seedling establishment along a degradation gradient in a semi-arid rangeland. *African Journal of Range and Forage Science* 21(2):37-47.
- Srinivasan, V., W.C. Bonde and K.G. Tejwani. 1962.** Studies on grasses and their suitability to stabilize and maintain bunds in the ravine lands of Gujarat. *Journal of Soil Water Conservation. India.* 10:72-78.
- Stoddart, L.A., A.D. Smith and T.W. Box. 1975.** Range Management. McGraw Hill, New York.
- Strickland, R.W. 1973.** Dry matter production, digestibility and mineral content of *Eragrostis superba* Peyr. and *E. curvula* (Schrad.) Nees. at Stamford, southeastern Queensland. *Trop. Grasslands* 7:233-241.
- Taerum, R. 1977.** A study of the growth and development of grasses with emphasis on their root system. *PhD Thesis, University of Nairobi, Kenya.*
- Tiffen, M. 1991.** Environmental change and dryland management in Machakos district, Kenya, 1930-1990. Population Profile, Working Paper No.54. London. Overseas Development Institute.
- Too, D.K., F.E. Smeins and R.D. Child. 1986.** Effects of defoliation frequency and intensity on production of grassland communities. In. Range Development and Research in Kenya. Proceedings of a conference, Agricultural Resource Centre, Egerton College, Njoro, Kenya on April 1-5, 1986.
- Touber, L. 1983.** Soils and Vegetation of Amboseli-Kibwezi area. Kenya Soil Survey Report No. R6, Nairobi, pp 29-138.
- Tueller, P.R. 1973.** Secondary succession, disclimax and range condition standards in desert shrub vegetation in Arid Shrublands, D.N. Hyder ed., Soc. for Range Management, Denver, Colo., pp 57-66
- Tweddle, J.C., J.B. Dickie, C. Carol and J.M. Baskin. 2003.** Ecological aspects of seed desiccation sensitivity. *Journal of Ecology* 91:294-304.
- UNCCD. 2003.** An introduction of United Nations Convention to Combat Desertification. United Nations. www.unccd.int/publicinfo
- USCCTP. 2005.** Technology Options for the Near and Long term. United States Climate Change Technology Program.

- USDA. 1975.** Soil taxonomy. *Agric. Handbook No. 436 Soil Conservation Service, USDA, Washington DC*
- van den Berg, L and K. Kellner. 2005.** Restoring degraded patches in a semi-arid rangeland of South Africa. *Journal of Arid Environments* 61:497-511.
- Veenendaal, E.M. 1991.** Adaptive strategies of grasses in a semi-arid savanna in Botswana. *PhD Thesis, Vrije Universiteit Amsterdam, Netherlands.*
- Visser, N., C. Morris, M.B. Hardy and J.C. Botha. 2007.** Restoring bare patches in the Nama-Karoo of South Africa. *African Journal of Range and Forage Science* 24(2):87-96.
- Wangari, E. 1991.** Effects of land registration on small-scale farming in Kenya: The case of Mbeere in Embu District. Ph.D. dissertation, New School for Social Research, New York, New York, U.S.A.
- Wasonga, V.O., R.K. Ngugi and A. Kitalyi. 2003.** Traditional range condition and trend assessment: Lessons from Pokot and Il Chamus pastoralists of Kenya. *Anthropologist* 5(2):79-88.
- WMO. 2005.** Climate and Land Degradation. World Meteorological Department (WMO), Geneva, Switzerland.
- Woie, B.M. 1986.** Effects of defoliation on range grasses. pp 263-270. In: Hansen, R.M., B.M. Woie and R.D. Child (Ed) Range development and research in Kenya. Winrock International Institute for Agricultural Development, Morrilton, AR, USA.
- Young, D., B. Frost and M. Schneider. 1994.** Establishing irrigated pasture at 4000 to 6000 ft elevations in Arizona. Arizona Cooperative Extension. University of Arizona, College of Agriculture, Tucson, Arizona. www.ag.arizona.edu/pubs/194028.pdf

APPENDICES

Appendix I: Survey Questionnaire

1. Date of Interview Questionnaire Number
2. Name of Enumerator
3. Name of Respondent
4. Age of respondent
5. District Division Location Sub-location
6. Total farm size in ha
7. Area under; Grass Food crops Multipurpose trees
8. Are you aware of any Range Improvement and/or Rehabilitation Methods?
[a] Yes [b] No
9. If Yes, in (8 above) what methods of Range Improvement and Rehabilitation do you know?
[a] Grass Reseeding [b] Tree Planting [c] Natural Rehabilitation [d] Others (specify)

-
10. How did you get to learn about the above mentioned method(s) ?
[a] Radio [b] Extension Officers [c] Radio [d] Neighbours/Friends [e] Local Forums
[f] Development Projects in the area [g] Others (specify).
-

11. Do you practice grass reseeded in your farm?
[a] Yes [b] No
12. If Yes, in (11 above) which grass species have you grown?
[a] *Cenchrus ciliaris* (C.C) (Ndata kivumbu)
[b] *Eragrostis superba* (E.S) (Mbeetwa)
[c] *Chloris roxburghiana* (C.R) (Kilili)
[d] *Enteropogon macrostachyus* (E.M) (Nguu)

13. Why did you choose to grow the above mentioned grasses?

Grass	Animal feed	Soil Conservation	Drought resistant	Thatching	Availability Of Seed	Grazing Resistant	Biomass Production	Sales/ Income	Others
Ndata kivumbu									
Mbetwa									
Nguu									
Kilili									

14. For how long have you practiced grass reseeded in your farm?
[a] 1-5yrs [b] 6-10yrs [c] 11-15yrs [d] > 15 yrs

15. If Not, in (11 above) what are your reason(s) ?
 [a] Lack of interest [b] Lack of knowledge [c] Plenty of grass available [d] Lack of seed
 [e] Not livestock keeper [f] Small farm size [g] Others (specify)

16. What was your **INITIAL** source of grass seeds?
 [a] Personal [b] Neighbours [c] KARI [d] Development Projects [e] Others (specify).

17. Did you purchase/pay for the grass seeds?
 [a] Yes [b] No
18. What is your **CURRENT** source of grass seeds?
 [a] Personal [b] Neighbours [c] KARI [d] Development Projects [e] Others (specify).

19. When do you sow your grass seeds?
 [a] Before the rains [b] After the rains [c] During the rains
20. Explain why for your answer in (19 above).

21. Which sowing method(s) do you practice in your farm?
 [a] Hand sowing [b] Seed drilling [c] Over-sowing [d] Broadcasting
22. Why did you choose the method (s) mentioned in (21 above)?
 [a] Easy to use [b] Quick/Fast [c] Requires less expertise [d] Cheaper [e] Others

23. Which form of reseeding style / approach do you use in your farm?
 [a] Pure stands [b] Mixtures [c] Both
24. Why did you choose the mentioned style/approach in (23 above)? Explain.

25. If mixtures, which grass mixtures do you have in your farm?
 [a] CR/CS [b] CR/CS [c] CR/ES [d] CC/EM [e] CC/ES [f] EM/ES [g] Others(Specify)

26. Have you put up a fence around your grass stand plots in your farm?
 [a] Yes [b] No
27. If Yes, in (26 above) why? Explain.
 [a] Keep of livestock [b] Show boundary [c] Keep of human interference [d] Aesthetic
 [d] Others (specify).

28. If No, in (26 above) why? Explain.
 [a] Lack of capital [b] Lack of knowledge [c] Minimal livestock disturbance [d] Others

29. What are the common weeds in your farm ? (Tick)

Scientific Name	Local Name	English Name
a. Ipomoea species	Uthui	
b. Ocimum species	Osmum	
c. Aconthospermum hispidum	Ikongo	
d. Commelina bengalensis	Mukengesya	
e. Oxygonum sinuatum	Songe	
f. Lactuca capensis	Usungu	
g. Datura stramonium	Mbongolo	Jimson Weed
h. Galinsoga parviflora	Mungei	
i. Tridax procumbens	Kismeleta	Coat Buttons
j. Digitaria scalarum		Couch Grass
k. Cynodon dactylon		Star Grass
l. Barleria taitensis		
m. Others		

30. What are the advantages and disadvantages of the above mentioned weeds in your farm? (Tick)

Scientific Name	Advantages							Disadvantages				
	Animal feed	Fuel Wood	Soil Conservation	Farm Manure	Medicinal	Ornamental	Others	Lowers Grass Yields	Poisonous to Animals	Reduce Area under Grass	Covers Grass	Others
a. Ipomoea species												
b. Ocimum species												
c. Aconthospermum hispidum												
d. Commelina bengalensis												
e. Oxygonum sinuatum												
f. Lactuca capensis												
g. Datura stramonium												
h. Galinsoga parviflora												
i. Tridax procumbens												
j. Digitaria scalarum												
k. Cynodon dactylon												
l. Barleria taitensis												
m. Others												

Others (Specify).....

31. Have you planted any multi-purpose trees in your farm? [a] Yes [No]

32. If Yes (in 31 above), which one have you planted and why did you choose them? (tick in table)

* Others (Check in the following table)

Tree	Fodder	Firewood	Green manure	Shade	Timber	Ornamental	Bee forage	Human Food	Medicinal	Carving	Others
Leuceana											
Terminalia											
T. indica											
M. indica											
C. papaya											
S. siamea											
*Others											

Tree	Fodder	Fuel	Green Manure	Shade	Timber	Ornamental	Bee Forage	Food	Medicinal	Carving	Others
Baobab											
Albizia spp.											
Mellia volkensi											
Neem Tree											
Guavas											
Lemon/ Orange											

33. When do you receive rainfall in a normal year?

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
(Tick)												

34. Which methods do you use to conserve moisture?
 [a] Micro-catchments [b] Macro-catchments [c] Mulching [d] Terracing [e] Others

35. Give a description of the soil types in your farm?
 [a] Loams [b] Sandy [c] Black/Greyish [d] Brown [e] Brick Red
36. What is the general slope of your rehabilitation site(s)?
 [a] Flat [b] Gentle Slope [c] Steep Slope [d] Very Steep Slope
37. What do you use to prepare the site(s) you intend to reseed?
 [a] Jembe [b] Ox-plough [c] Tractor
38. Briefly discuss the process in (37 above).

39. Do you participate in any community based activities?
 [a] Yes [b] No
40. If Yes, in (39 above) which ones are you still practicing and why?

Community Activities	Tick	Reasons						
		Animal Feed	Income	Water Supply	Food Security	Improves Yields	Range Improvements	Others
Water Mgt								
Soil Mgt								
Reseeding								
Dairy Goats								
Bee Keeping								
Ethnovet								
Multipurpose Trees								
Others								

41. In your opinion, what factors contribute to range degradation?
 [a] Poor agricultural practices [b] Recurrent Droughts [c] Low Rainfall [d] Overgrazing
 [e] Erosion [f] Others (specify).

42. In your opinion, what is/ are the causes of range degradation in this area
 [a] Tragedy of the Commons

- [b] Persistent droughts
[c] Lack of government support mechanisms
[d] Poor agricultural/cropping systems
[e] Overgrazing
[f] Others (specify).....
43. In your opinion, what led to the change in vegetation type from the initial grazing pastureland to a more woody vegetation type?
.....
.....
44. When do you think these changes occurred?
[a] Before 1950's [b] 1950's-1960 [c] 1960's-1970 [d] 1970's-1980 [e] After 1980's
45. Do you find the current vegetation type in the surrounding area suitable for grazing livestock?
[a] Yes [b] No
46. If No, in (45 above), what solutions do you suggest to ameliorate the condition?
.....
.....
.....
47. Have you experienced any failures previously while trying to establish a grass stand?
[a] Yes [b] No
48. If Yes, in (47 above) what factors do you think contributed to your failures previously?
[a] Recurrent Droughts [b] Low rainfall [c] Poor seed quality [d] Livestock destruction
[e] Pests and Rodents [f] Erosion/Flash floods [g] Poor timing [h] Poor soils
[i] Farm Slope [j] Poor skills and knowledge [k] Grass Diseases [l] Others (specify).
.....
.....
49. If No, in (47 above) what factors do you think contributed to your successes previously?
[a] Fencing my plots [b] Use of good quality seed [c] Good seed sowing timing
[d] Water management [e] Soil/Ecologic factors [f] Others (specify)
.....
.....
50. What is your **MAIN SOURCE** of water for your rehabilitation plots (Reseeded Sites)?
[a] Rainfall [b] Boreholes [c] River [d] Water Tanks [e] Piped / Tap [f] Others (specify)
.....
.....
51. Do you practice any form of water harvesting and management in your farm?
[a] Yes [b] No
52. If Yes, in (51 above) which methods of water harvesting/management do you practice in your farm?
[a] Rock Catchment [b] Micro-catchments [c] Roof catchments [d] Mulching [e] Others
.....
53. What are the uses of the harvested water?
[a] Domestic Use [b] Watering Livestock [c] Irrigating reseeded plots
[d] Watering tree nurseries [e] Others (specify).

54. If No, in (51 above) why aren't you not practicing any water management and harvesting? . [a] Available Piped Water [b] Proximity to river [c] Others (specify)

55. In your opinion, what is the range trend in your farm and what can you attribute this to?

Range Trend	Reasons Attributed							
	Tick	Grazing Mgt.	Climate	Sensitization	Better Farming	Human Activities	Rehabilitation Initiatives	Others
Improving								
Constant								
Gradual Deterioration								
Rapid Deterioration								

56. Were you involved and did you participate in any of the DHP Activities?
[a] Yes [b] No

57. If Yes, in (56 above) which activities introduced by the DHP do you consider a success?
[a] Livestock Development [b] Bee-keeping [c] Training Para vets
[d] Grass reseeding [e] Multi-purpose trees [f] Dryland hybrid maize
[g] Water Management [h] Training Agro-Pastoral Dev. Agents (APDA's).
[i] Self help groups.

58. Which of the mentioned activities in (55 above) did you like most and thus still practicing to date? (Tick against corresponding letter).
[a] [b] [c] [d] [e] [f] [g] [h] [i]

59. Which of the mentioned activities in (55 above) do you think were least successful and you would like them to be addressed in the near future? (Tick against corresponding letter).
[a] [b] [c] [d] [e] [f] [g] [h] [i]

Appendix II: Partial correlation matrix for variables used in the regression analysis

	YR	RF	DR	LP	GC	HP	CA	WL
YR	1							
RF	-.028	1						
DR	0	.587	1					
LP	.759	.047	.087	1				
GC	.993	.041	.019	-.780	1			
HP	.780	.073	.214	.779	-7.91	1		
CA	.996	-.035	.010	.756	.995	.792	1	
WL	.991	-.066	-.010	.721	.991	.788	.995	1

Notes: Where YR – Year, RF – Rainfall, DR- Drought, LP – Livestock population, GC- Grassland cover, HP- Human population, CA- Cultivated area, WL – Woodland

NB: All the variables are insignificantly correlated at 0.05

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