

**STRATEGIES TO INCREASE SUCCESS RATES IN
NATURAL PASTURE IMPROVEMENT THROUGH
RE-SEEDING DEGRADED SEMI-ARID
RANGELANDS OF KENYA**

BY

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FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF
DOCTOR OF PHILOSOPHY IN PLANT ECOLOGY**

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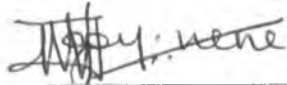


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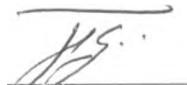
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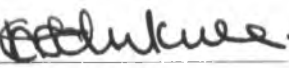
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DEDICATION

I dedicate this thesis to my late mother (May the Almighty rest her soul in eternal peace), *Mcheku* Naomi Nangena Ngoyawu whom after seeing that I was the only one among her siblings that had formally completed secondary school, encouraged me to strive to attain the highest level of education. However long it would have taken.

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LIST OF ABBREVIATIONS

A&M	- Agricultural & Mechanical
AMOVA	- Analysis of Molecular Variance
ANOVA	- Analysis of Variance
ARC	- Agricultural Research Council
ARSP	- Agriculture / Livestock Research Support Programme
ASAL	- Arid and Semi-Arid Lands
bp	- Base Pair
Cap	- Chapter
CCRS	- Canadian Centre for Remote Sensing
CECI	- <i>Cenchrus ciliaris</i>
CHRO	- <i>Chloris roxburghiana</i>
CTAB	- Hexadecyltrimethyl Ammonium Bromide
df	- Degrees of Freedom
DM	- Dry Matter
DNA	- Deoxyribonucleic Acid
EC	- Electrical Conductivity
EDTA	- Ethylene Diamine Tetra Acetate
Educ.	- Education
ENMA	- <i>Enteropogon macrostachyus</i>
ERSU	- <i>Eragrostis superba</i>
EU	- European Union
F	- Female
FAO	- Food and Agriculture Organization
Fig.	- Figure
GAA	- German Agro-Action
GEO	- Global Environment Outlook
GIS	- Geographical Information system
GL-CRSP	- Global Livestock -Collaborative Research Support Programme
GLM	- General Linear Model
gm	- Gramme(s)
Gok	- Government of Kenya
GPS	- Geographic Positioning System
Ha	- Hectare(s)
HCL	- Hydrochloric Acid
HSU	- Herbage Seed Unit
ICARDA	- International Centre for Agricultural Research in Dry Areas
IDS	- Institute of Development Studies
IFAD	- International Fund for Agricultural Development
ILCA	- International Livestock Centre for Africa
ILRI	- International Livestock Research Institute
IRRI	- International Rice Research Institute
ISTA	- International Seed Testing Association
ISU	- Iowa State University
Kaji. Central	- Kajiado Central

KARI	- Kenya Agricultural Research Institute
KAV	- Kavatini
KEPHIS	- Kenya Plant Health Inspectorate Service
Kg	- Kilogramme(s)
KIB	- Kiboko
KIM	- Kimala
Km	- Kilometre(s)
LEWS	- Livestock Early Warning System
M	- Male
MAX T	- Maximum Temperature
me	- Micro-equivalent
MER	- Merueshi
MIN T	- Minimum Temperature
ml	- Millilitre(s)
mm	- millimeter(s)
N/A	- Not Applicable
NaCl	- Sodium Chloride
NARL	- National Agricultural Research Laboratory
NGO	- Non-Governmental Organization
NTSYS	- Numerical Taxonomy and Multivariate Analysis System
°C	- Degrees Celsius
OD	- Optical Density
ODI	- Overseas Development Institute
OM	- Organic Matter
PCR	- Polymerase Chain Reaction
PGS	- Pure Germinating Seed
pH	- French 'pouvoir Hydrogène' meaning: "hydrogen power" Acidity or alkalinity measure of a solution.
PLAR	- Participatory Learning and Action research
POPGENE	- Population Genetics (analytical software)
ppm	- parts per million
Pr	- Probability
PRA	- Participatory Rural Appraisal
Proc	-Procedure
RAPD	- Random Amplified Polymorphic DNA
RELMA	- Regional Land Management Unit
Rep or REP	- Replication
SAR	- Sodium Absorption Ratio
SAS	- Statistical Analysis System
SE	- Standard Error
SM	- Soil Moisture
SNV	- Netherlands Development Organization
SARDEP	-Semi arid Development Programme
SPSS	- Statistical Package for Social Sciences
SRM	- Society of Range Management
SS	- Sum of Squares

ST1	- Soil Type One (orthic FERRALSOL)
ST2	- Soil Type Two (rhodic FERRALSOL)
ST3	- Soil Type Three (histic GLEYSOL)
STD DEV	- Standard Deviation
TBE	- Tris Boric EDTA
TLU	- Tropical Livestock Unit
TRT	- Treatment
TTAP	- Taita-Taveta Agricultural Programme
UNDP	- United Nations Development Programme
UPGMA	- Un-weighted Pair-Group Method with Arithmetic Averaging
USAID	- United States Aid for International Development
USA	- United States of America
WR1	- Watering Regime One (Daily)
WR2	- Watering Regime Two (Every 2 days)
WR3	- Watering Regime Three (Every 3 days)
WR4	- Watering Regime Four (every 4 days)
WRI	- World Resources Institute

ABSTRACT

This study was initiated to address degradation in the semi-arid rangeland of southern Kenya by assessing the level of pastoral and agro-pastoral communities' awareness, what they are doing about it, difficulties they face in re-vegetation and identify strategies to alleviate those difficulties. Participatory community surveys and feedback workshops, laboratory tests and field trials at station and on-farm level were conducted.

Nine divisions across three districts, namely Makueni, Kajiado and Taita-Taveta were surveyed involving 353 households with diverse background and resource endowment. Communities confirmed that rangelands are degraded thus constraining livestock production. Approximately 79% (range 16-97% among divisions) of the communities knew about this degradation caused by a number of factors, principally continuous overgrazing and drought. About 35% of the respondents estimated that bare patches in excess of 50% in some of the grazing areas exist and soil erosion is evident. Previously dominant and important forage plants (mostly herbaceous and a few browse species) had either declined drastically or disappeared altogether.

Over 70% of the households knew methods to stop further degradation and / or restore the rangeland integrity. These included deferred grazing, protecting bare patches with thorny branches, terracing and reseeding. About 62% of the households had tried at least one method. Of the above methods, reseeding was identified as the likely opportunity that is researchable on the basis that it was the most known among the communities yet it ranked third in adoption. However, reseeding had previously failed or had not been attempted at all because of inappropriate land tenure, labour costs, lack of or

poor seeds, drought, poor establishment, loss by wind and runoff, low persistence and lack of know-how.

Land tenure is ever-changing in the pastoral areas because while some communities are still in communal group ranches many have agitated and succeeded to sub-divide them into small family parcels. In the latter situation as in the agro-pastoral areas the family heads control the land and are mostly older and rarely accommodate new technologies. Younger family members are constrained as they cannot freely decide to implement their wishes in any part of the land. It is a social issue that calls for sustained public awareness and possibly exposure to success case studies.

Labour costs constraint arises from failure to see tangible returns to investment because where, for instance, arable farming is concerned the same people would readily open up large acreage within a short time. So, there was need to demonstrate that investing in pasture is worthwhile through on-farm trials and field tours.

The rest of the difficulties in reseeded were related to seed quality and establishment for which a series of experiments were designed and carried out. Seed unavailability meant testing the published techniques of harvesting local materials and storing them for future use without compromising viability. Further, lack of seeds meant that any material obtained from whatever source would be tried in most cases without success because plant species have different growth requirements, especially soils type and moisture. Where the right species is matched with right soil type and attendant moisture level, establishment could be poor depending on the planting technique used.

Seeds of four grass species, namely *Cenchrus ciliaris*, *Chloris roxburghiana*, *Enteropogon macrostacyus* and *Eragrostis superba*, considered the most important by the

communities were harvested using two recommended methods: (1) cutting the stalk of a mature panicle with the flag leaf, keeping them under shade for 3-5 days before threshing (2) stripping the seeds when dry. Seeds were put separately in four types of containers, namely aluminium tins, nylon sacks, brown paper bags, and white cotton cloth bags. They were stored in a traditional grain store. Sub-samples of the seeds were periodically collected and caryopses tested for viability through germination in Petri dishes for 14 days. Harvesting with stalks was superior to stripping, particularly for *E. superba*. Different species had different levels of viability right from harvesting time and over the storage period, regardless of method of harvesting. Daily seed germination increased by 37.5% on average with storage for all species. The overall best container material was the metal tins with 5.7% higher daily seed germination than the worst container which was the cloth bags.

Seeds were sown in plastic pots filled with three soil types (rhodic FERRALSOL, orthic FERRALSOL and histic GLEYSOL) and subjected to four regimes of watering (250 ml daily, 500 ml every other day, 750 ml every third day and 1000 ml every fourth day) for 70 days. The highest seedling population was that of *E. macrostachyus* (31.27 ± 3.493) while the least was that of *C. roxburghiana* (7.63 ± 1.009), which was similar to that of *E. superba*. Seedling population did not differ between the FERRALSOLs but was four-fold that on the GLEYSOL. These differences persisted into maturity where tillering and biomass was lower on the GLEYSOL and not different between the FERRALSOLs. However, plants growing in the GLEYSOL suffered less moisture stress as they maintained a relatively higher level of greenness for a longer period. Watering every third day produced the highest seedling population (23.94 ± 3.612) and daily

watering the least (8.02 ± 1.243). These results reflected soils' differences in water holding capacity and chemical activity, especially leaching and salts build up.

On-farm trials involved sowing a mixture of the four grasses using two techniques: (1) broadcasting of seeds onto the soil surface among existing vegetation or bare ground, and (2) preparing the seedbed by pitting along contours and placing the seeds on the crescents of the pits. Sowing on pits had 89.7% more seedlings than broadcasting. However, individual species establishment varied from site to site due to variation in soil fertility and the concomitant variation in rainfall.

Poor reseeding results could further be explained by introduction of un-adapted seed material. It is possible that seeds brought in, mostly from KARI – Kiboko, were of a different ecotype. Genotyping of *C. roxburghiana* using the random amplified polymorphic DNA (RAPD) technique found that there is a significant genetic variability within and between four natural populations, with the Kiboko population being the least diverse. Greater genetic diversity within a population where seed is obtained from implies a greater chance of obtaining a good establishment when reseeding. Possibly, other species have similar variation making it imperative that decisions on where to obtain seeds are more judicious.

The overall conclusions are that southern Kenya rangelands are degraded and the communities are not only aware of this fact but also they have attempted to address it in a number of ways albeit at a limited level. Reseeding difficulties are of social, economic and biophysical kind. So, strategies to alleviate the problem of rangelands degradation must be of necessity be multi-disciplinary because each component is almost equally crucial.

CHAPTER ONE

1.0. INTRODUCTION

Range condition and trend assessments over the years have often pointed at worsening productivity of natural pastures both in the arid and semi-arid areas of East Africa (Coughenour *et al.*, 1990; McPeak, 2001; Coughenour, 2004). In Kenya, community surveys using participatory rural appraisal (Lelo *et al.*, 1995) to identify constraints to livestock production invariably confirms this situation. For example, Wandera *et al.* (1996) highlighted the need for pasture improvement for greater meat production from indigenous livestock in pastoral areas of Kajiado and Baringo Districts. Later, the findings of Mnene and Mbakaya (1997) in a follow up survey among communities in Kajiado through participatory learning and action research (Defoer *et al.*, 2000) agreed with those results. Possible opportunities to alleviate feed shortage and the community action plans developed in these surveys more or less mirrored one another. The options for improving the state of natural pastures were limited to reseeding, de-stocking, change of herd structures and bush management. From the subsequent survey (Mbogoh and Shaabani, 1999), the situation was largely the same but there was no agreement as to what was feasible under research, where the research could be undertaken and how to accelerate the most likely option.

Reseeding had been demonstrated as possible option to improve forage condition in range areas (Pratt and Knight, 1964; Pratt and Gwynne, 1977), however, adoption rate remained low over the years for reasons not well understood. But perhaps before one deals with reasons why adoption rate has continued to be low, it is necessary to

understand why natural pastures have been degraded over the years in terms of loss of palatable grass species. Degradation of natural pastures has been occasioned by a varied set of pre-disposing conditions no doubt dictated upon by the equally varied backgrounds associated with different production systems. To exemplify this, two scenarios are described here.

The first scenario concerns the pastoral communities in southern Kenya who traditionally managed pasture resources in a communal arrangement until the advent of Group Ranching policy in 1960s. With good intentions but without regard to traditional management structures, the government appointed and set up management committees for these group ranches. The committees were to provide a central point of grazing management. Group ranches themselves were fashioned along the beef ranching systems / models (Stoddart *et al.*, 1975) of North America. Unlike in America, group ranches did not have paddocks to assist in the control of grazing, and the number of livestock accessing the common range. Rather, each household maintained their own herds and accessed nearly every part of the ranch as they wished. There was no central control over population numbers, breed types or herd structures. Over the years, the committees proved ineffective and this led to over-grazing of the range.

Southern Kenya pastoral communities have in recent years opted for the sub-division of the group ranches. Sub-division of land has gained momentum and most ranches are now either already sub-divided or are in advanced stages of the process. Unfortunately, many people have settled on degraded areas with extensive bare ground patches. In a survey conducted in Kajiado District of southern Kenya, it was found that more than 35% of the respondents interviewed were allocated areas that were more than

50% denuded (Mbogoh and Shaabani, 1999). Although it is evident that rehabilitation through vegetation with appropriate pasture species would be necessary, that is not happening. It seems most of these pastoral communities do not know how to undertake rehabilitation with a view to improving the pastures now that they have the control over their land (Lesorogol, 1998). Since the earlier alternative of moving herds to better areas is no longer tenable, something needs to be done to improve the poor pastures and generally rehabilitate these degraded rangelands.

The second scenario addresses the agro-pastoralists that settled in former medium potential rangelands from the highlands and employed unsuitable arable agriculture technologies. For instance, they cultivated extensively, felling all trees in the process and only a few farmers used terracing on land with steep slopes. While they did not give up livestock keeping altogether, pastureland allocated for their animals is often insufficient. With human population increase, more and more land has been put under cultivation. The little grazing land available is thus heavily utilized leading to loss of important forage species and subsequent out right denudation. The ploughed areas have largely remained bare most of the years, as crop failure is common (one good harvest every five seasons) due to typical unpredictable rainfall in these arid and semi-arid lands (ASALs). Frustrated by frequent crop failure, some of the people have wished to revert to or concentrate more on livestock production. The communities perceive livestock as a major means of household food security during seasons of crop failure. Often, while crops fail due to even mild droughts, that little rain seems adequate for forage production. But, the areas set aside for natural pastures are not only limited in size, the forage is too poor to support associated livestock herds. For example, in an area where *Aristida* sp.

has replaced *Heteropogon contortus*, forage quantity and quality has declined (Wandera, 1993).

Whether these two scenarios are permanent or not, is unclear. However, an ecological down ward trend is continuing and this is worrying particularly where extensive denudation and erosion (Plate 1.1) or bush infestation has occurred as it depresses potential carrying capacity for livestock thus threatening the livelihood of communities inhabiting the affected areas. Typical examples are found in Kajiado, Taita-Taveta and Makueni Districts.



Plate 1.1. A site degraded through severe denudation in Kajiado. (No grasses and the only vegetation present comprise of shrubbery).

Shortage of forage is real and improvement of pasture production has become a necessity (Wandera *et al.*, 1996; Mnene and Mbakaya, 1997), be it in pastoral or agro-pastoral production system. For the denuded areas, natural recovery with deferred grazing is possible but that may take many years especially if soil seed bank is depleted and the surface soil structure destroyed. Generally, however, rangeland resilience is still a poorly understood and inadequately researched phenomenon (Mworia *et al.*, 1997). To accelerate the forage recovery process would require some external input such as seedbed preparation and reseeding with native species. Whereas reseeding techniques have been developed through research, adoption by farmers has been rather low for unknown reasons.

This study, therefore, aimed at estimating the magnitude of the natural pasture degradation in semi-arid areas of Makueni, Kajiado and Taita-Taveta Districts and developing strategies of improving chances of success in natural pasture improvement through reseeding. It was postulated that chances of success in re-seeding would be increased significantly when efficiency is improved at all stages of reseeding. The information generated from the study will provide a better understanding of the significance of natural pasture degradation in semi-arid rangelands of Kenya and how to rehabilitate the range through re-introduction of lost forage species more successfully.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 RANGELAND AND VEGETATION CHANGE

Rangelands are uncultivated lands that will support grazing and browsing animals (Herlocker, 1999). These animals may be livestock or wildlife. Although primarily arid and semi-arid, rangelands also include areas that have in the past or may in future be used for cultivation or forestry (Holocheck *et al.*, 1989). It implies, therefore, that some rangelands are to be found in humid and sub-humid areas. Examples in Kenya are Transmara, Ngong, Loitokitok, and areas around the mountains in the arid north including Samburu and Marsabit (Lesorogol, 1991; Thurrow, 1995; Herlocker, 1999). All together rangelands cover approximately 80% of Kenya and are found in virtually every district with a great diversity in vegetation types (Pratt and Gwynne, 1977)

Vegetation in the rangeland changes over time, whether in use by man or not. The main factors are fluctuation in climate and the natural tendency of vegetation to change (Pratt and Gwynne, 1977; Branson, 1985; Archer and Smeins, 1991). The latter is through a succession of secondary (seral) vegetation communities towards an ecologically steady (or climax) state. For example, vegetation biomass and density including that of trees was observed to increase three times when rainfall in a six-year period was above normal in the Serengeti National Park, Tanzania (Sinclair, 1979). As a result, both herbivore and carnivore populations increased. Seasonal changes can be greater than those occurring over a number of years as observed in Kajiado (Njoka, 1984). But, recovery could also occur over a number of years and not just a few seasons

as reported in the United States (Branson, 1985). In South Africa, changes in botanical composition of a semi arid savanna were strongly influenced by rainfall variability with a dramatic shift induced by drought during a 10-year period (Fynn and O'Connor, 2000) towards less productive and less palatable species. However, a combination of natural processes and human perturbations has often resulted in more drastic vegetational changes. In the South African example above (Fynn and O'Connor, 2000), high stocking rates had an additional effect especially on sloping land. Other human activities that might accelerate vegetation change are burning tree cutting or outright cultivation.

Fire has had a widespread influence on the semi-arid rangelands where rainfall and relatively light grazing have ensured a good fuel in the form of dead grass for late dry season burning. Under such circumstances, fire-tolerant plants species such as *Themeda triandra* and other mid-grasses will dominate an area as long as it is periodically burnt (Tueller, 1973; Skovlin, 1984; Deshmukh, 1986b; Skerman and Riveros, 1990; Mnene, 1995). If, however, fire is curtailed for a number of years the cover of invading shrubs may make it impossible for the grasses to ever re-establish in the area due to a modification of the micro-environment (Trapnell, 1959; Tueller, 1973; McNaughton, 1979; Too, 1995). A good example is the KARI land at Kiboko that used to be largely grassland but over the last 20 years there has been rapid bush encroachment such that some areas are now devoid of grass altogether (W.N. Mnene— personal observation).

Abandoned areas where grazing and tree cutting / cultivation occurred can experience secondary succession so long as conditions are right. If protected from further disturbances, the original vegetation may re-establish (Lusigi, 1984; Keya, 1998). In a steady state-and-transition model study in Australia, light or no grazing of an area with

less palatable perennial and annual grass promoted recovery of desirable grass species but did not lead to recruitment because of persistence of large bare patches (Ashet *et al.*, 1999). Patches that are bare or dominated by undesirable forage species could be regarded as signs of early stages of the process of degradation, especially if they tend to increase with time (Wandera, 1993). Even where rainfall conditions have improved, perennial grasses have in most cases not returned once lost because the seed bank in the soil is depleted (White, 1983; Le Houerou, 1993). Therefore, in the final analysis, such areas (found throughout the rangelands) remain vulnerable to repeated degradation events. Consequently, soil erosion may ensue which not only alters the fertility of the soil and but also lowers the production potential of the affected sites permanently, meaning that the sites are degraded (Archer and Smeins, 1991; Hinchcliffe *et al.*, 1996; Herlocker, 1999). To prevent that from happening, it has long been recognized that some form of investment in the application of capital inputs such as clearing, ploughing and reseeding is necessary (Jordan, 1957; Pratt and Knight, 1964; Bogdan and Pratt, 1967; Thurrow, 1995).

Generally, land degradation refers to the reduction or loss of biological or economic productivity of cropland, pastures, forests and woodlands (Hinchcliffe *et al.*, 1996). Land degradation occurs as result of inappropriate land uses and agricultural practices, overgrazing or de-vegetation and drought which leads to erosion and deterioration of soil properties (Stahl, 1993). Droughts occur naturally every one out of five years in East African rangelands (USAID, 1994). With respect to natural pasture, degradation is a process and involves one or more of the following (FAO 2002):

- a) Net loss of vegetation as a result of heavy grazing without sufficient time to rest,

- b) Reduction in palatable forage species,
- c) Decrease in palatable perennial grasses,
- d) Increase in annual plants,
- e) Species rarity,
- f) Bush encroachment, and
- g) Weed invasion.

The net result is that 80% of pasture in Africa is degraded, the problem being particularly serious in certain regions of the Greater Horn of Africa due to political and social pressures that have forced traditional pastoralists to become sedentary (Lane and Pretty, 1990; Galaty *et al.*, 1994; IDS, 1995; McNeely *et al.*, 1995; Steinfeld *et al.*, 1996; Kimani and Pickard, 2002). About a decade ago, Kenya was estimated to have lost 40% of its savannas and grasslands to land degradation (Cleaver and Schreiber, 1994). With the increasing frequency of droughts it is possible that the situation is worse at the moment.

2.2. RANGE IMPROVEMENT

Stoddart *et al.* (1975) stated that rangelands do not always provide the maximum usable forage of which they are capable. Various reasons render rangelands less productive including heavy and indiscriminate grazing and wild fire. Therefore, for over 100 years range managers have been addressing this problem with a view to devise range improvement practices to increase forage production without waiting for nature to restore degraded areas (Smith, 1898; Pratt and Gwynne, 1977; Herlocker, 1999).

Over the decades, three main approaches have been practiced, namely:

- i. Reseeding,
- ii. Loosening the soil by means of harrows, and
- iii. Water harvesting by cutting furrows to intercept runoff.

These techniques are beside those dealing with manipulation of range vegetation such as use of fire, mechanical equipment, chemicals and biological agents (Stoddart *et al.*, 1975; Pratt and Gwynne, 1977; Scifres, 1983; Herlocker, 1999). Pratt and Gwynne (1977) observed that it is by use of various range improvement techniques that the objectives of range management are realized.

2.2.1. Prescribed burning

Fire is believed to be a good tool for maintaining a good grass cover and quality (Bogdan, 1977; Pratt and Gwynne, 1977; Boonman, 1993; Brock and Hay, 1993; Mnene, 1995). Some grasses tend to thrive well under some regimes of burning. Apart from rejuvenation of standing crop, fire scarifies seed rendering it easier to germinate (Tueller, 1973; Skovlin, 1984; Deshmukh, 1986b; Skerman and Riveros, 1990; Mnene, 1995). Temperature is a major factor influencing seed viability and hence seed germination potential. As a rule of thumb, for every 5°C drop in temperature (below 50°C) seed viability of domesticated species is doubled (HSU, 1994). It is not well documented as to what extent this principle applies to wild rangeland grasses. *Cenchrus ciliaris* seed was reported to germinate better after pre-drying for 10 days at 40°C than pre-chilling for the same period at 5°C (Burtler, 1985). However, for an effective fire, sufficient fuel in the form of dry herbaceous vegetation is essential. So, where land has lost its herbaceous

component and is either bare or dominated by woody plants, fire is not easy to apply as a range rehabilitation tool.

2.2.2. Deferment

The history of an area may well determine the rate of its recovery when implementing rehabilitation. In some less degraded parts, protecting denuded areas over several growing seasons may lead to self re-vegetation due to existence of seeds in the soil. Evidently, soil seed banks only require the opportunity to emerge and establish stable rooting systems. Subsequent stability of the stand would depend upon proper management to maintain the area in good range condition (Lusigi, 1981, 1984). Optimum time periods and duration of resting / protecting denuded areas for various plant species to establish is unknown, and depends upon viable seed stock on site. Seeds of some species are capable of staying viable in the soil for decades (Lloyd and Cavers, 2002). Why seed banks in the soil do not germinate and establish could be due to poor growing conditions such as soil capping, among others.

Capped soils experience lowered infiltration rate and tends to be a physical impediment to seed emergence (Bogdan, 1977; Boonman, 1993) and may require braking up before sowing. Too (1995) while over-sowing with perennial native grasses in order to increase primary productivity of different range sites at Kiboko had to scratch the soil surface so as to incorporate the seeds properly. The study showed positive results of reseedling and this has been demonstrated in other studies elsewhere (Mott *et al.*, 1976; Cook and Dolby, 1981; McIvor, 1981). Breaking the hard soil surface allows better water infiltration and thus leads to a better seedbed for the seed, both that naturally exists in the soil and introduced ones (McIvoir, 1981; McIvor and Gardener 1985).

2.2.3. Reseeding

The purpose of reseeding a rangeland is to improve existing ground cover and biomass (Pratt and Gwynne, 1977). This can be accomplished by:

- i. Over-sowing into existing vegetation with a superior species,
- ii. Establishing a completely new pasture, with or without the aid of irrigation, and
- iii. Reseeding denuded land.

Except in arid environments where annual grasses are best suited, perennial grasses are preferred to all other types of plants for reseeding purposes. This is because grasses have good self-seeding ability so that with proper management they can establish and spread quickly to give good cover. On the other hand, legumes have often failed to give good results in reseeding (Pratt and Gwynne, 1977; Boonman, 1993; Herlocker, 1999).

Grasses are also known to have good grazing value and persistence.

The requirements of grass for reseeding include the following qualities:

- i. Easy to establish,
- ii. Sufficiently drought tolerant and be able to survive and perpetuate itself,
- iii. Provide good quality herbage, and
- iv. Able to produce an adequate amount of viable seed which can be easily harvested.

Grasses that have been used with good results in reseeding in Kenya and other East African countries are local species. Some examples of these species are presented in Table 2.1.

Range reseeding is not new in Kenya. During the 1950/60s, among a number of techniques that were developed / introduced for rangeland rehabilitation some had the options of pitting and re-seeding or over-sowing (Jordan, 1957; Pratt and Knight, 1964; Bogdan and Pratt, 1967). 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).

Mnene *et al.* (1998) also worked in *Olopololis* using three perennial grasses and a legume sown after pitting. The main lessons learnt were that success depended very much on site conditions, particularly on rainfall and soil types. In that study, past history of utilization was also suspected to be among factors influencing performance of individual species.

When a seed stock is healthy, only two environmental factors will stop it from germinating and establishing well in the semi arid rangelands of Kenya, namely soil type and moisture. Keya (1997) reported significant effect of rainfall amount on emergence of a number of grasses including *Leptothrium senegalense* and *Chloris roxburghiana* in Marsabit in Kenya, agreeing with earlier results of Veneenda *et al.* (1996) and Johnson *et al.* (1990) under similar arid conditions in Botswana.

Table 2.1 Description of four selected species according to Bogdan (1977), Pratt and Gwynne (1977) and Boonman (1993).

Botanical and Common Plant Name	Growth Habit	Habitat / Distribution	Use in Reseeding
<i>Cenchrus ciliaris</i> L Buffel grass; African foxtail	Tufted or rhizomatous perennial. Stems erect up to 140 cm high, stout or slender. Leaves glabrous or hairy, 7-30 cm long and 2-5 cm wide. Panicle in the form of a single cylindrical spike bearing several clusters of spikelets. Approximate number of seeds per kg is 350,000 – 400,000.	Distributed in tropical and subtropical Africa, North Africa, Madagascar, Canary Islands, Arabia, India and Pakistan from sea level to 2000 m altitude. Drought resistant and grow in areas with 250 - 300 mm. Grows best in loam soils but can do well in sandy or alluvial soils but avoids heavy clays.	It is cultivatable. Has been used in reseeding denuded arid pastoral land or for improving worn-out pastures. Established almost exclusively from seed although tuft splits can be used. Seed rate is 3-12 kg ha ⁻¹ . Widely used in E. Africa and elsewhere in the tropic and sub-tropics (Bogdan 1977; Boonman 1993).
<i>Chloris roxburghiana</i> Schult. Horsetail grass	Tufted perennial, 50-150 cm high with fan-shaped arranged basal leaf sheaths and shoots. Leaf blades flat or folded, 10-20 cm long and 2-10 mm wide. Panicle a compact feathery oblong head with spikelets containing three to four florets each. Approximate number of seeds per kg is 6,000,000 – 13,000,000.	Occurs naturally in tropical E. Africa, southern India up to 1,500 m altitude in open or bushed grassland.	Used in Kenya for reseeding with moderate to good success by Jordan (1957) and by Pratt (Bogdan and Pratt 1967).
<i>Enteropogon macrostachyus</i> (A. Rich) Benth. Wild ryegrass	Tufted perennial up to 1 m high with narrow flat leaves. Slender stem terminates in a single rarely paired, one-sided dense spike 8-20 cm long. Spikelets three flowered but with only the lower most floret being fertile. Approximate number of seeds per kg is 180,000.	Occurs in semi-arid areas of tropical Africa, in bush, and on forest margins and in clearings often on rocky ground.	Tried with moderate success for reseeding denuded pastoral land in Kenya (Bogdan and Pratt 1967) under annual rainfall of 550-800 mm. Also by Freddenslug and Cassady 1969).
<i>Eragrostis superba</i> Peyr. Maasai lovegrass	Tufted perennial 20-120 cm high with flat leaves up to 10 mm wide. Panicle 10-30 cm long sparsely branched. Spikelets flatly compressed from the sides, 6-20 mm long and 3-10 mm wide with 6 florets which remain attached to the spikelets at maturity, the spikelet falling off as an unbroken unit. Approximate number of seeds per kg is 100,000.	Occurs mainly in E. Africa under an annual rainfall of 500-900 mm in grassland, and is often abundant on sandy soil.	Used successfully for reseeding denuded pastoral land in Kenya (Jordan 1957; Pratt 1963; Pratt and Knight 1964; Bogdan and Pratt 1967). Competes well with weeds.

2.2.4. Other factors

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. Within a species, relatively small seeds are as a result of under development such as occurs when filling is not complete due to early cessation of rainfall (Carren *et al.*, 1987; Boonman, 1993). Such 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 (Coyne and Bradford, 1985; Veneenda *et al.*, 1991). Both endogenous and exogenous inhibitors control this mechanism. The former wears down in most species within a few months after seed ripening (Tothill, 1977a; Cohen, 1991; Wu *et al.*, 1998; Lloyd and Caver, 2002) while the latter are mechanical (Martin, 1975; Hagon, 1976; Boonman, 1993).

2.3. PLANT GENETIC VARIABILITY

All plants, including rangeland vegetation, exhibit genetic differences between genera, species and variety or ecotypes occurring as a result of adaptation to unique environmental factors of specific sites (Gardner and Snustad, 1984; Nevo *et al.*, 1983; Nevo, 1988). This intra- and inter-population genetic diversity is essential as it ameliorates survival potential by enhancing the adaptation potential of a species to

present and future environmental changes. However, populations may be distinct at the molecular level (genotypic) but at other levels (phenotypic or anatomic); this may well not be discernible (Li and Graur, 1991). The greater the genetic diversity within a population of an ecotype, the greater the probability of its germplasm establishing well when transplanted (Nevo, 1988), thus making reseedling more successful.

Molecular genetic markers can provide a relatively unbiased method of quantifying genetic diversity in plants (Williams *et al.* 1990). Random amplified polymorphic DNA (RAPD) markers have been used to fingerprint genotypes in phylogenetic studies of population diversity in different plant species (Gunter *et al.*, 1996; Graham *et al.*, 1997; Paran *et al.*, 1998; Lowe *et al.*, 2000; Agufa, 2002). RAPDs are molecular markers based on polymerase chain reaction (PCR; Arnheim and Erlich, 1992; Timmerman and McCallum, 1993) which is a simple yet powerful technique that permits amplification of specific sequences from small amounts of template DNA. Williams *et al.* (1990) and Welsh and McClelland (1990) reported amplification of anonymous genomic DNA sequences using single primers selected without prior sequence knowledge. Polymorphisms between different genotypes were produced that could be observed as presence or absence of bands after products were separated by gel electrophoresis. Since then, this technique has been found to be sensitive, quick to perform and can be applied to a large number of samples.

Dawson *et al.* (1993) in a study on RAPD analysis of *Hordeum spontaneum* (the immediate evolutionary progenitor of cultivated barley, *H. vulgare*) observed that on a macrogeographical level, the distribution of diversity between pairs of populations appears to be associated more with ecological factors than with simple geographical

proximity. Genetic diversity would therefore correlate significantly with a combination of climatic factors of rainfall, humidity and temperature (Nevo *et al.*, 1979; Nevo *et al.*, 1986). *Hordeum* polymorphism has also been associated with soil type and topography (Nevo *et al.*, 1983). Similarly, Huff *et al.* (1998) found a strong correlation between soil fertility and genetic diversity of Little Bluestem [*Schizachyrium scoparium* (Michx.) Nash] grass populations using RAPD analysis. In Huff's study it was concluded that for a wide-ranging and highly variable species, local site differences in fertility and ecological history could promote genetic differentiation equal to or greater than geographical differentiation.

Graham *et al.* (1997) observed that the presence of many banding differences between populations of raspberry (*Rubus ideaus*) from neighbouring sites in Scotland was as a result of a high degree of genetic isolation. Similarly, studies in Thailand found that populations of *Afgekia sericea* Craib. (Leguminosae), a medicinal plant varied genetically from province to province (Prathepha and Baimai, 1999). In these studies, surprisingly, the important isolating features were hedges, car parks and roads. Other barriers like creeks and steep hills were found to restrict gene flow between populations of rheophytes such as *Acorus gramineus* Scoland. (Araceae) in Taiwan (Liao and Hsiao, 1998). Therefore, germplasm required for reseedling purposes should be obtained from ecotypes that are not isolated so that such material may be of a wide genetic variation and thus better able to adapt to and establish in various degraded sites that are ecologically different from the point of origin.

2.4. SEED QUALITY

Griffiths (1993) reported that by the 1990s only 20% of farmers needs for herbage seeds could be met by the formal seed production and marketing system, including individual and collaborative arrangements between the public and the private sector in the sub-Saharan Africa. Therefore, the informal sector has had a role to play as farmers collect their own seed and/or buy from neighbours. Consequently, seed quality of domestic species is highly variable and poor in the tropics as a result of poor harvesting and storage technology (Chin and Wong, 1993; Loch and de Souza, 1999). Wild species not selected and bred for pasture production have greater variability in seed production characteristics. Records of work on pasture seed indicate that it is a recent and largely neglected field, particularly in Africa. Early documentation date back to about 60 years beginning with work by Edwards (1935; 1940 and 1943) in Kenya, and Liebenberg (1942) of South Africa, cited by Loch and Ferguson (1999).

Although Kenya is still considered a major pasture seed producer (Loch and Ferguson, 1999), the emphasis has been on a few species of grasses, especially the two most commercialized ones *Chloris gayana* and *Setaria sephacelata*. Elsewhere, Australia and the USA in particular, great strides have been made on a number of species as far as proper seed harvesting, processing and storage is concerned (Loch and Ferguson, 1999). Fortunately, a few of what have been domesticated elsewhere originated from Kenya and *C. ciliaris* is a good example. For the other southern Kenya rangeland species, seed technology on harvesting, processing and storage may have to be developed while adopting from those of commercial value.

Further, the major reason for low and variable yields of herbage seed in the tropics is limited understanding of crop development (Hill and Loch, 1993). As a result, seed crops are not always grown in suitable environments. Knowledge of how best to manipulate their development under different seasonal conditions, on different soils and in different climates is lacking. Another factor is managerial control in opportunistic harvesting systems (Hill and Loch, 1993; Kawithayakorn and Phaikaew, 1993). These are systems whose primary objective is forage production but when conditions are favourable and pasture is plenty they allow seeds in portions of the pastureland to mature and harvest them for added income.

2.4.1. Seed harvesting

Seeds of grass species that are largely found in the semi-arid and arid rangelands cannot be found readily in the market. For these grasses to be re-introduced in the target degraded natural pastures, sources of seed must be identified. Currently, the push, not only in Kenya but also in most developing countries, is for community based seed multiplication of locally adapted species (Kowithayakorn and Phaikew, 1993). That calls for packaging of information for the local communities on the techniques of harvesting, processing and storage of forage seeds.

The process of seed harvesting begins with deciding when to harvest. For grasses that have no synchrony, this is a big challenge and may either lead to harvesting too early or too late. Either way, the results are usually poor seed lots. In such a case, seed heads emerge progressively and may take up to 6 weeks depending on species and prevailing growth conditions. This leads to a continuous turn over of seed produced in a standing crop as seed formation and ripening also takes days or even weeks (Humphreys and

Riveros, 1986; Boonman, 1993; Loch and Ferguson, 1999). Often, late timing in deciding when to harvest leads to losses of up to 20-40% of the potential seed yield. The total loss could amount to 50-70% by the end of harvesting (Loch and de Souza, 1999). Examples of grass species that have such behaviour are *C. gayana*, *Panicum maximum* and *S. sephacelata* (Loch and de Souza, 1999). However, there are examples of grasses that behave differently such as *Melinis minutiflora* whose seed head emergence is well synchronized and *Pennisetum clandestinum*, which does not shed its ripe seed (Loch and de Souza, 1999). Unfortunately both species are found in humid areas. So, the guide of how to achieve correct timing in grass seed harvesting is based on personal experience and regular inspection of visual indicators. These indicators are grouped into three:

- a) Ease of seed removal – harvesting towards the end of the period of maximum presentation of yield, at which time most of the seeds are close to shedding.
- b) Amount of seed shed – early formed seed also shed early, so by the time most of the stand is ripe and looks ready for harvest, approximately 15-20% of the seed will be on the ground.
- c) Field colour – as seed mature the heads usually change to colours characteristic of the species / cultivar. This indicator is normally frustrating due the lack of synchrony in many species.

In the end, it is a combination of these indicators that would result in a more accurate timing of grass seed harvesting (Loch and de Souza, 1999).

There are many methods recommended for harvesting tropical and subtropical grass seed (Bogdan, 1977; Boonman, 1993; HSU, 1994; Loch and de Souza, 1999) but they all could be summarized into three:

- a) Single destructive harvest of standing crop,
- b) Multiple non-destructive harvests from the standing crop, and
- c) Recovery of mature seeds shed from the standing crop.

Single destructive methods can be mechanical (Hopkinson and Clifford 1993) or manual, using sickles. Whole plants of the entire sward are cut at or slightly above ground. Usually the cut material is tied into bundles for stooking (standing the bundles on their cut ends) for a few days before threshing. This has been found to improve harvest efficiency because after that the seeds fall off easily. The main disadvantage of single destructive method is that it includes all the immature seeds as well which are known to have low viability initially and deteriorates rapidly. The manual system has been in practice in Kenya (Boonman, 1993), Thailand (Hare, 1985; Phaikaew *et al.*, 1993) and Brazil (Loch and de Souza, 1999).

Multiple non-destructive methods target only the mature seed heads and aim at leaving immature ones intact to continue ripening for the next and subsequent harvests. Mechanical harvesters have been developed for use in this approach, for example the beater (Cavaye, 1991), the brush (Dewald and Beisel, 1983) and the stripper (Klinner *et al.*, 1987). Manual techniques for non-destructive seed harvesting include either shaking the seed heads one by one into a receptacle or tying a number of the heads together and periodically beating the seeds out of the 'live sheaves'. This is repeated every 3-5 days

for as long as it is economical to continue doing so. Another alternative is to place sheets of polyethylene or canvas between rows on which seeds are shaken and collected.

Other non-destructive methods are stripping (milking) the seeds by hand from the panicles when dry or cutting the stalk bearing the panicle with mature seeds together with the flag leaf at the last node. Stripping targets mostly dry seed heads. However, a number of seeds may not be entirely dry but mature and when stripped they are abruptly cut off from the normal supply of nutrients. This leads to shriveling and thus a reduction in seed quality with low germination potential. On the other hand, cutting the seed heads with the stalk and flag leaf allows the seeds time to continue maturation when air-drying on a canvass under shade for 3-5 days (HSU 1994; Loch and Ferguson 1999).

Recovery of fallen seed is a necessity because of a number of reasons but chiefly due to the problem with lack of synchrony and the associated huge seed losses. Recovery of fallen seed is largely a manual procedure used in dry weather since it involves sweeping the fallen seed into a basket or any other container (Kowithayakorn and Phaikaew, 1993). The procedure has been applied to *Brachiaria decumbens*, *B. brizantha*, *P. maximum* and *Andropogon gayanus*. The seed recovered from the ground have high germination and vigour leading to rapid and uniform establishment (Chin and Wong, 1993). Such seed has thus fetched premium prices in the market (Loch and Ferguson, 1999). Mechanization of the recovery of fallen seeds has also been attempted (Hopkinson and Clifford, 1993), however, unless combined with the destructive method, the approach is not applicable with sod / mat forming grass species.

Whether or not to mechanize the above approaches would be a decision based mainly upon such factors as relative costs and availability of labour and machinery /

equipment (Loch, 1991; Hopkinson and Clifford, 1993). Which method to choose however, depends on both these factors. In addition, the particular species of grass and its market preference have to be considered. Forage plant species vary considerably in growth habits, seed structure, and synchrony of crop development and relative abundance of standing and fallen seed. Where higher quality seed would command a premium price then this becomes a factor in selecting a harvesting method (Loch and de Souza, 1999).

2.4.2. Seed storage

Assuming that seed is harvested properly, storage then becomes the next most important step influencing seed quality (HSU, 1994; Lloyd and Cavers, 2002). Storage is all the more critical since it is not practical to harvest and plant seeds in the same season. More often than not, it is necessary that seed be stored for use in the subsequent season(s). In any case, pasture seed has been reported to require some amount of storage time (post-harvest ripening) for better germination and subsequent establishment (Pratt and Gwynne, 1977; Skerman and Rivieros, 1990; Boonman, 1993; HSU, 1994). However, post-harvest ripening has been reported to vary among species. For instance *Brachiaria mutica*, *C. gayana* and *Andropogon gayanus* requires 0, 6-12, and 12-24 months post-harvest storage time, respectively, for optimal seed viability (Bogdan, 1977; Boonman, 1993). *Heteropogon contortus* reaches peak viability during the first year after ripening and declines very rapidly in the fourth year (Tothill, 1977a). Within four months after harvest, *C. ciliaris* was reported to lose all its dormancy and begin to lose its viability soon after (Burtler, 1985). Hence, necessary storage time for the important rangeland grasses must also be varied, and is still largely unknown.

Seed attains physiological maturity at moisture contents ranging from 32-55%, depending on species (Humphreys and Riveros, 1986). Seed harvested by direct heading usually has 50-60% moisture content (Loch and de Souza, 1999) and can ferment rapidly if left in tight packs even for a few hours and the smaller the seed size the worse the threat (Hopkinson *et al.*, 1988; HSU, 1994). If seed is to be stored for any length of time, it must be at safe moisture content normally between 10-12% or less to minimize seed damage through fermentation. It is noteworthy that within the range of 4-14% moisture content, for every decrease by 1% of moisture, seed longevity is doubled. Also, between 50°C and 0°C, every reduction of temperature by 5°C doubles the storage life of a seed lot (HSU, 1994; Chin and Hanson, 1999).

Tropical environments naturally are not suitable for storage of seeds specifically because of high ambient temperatures and relative humidity. The two conditions are however, favourable to a host of storage pests and diseases (Delouche *et al.*, 1973). Further, the developing economies of most of the tropical countries can ill afford conventional seed storage facilities (Chin and Hanson, 1999). Yet a country's need for seed can only be met when both an appropriate and adequate storage capacity is in place.

Apart from ensuring that seed is properly dried soon after harvest, the seed therefore may require treatment with pesticides / fungicides to minimize damage by storage insects and fungus (Delouche *et al.*, 1973; HSU, 1994; Chin and Hanson, 1999). The seed would also have a longer shelf life if packed in waterproof containers. Naturally, grass seeds are hygroscopic and will absorb moisture from the air when ambient relative humidity is high (HSU, 1994; Chin and Hanson, 1999). This is unlike what farmers believe that seed should be kept in 'breathing' containers, especially sisal

and jute sacks (Chin and Hanson, 1999; Mnene – personal observation). Even some public institutions in Kenya have often used cotton cloth bags to store pasture seeds for years. It should be noted that, whatever the container type used seeds should be kept in rat-proof stores (HSU, 1994; Chin and Hanson, 1999).

2.5. PRIMARY PRODUCTION

Although much work has been done on primary production of grasslands in the tropics (Singh and Joshi, 1993; Ibrahim and Kabuye, 1988; Skerman and Rivieros, 1990; Long *et al.*, 1992; Baker, 1993; Boonman, 1993; Keya, 1998) limited literature exists for species dominating semi-arid and arid rangelands. The work based in the northern part of Kenya (Keya 1997, 1998, 1998b) is probably the most recent example. A few grass species most of whose seeds originated from Kiboko in southern Kenya was used in those studies. All species germinated and established rather well except *C. roxburghiana*, which had both a delayed and low germination. At the end of the first rainy season the seedlings of *C. roxburghiana* were still very young. Their chances for survival into the following growing season were low, eventually producing insignificant standing crops.

Work at Kiboko (Woie, 1986), Katumani (Tessema, 1986) and Kitale (Boonman, 1993) demonstrated that grasses have different forage production capabilities and nutrient contents. They also differ in their ability to tolerate varied frequency and intensity of utilization. Further, large numbers of tillers and leaves produced by some grasses such as *C. ciliaris*, *P. maximum* and *Digitaria macroblephara* allow the grasses to attain a maximum growth rate at an earlier age and recover sooner after defoliation (Woie 1986). In savanna grassland at Lamto in West Africa, total aboveground biomass production

declined with increasing frequencies of harvest / clipping (Leriche *et al.*, 2003). That is because, defoliation aimed at removing leaves as happens during grazing, retards tillering and results in a reduction in photosynthetically active tissue with a resulting reduction in carbon assimilation (Toughton, 1957). Therefore, in order to maintain a maximum rate of dry matter production, sufficient leaf area must be present to effectively intercept incoming radiation (Esau 1953; Nobel *et al.*, 1993). Further, the hypothesis that grazing could stimulate the aboveground dry matter available to grazers has no blanket application in rangelands with a mosaic of plant associations.

Some grasses grow in different associations on different soils (Bogdan, 1977; Kemei, 1986; Boonman, 1993). Mnene (1997) reported results on work with seven grasses growing in a natural association at Bachuma that showed variations between grass species in terms of on-set of growth, flowering and eventual dieback. None of these reports highlighted the effect of soil type on plant biomass production and possibly phenology.

The work of Kinyamario and Imbamba (1992) was perhaps the most detailed study of primary production in Kenya. It reported that East African grasslands are more productive than may have been previously appreciated. Production was limited by lack of rainfall during the dry seasons. The work was based at the Athi-Kapiti plains within the Nairobi National Park. The vertisol soils found in those plains are wide spread in Kenya's rangelands. Nonetheless, the work was not exhaustive since there are other soil and vegetation types in these rangelands where it was not replicated. Variation in soils interacts with rainfall to determine soil moisture and subsequently the type of vegetation to be found in a particular area. Plant biomass production is a function of species genetic

potential that can only be fully expressed depending on the various environmental factors such as soil moisture (here determined by rainfall), day length, air and temperature (Esau, 1960; Hacker, 1999). Soil moisture holding capacity varies with soil type (Nill, 1996). Generally, sandy soils tend to allow fast water infiltration and percolation. They also lose water rapidly through evaporation. Clay soils behave nearly the opposite. As a result, small rain showers may boost clay moisture content sufficiently to trigger and sustain plant growth while heavy rain storms may lead to water logging (Nill 1996). These characteristics are part of what distinguishes soil types and for a plant to grow in any one kind of soil it would need the ability to adapt to the inherent characteristics.

Understanding how much standing crop is available in a site is the first step in making informed decisions on stocking rates. It forms the basis for estimating the area's carrying capacity since normally, there is marked variation in standing crop of plant biomass from site to site. For example, in the *Hyparrhenia* and *Themeda* grasslands of Ruwenzori Park in Uganda the range is 59-405gm⁻² while the drysweet bushveld open savanna in South Africa has a range of 8-753gm⁻² (Bogdan, 1977). Also Kinyamario and Imbamba (1992) recorded 73-338gm⁻² in *Pennisetum* and *Themeda* grassland in the Nairobi National Park. In all these cases, the minimum and maximum values are associated with season although species composition also plays a role. In the arid northern Kenya, Keya (1998) recorded 4.73-69.75gm⁻² at Ngurunit in Marsabit. The minimum and maximum values in this case are associated with grazing over 9 years. Generally, it has been observed that net production has no direct relationship with annual rainfall when comparing different sites that receive different annual rainfall. This is because the tropical grasslands may represent different successional stages in local sere,

depending upon the mode and age of origin, and the kind of and intensity of biotic influences (Singh and Joshi, 1993).

Grazing influences the structure and function of grasslands depending upon the vegetation type, rainfall, the type of grazing animal and the duration and intensity of grazing (Kinyamario and Muthuri, 1986; Herlocker, 1999). Grazing creates relatively open canopies thus making the invasion of annuals and other alien plants possible (Pratt and Gwynne, 1977; Herlocker, 1999). Under heavy grazing, unpalatable plants of low successional order invade the open grasslands, eventually reducing the basal cover leading to greater chances of soil erosion while reducing desirable standing crop (Gill, 1975). The percentage of annual above-ground production utilized by herbivores is estimated to vary from 20 to 50% but in some regions or years, utilization can occur in excess of 90% (Detling, 1988; Briske and Heitschmidt, 1991). At such high levels of utilization, biomass production is impaired because grazing targets leaves and it is leaf area that contributes to efficient biomass production (Parson *et al.*, 1983; Briske and Heitschmidt, 1991).

Similarly, burning has profound effect on grasslands. Burning increases annual herbage net production and improves soil nitrogen content while killing tree and shrub seedlings (Olindo, 1971; Skovlin, 1971). Grasses tiller more under burning which is associated with increased biomass production. Olindo (1971) listed fire among three major factors responsible for the formation and maintenance of savanna in Kenya, the other two being shifting cultivation and grazing. The impact of any of these three factors is regulated by topography and climate. However, short-term evaluation of fire and frequency of defoliation in four different plant communities showed that fire had no

effect on overall yields while defoliation did depending on plant species (Too *et al.*, 1986).

Ranches in many parts of Kenya are currently being sub-divided and settlement schemes developed whereby individual households are allocated between 4 and 100 ha of land (Kimani and Pickard, 2002). On these smaller parcels of land, forage is scarce after being subjected to many years of continuous overgrazing. Efforts to re-seed tend to be influenced by prevailing environmental conditions, mostly soil and rainfall (Keya, 1998; RELMA, 1999; Herlocker 1999). Therefore, broad recommendations of stocking rates on the basis of ecological zones (Pratt and Gwynne, 1977) ought to be refined to make them more sites specific.

Diagnostic surveys (Wandera *et al.*, 1996; Mnene and Mbakaya, 1997) among the agro-pastoral and pastoral communities in the southern Kenya's rangelands have identified several grasses that are considered more productive and valuable to livestock but they have either disappeared already or are very sparse. These include *D. macroblephara* and *E. macrostachyus* among others. Under what circumstances these and other forage species have disappeared is not well understood. There is a dearth of documentation on the pastoralists' opinion on what causes disappearance of valuable plants, eventual pasture denudation and more importantly, what the communities have done about this problem (Lesorogol, 1991; Herlocker, 1999; RELMA 1999).

2.6. THE ROLE OF THE COMMUNITY IN NATURAL PASTURE IMPROVEMENT

Natural pasture improvement and rangeland rehabilitation in the pastoral and agro-pastoral systems generally would require community participation, whichever technique is selected. This assertion has been argued and presented well in the past (Baland and Platteau, 1996; Herlocker, 1999; Tefera *et al.*, 2002). Previously, social organization and structure has been ignored in the project planning process. The assumption has been that coercion and indirect approaches would get the communities to participate in the implementation. However, the results have often been that the projects collapse as soon as the lead agency, whether an NGO or GoK, disengages from the projects. In some instances, whatever gains might have been made are neglected or even destroyed. The experience of the Integrated Food Security Programmes in various districts during the 1980s (Herlocker, 1999) serves as a good example. In Kajiado, fences were pulled down and sold off for cash or exchanged for livestock less than six months after the research trials (W.N. Mnene - Personal experience). Participatory approaches that involve the community right from the inception stage of the projects through planning, implementation and evaluation have been available (Waters-Bayer and Bayer 1994) but not readily practiced. It is hypothesized that for research findings in this re-seeding study to be adopted, participation of the community at the test sites is critical.

2.7. CONCLUSIONS

The main points that come out of the review are:

- a) Rangelands are uncultivated lands that will support grazing and browsing animals and whether in use by man or not, vegetation in the rangelands changes over time

due to environmental and human related factors including rainfall / droughts, burning, tree cutting or outright cultivation and grazing.

- b) Fire has been a widespread influence on the semi-arid rangelands. Apart from causing rejuvenation of a sward standing crop, fire scarifies seed rendering it easier to germinate. However, rainfall and adequate fuel in the form of dead grass for late dry season burning are essential to successful use of fire as a tool in range improvement.
- c) Reseeding to improve rangelands has been done in pastoral areas with limited success. Different species tend to establish well in some areas than others possibly due to variation in soil types and rainfall. Another factor could be that individual species' physiological differences may affect germination and subsequent growth.
- d) Soils may have a rich seed bank and will usually only require the opportunity to germinate, emerge and establish. Optimum time periods and duration of resting / protecting denuded areas for various plant species to establish is unknown, but it is usually in terms of years and not just a few seasons.
- e) Further, seed banks in the soil do not germinate and establish due to poor growing conditions such as soil capping and therefore, while over-sowing / re-seeding different range sites may require some form of seedbed preparation so as to incorporate the seeds properly and to improve infiltration.
- f) Seed quality of domestic species is highly variable and poor in the tropics as a result of poor harvesting and storage technology. This is even a bigger problem

considering that wild species not selected for pasture production have greater variability in seed production characteristics. Proper seed technology is therefore necessary at harvesting, processing and storage, especially where communities are expected to undertake pasture seed multiplication to meet the current shortage.

- g) Although much work has been done on primary production of grasses in the tropics limited literature exists for species dominating semi-arid and arid rangelands. In particular, work on effects of soil type on forage plants establishment and biomass production has not been document, especially under varying moisture availability. Such detail is essential when formulating hypotheses on response of reseeding with different species in different parts of the semi-arid rangelands of Kenya, which are endowed with diverse soils.
- h) Plants have different degrees of genetic variation. Therefore, understanding of the extent and distribution of genetic variation within populations of the selected species is essential when formulating seed collection strategies. This will ensure efficacy in genetic diversity for re-seeding trials and subsequent distribution to farmers / pastoralists.
- i) In addressing pastoral and agro-pastoral rangelands improvement, several points should be considered including the following:
 - i. Consultation and involvement of the local communities as partners while respecting and building upon their local knowledge, and
 - ii. Tap on the existing community structures, working with the smallest organized groups who share and identify with the project's purpose.

CHAPTER THREE

3.0. GENERAL MATERIALS AND METHODS

3.1. STUDY AREA

The research study involved experiments on-station as well as on-farm. On-station work was carried out at Kiboko Research Centre while on-farm was within farms in the Districts of Makueni, Kajiado and Taita-Taveta (Fig. 3.1).

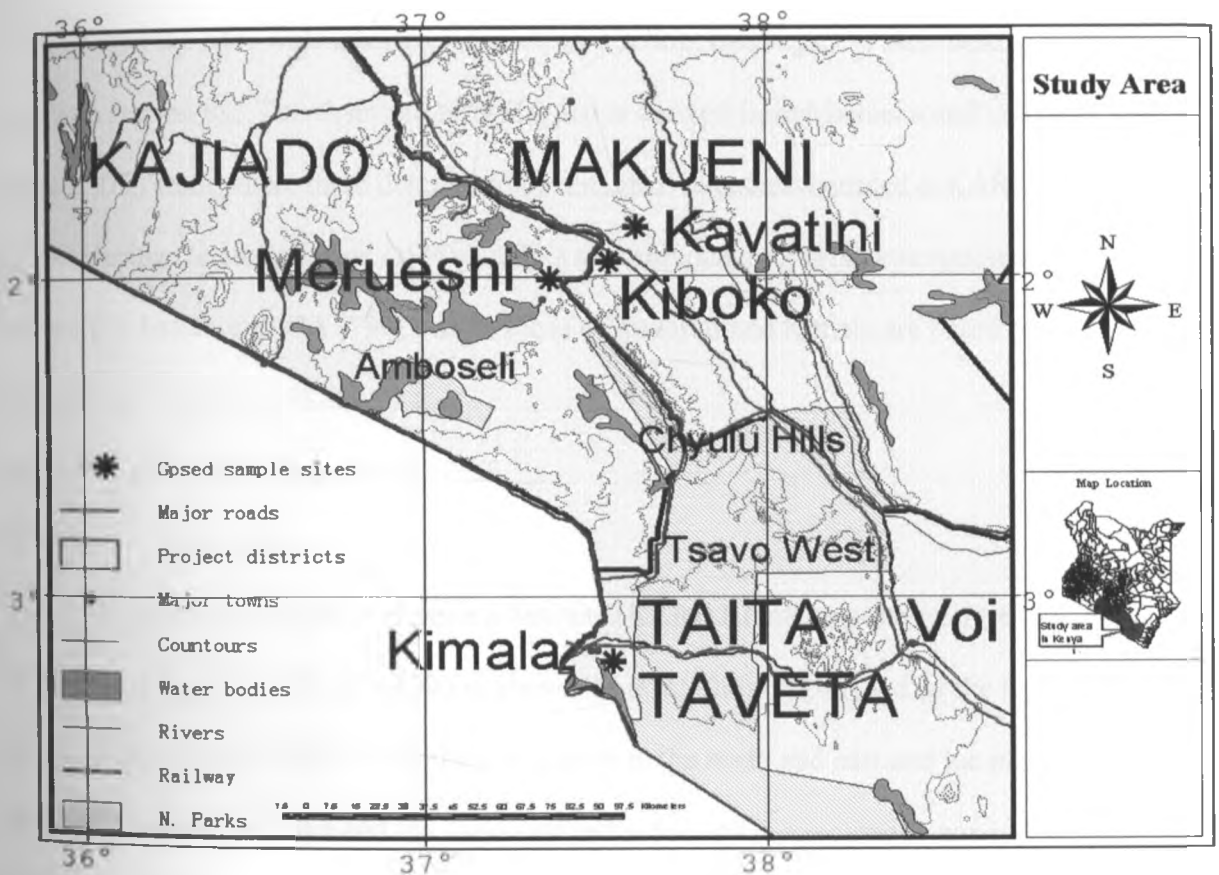


Figure 3.1 Location of study sites, physical features and infrastructure in Makueni, Kajiado and Taita-Taveta Districts.

Specifically, seed harvesting, storage and propagation trials were conducted at KARI - Kiboko. Natural pasture improvement experiments with or without reseeding were done at two sites; Merueshi in Mashuru Division in Kajiado District and Kavatini in Makindu Division in Makueni District. In addition, *Chloris roxburghiana* samples for genetic characterization were collected from the three sites above as well as from Kimala in Taveta Division in Taita-Taveta District.

3.2. SITES DESCRIPTION

Since the sites were situated far apart, 15-120 km, (see Fig. 3.1) their descriptions are given separately. The description for Kiboko is derived from Michieka and van der Pouw (1977) from where more details can be obtained. Weather recorded at KARI - Kiboko during the study period (1999-2002) is also summarized. The description of Merueshi is based on ILCA (1991) while those of Kavatini and Kimala are based on Jaetzold and Schmidt (1982).

3.2.1. KARI - Kiboko study site

3.2.1.1. Location

The Kenya Agricultural Research Institute (KARI) Kiboko research centre is situated about 2.3°S and 37.8°E, 1000 m above sea level. It is surrounded by the Kyulu hills to the south, agro-pastoral Kamba community to the north and east and the pastoral Maasai to the west. Kiboko and the region around it fall under eco-climatic zone V. Previously, Kiboko was a hunting ground for licensed hunters of wild game animals.

3.2.1.2. *Climate*

An average annual rainfall of 615 mm characterizes the climate of Kiboko. The rainfall has a bimodal distribution pattern with peaks in April and November for long and short rainy seasons respectively. This implies that the study area is within the rainfall region No. 4a (Griffiths, 1962) that is considered to be good to moderate for millet. Each rainy season is followed by extended periods of limited precipitation. The dry periods, especially after the long rainy season, can last up to five months at times although the first two are usually cool. The shorter dry period after the short rainy season is characterized by hot and windy weather, especially during the month of February. The medium-term rainfall average and monthly distribution pattern is as shown in Figure 3.2. The four-year study period (1999-2002) monthly rainfall distribution varied from year to year; for instance there were only 3 months with rains in 2000 compared to 8 in 2002. This period also experienced unusually high monthly total rainfall particularly November 1999, April 2000 and November and December 2001. In the year 2000 nearly half of the year's total rainfall was received in April, which was almost equivalent to the long-term average total amount for the long rainy season.

Annual total rainfall also varied over the four years and ranged from below average (539.4 mm) in 2000 to above average (763.4 mm) in 2001. Generally, however, the distribution tended to follow the long-term trend.

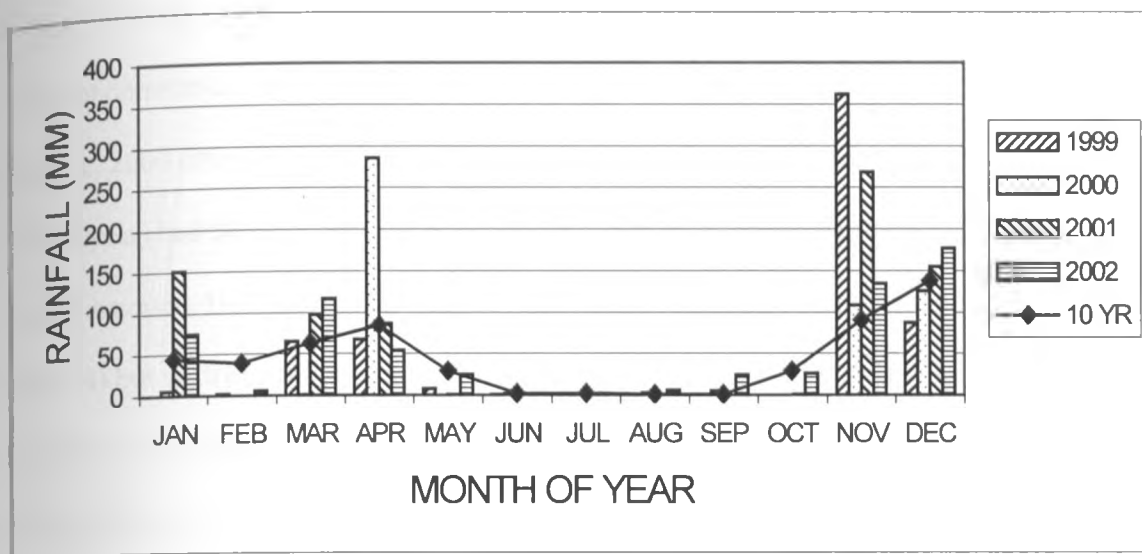


Figure 3.2. Mean monthly rainfall (1989-1998) and monthly totals received during the study period (1999-2002) at KARI – Kiboko.

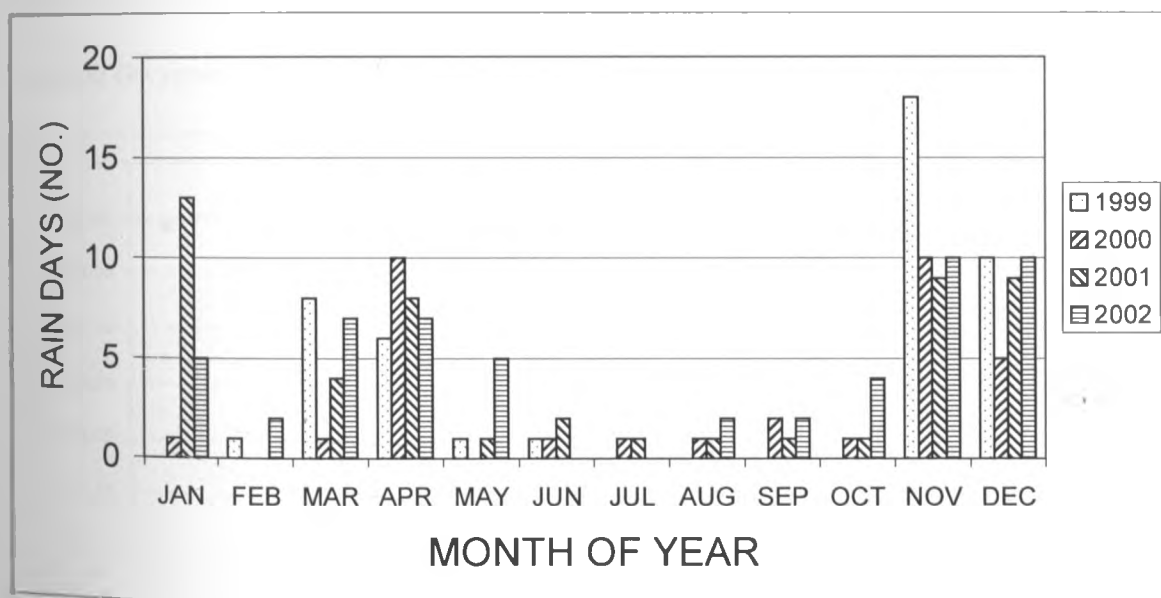


Figure 3.3. Number of rainy days during the study period (1999-2002) at KARI – Kiboko.

Annual total number of rainy days varied with years (Fig. 3.3), where a rainy day meant a day when $\geq 0.5\text{mm}$ of rainfall was received (Mwebesa, 1970). There was no apparent correlation between the annual rainfall and total number of rainy days. For instance, 2000 (the driest year) had 33 days (the lowest in the four years) and 2001 (the wettest year) had 50 days, tending to suggest a direct relationship between rainy days and rainfall amount. However, 2002 (the second wettest year) had the most number of rain days (54) but with much lower rainfall. Such variation in rainfall amount and its distribution is a normal phenomenon characteristic of semi-arid rangelands (Griffiths, 1962; Pratt and Gwynne, 1977). However, the 10-year period before the study had a December peak while half of the years during the study had a November one and the year 2001 had a peak in January, giving no clear rainfall distribution pattern. This confirms that rainfall distribution in the study area could be highly unpredictable as reported by Pratt and Gwynne (1977).

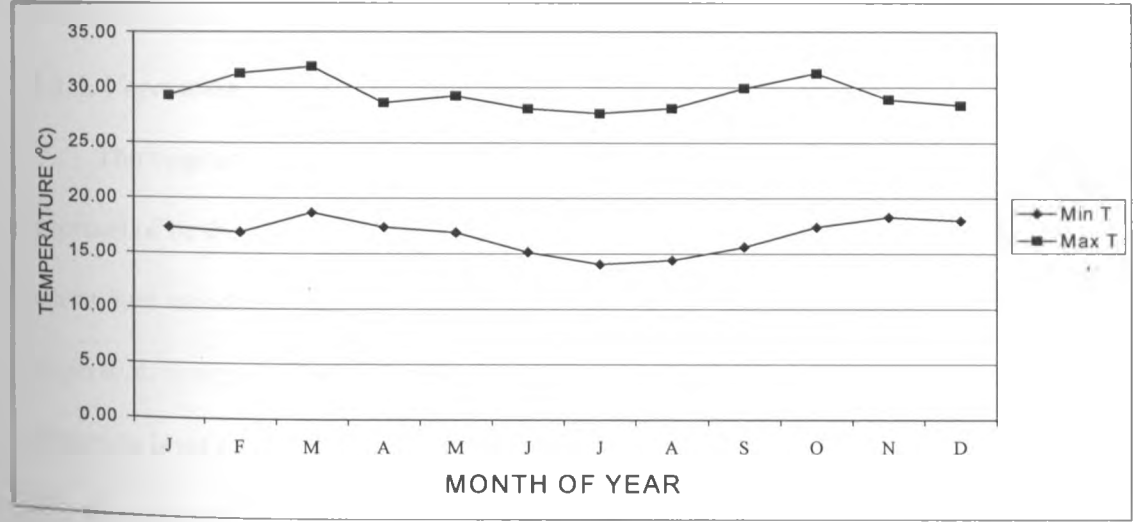


Figure 3.4 Mean monthly temperatures (minimum and maximum) during 1989-1998 at KARI – Kiboko.

The average temperature of Kiboko is 26°C and average evapo-transpiration is 2000 mm (Pratt, 1966; Michieka and van der Pouw, 1977; Pratt and Gwynne, 1977; Musembi, 1986). There are two main dry seasons and two wet seasons; the mean maximum temperatures for these two periods are 32°C and 26°C, and mean minima are 19°C and 14°C, respectively. Absolute minimum temperature can go below 8°C (Musembi, 1986). The 10-year mean temperature trends are shown in Figure 3.3, which conform to long-term patterns with peaks during February to March and September to October while troughs are experienced during July to August (Musembi, 1986).

3.2.1.3. Geology and soils

Kiboko has various soils arising from the Basement System rocks and Quaternary Volcanics with volcanic ash but clays and sandy clays predominate. Both red and brown FERRASOLS particularly occupy most of the lowlands and flat plains while black GLEYSOLS are mostly in flood bottomlands (Michieka and van der Pouw, 1977). The FERRALSOL soils are deeply weathered and can support deep rooted tree biomass.

3.2.1.4. Vegetation

The vegetation found in this area varies due to variation in soil type and comprises of bushed grassland with a significant presence of woodland. The predominant woody species are *Commiphora riparia*, *C. africana*, *Acacia tortilis*, *A. mellifera*, *A. senegal*, *Cordia ovalis*, *Combretum* spp. and *Balanites aegyptiaca*. The herbaceous layer comprises of mainly *C. ciliaris*, *C. roxburghiana*, *E. superba*, *Cymbopogon pospischilii*, *D. macroblephara*, and *E. microstachyus* (Michieka and van der Pouw, 1977).

3.2.2. Merueshi study site

3.2.2.1. Location

Merueshi is situated 02° 18.186'S, 037° 33.942E in Merueshi location within Mashuru Division. The site is on the plains west of the Kyulu Hills. The area is adjacent to the Kyulu Game and Forest reserves, with Amboseli National Park farther south. The area is inhabited by the pastoral Maasai community who move their animals across the hills, mostly south and southeastwards in search of pasture. Merueshi has been a Group Ranch for many years and recently it was sub-divided into individual holdings. Under the Group Ranching system land ownership is entrusted by the state to an ethnic group or clan for communal use but with a central management committee (Cap 284 of 1970 Laws of Kenya).

3.2.2.2. Geology and soils

The geology of Merueshi experimental site is Basement system rocks comprising various gneisses that give rise to soils such as FERRALSOLS. They are deeply weathered and have been found to be chemically poor hence requires high input levels to improve fertility for crop production.

3.2.2.3. Climate

The rainfall has a bimodal pattern although there has been no rain gauge on site, the nearest ones been at Masimba Railway Station and at KARI Kiboko (Musembi, 1986). The short rainy season starts late in October and ends in December. The long rainy season starts in Mid March and ends in May. The average annual rainfall is 400-600 mm.

The temperature ranges from a mean maximum of about 30°C and a mean minimum of 19°C. The average annual potential evaporation is 2000 mm. That means, like Kiboko for the greater part of the year there is a soil moisture deficit. Generally, the site is therefore, within agro-ecological zone V, which is semi-arid and comprises 55% of Kajiado District (Sombriek *et al.*, 1982). The dry months are 7-9 making crop production a risky undertaking. However, livestock production under extensive grazing system is most appropriate.

3.2.2.4. Vegetation

The main vegetation type is bushy grassland with scattered trees. Woody species include *A. tortilis*, *B. aegyptiaca* and *C. africana* in the tree layer while *Sericocomopsis* sp. is the dominant shrub. Grasses include *P. mezianum*, *C. roxburghiana* and *C. ciliaris*. An invasive species, *Ipomoea kituensis* which is a climber with broad leaves was also present. Over several years, now annual forbs and grasses are dominating much of the study area due to degradation (SNV/SARDEP – Undated report).

3.2.3. Kavatini study site

3.2.3.1. Location

Kavatini is situated 02°08.693'S, 037°48.148'E in Twaandu location within Makindu Division. The site has an altitude of 997m and is on the plains north of the Kyulu Hills. The area is inhabited by the agro-pastoral Kamba community.

3.2.3.2. Geology and soils

The site sits on the undifferentiated Basement System rocks with scattered hills such as Twaandu and Mitendeu. The soils are well drained, deep to very deep, dark red to strong brown friable sandy clay to clay (rhodic and orthic FERRALSOLS).

3.2.3.3. Climate

The average annual rainfall based on 72 years record at Makindu Meteorological Station is 616mm. It has bimodal distribution with peaks in November and April, the highest being November with 174mm. June to September are dry months each receiving an average of 1-2 mm. The site is under agro-ecological zone 5, considered suitable for livestock and millet.

3.2.3d. Vegetation

Kavatini is part of a bushed savanna; the dominating tree are *A. tortilis*, *Adansonia digitata* and *C. africana*. Grasses comprise *C. roxburghiana*, *C. ciliaris*, and *E. macrostachyus*. In most areas the perennial grasses have been grazed out giving room for annuals and forbs to dominate or bare ground.

3.2.4. Kimala study site

3.2.4.1. Location

Kimala is situated 03°25.707'S, 037°44.210'E in Jipe location within Taveta Division. The site is on the plains east of Mt. Kilimanjaro, at the fringes of Tsavo West National Park. The area is inhabited by the agro-pastoral Taveta community. There is also a strong presence of the Maasai and Kamba communities who moved into the area recently.

3.2.4.2. Geology and soils

The soils found in this area developed on Basement System rocks rich in magnesium minerals. The soils are classified as low in fertility. They are well drained, deep to very deep, dusky red to dark red, friable sandy clay (rhodic FERRALSOL).

3.2.4c. Climate

The Kimala site fall under the agro-ecological zone V. It has an altitude of 900m and the average annual temperature is 23.5-22.4°C. The mean maximum temperature is 30°C while the mean minimum is 14.5°C. The average annual rainfall is 530mm but ranges from 500-700mm, with a bimodal distribution based on 31 years of weather data recorded at Ziwani Sisal Estate. The peaks occur in April and November, the highest being that of April averaging 122mm.

3.2.4.4. Vegetation

The area is dominated by *A. tortilis*, *A. melliferra* and *A. digitata* as the tree forms. The main grass species are *C. roxburghiana*, *C. ciliaris*, *E. superba* and *B. insculpta*. For decades the area has been used for communal livestock grazing and due to continuous grazing most of these perennial grasses have either been replaced by annuals such as *Aristida keniensis* or bareground.

3.3. WILDLIFE PREVALENCE

At all the study sites, significant presence of wildlife occurs at times, which compete heavily with livestock for forage and water resources but mainly within the pastoral Kajiado District. Most common species are kongoni, zebra, buffalo, giraffe, and small gazelles (Thompson's and Grant's). Often, Merueshi is invaded by large migrating herds of wildebeest from the Amboseli National Park in the south during which time a great grazing pressure is exerted on the local resources with a tendency to overgraze the area. The same applies to Taveta, which has a history of livestock sharing resources with

wildlife from adjacent Tsavo West National Park, especially during the dry seasons. The only major wildlife challenge in Makindu division is from elephants that occasionally stray from the Kyulu Game Reserve into the riverine vegetation where they also destroy crops.

3.4. LIVESTOCK POPULATION

Table 3.1 shows the relative abundance of livestock wealth among the three districts of Makueni, Kajiado and Taita-Taveta. The values were estimates extrapolated from earlier census because none of the districts has done a comprehensive census for many years. However, some divisions which had operational special programmes had some up to date counts that were used by the Statistics Officers present at each district headquarters to derive these estimates. From these figures, it is apparent that there are a large number of livestock populations in each district. The highest density is in Makueni and the least in Taita-Taveta. Nonetheless, most of Taita-Taveta comprises the Tsavo East and West National Parks with only a third of the district available for human settlement.

Table 3.1. Livestock population of major species, their total and density (No. km⁻²) in some Districts in southern Kenya region, 2002.

District Name	District Area (Km ²)	Livestock Population					
		Cattle	Goats	Sheep	Donkey	Total (000)	Density
Makueni	7,966	225,000	250,250	90,000	6,000	571	72
Kajiado	21,851	355,339	433,305	496,246	N/A	1,286	59
Taita-Taveta	17,128	125,457	115,790	34,283	N/A	276	16

NB: Source – Respective livestock offices in the Districts.

3.5. COMMUNITY SURVEY

Ex-Ante community survey at household level was conducted in three districts, Makueni, Kajiado and Taita-Taveta. This survey was necessitated by past experiences by the KARI – Kiboko scientists which showed that diagnostic surveys are a necessary starting point of project identification and formulation. The survey involved the extension service and local administrators as detailed in the methodology (Chapter 4). The approach used was single subject interviews at household level using semi-structured questionnaires, focusing on issues pertaining to natural pasture degradation and improvement. Subsequently, the results of this survey formed the basis for the on-station and on-farm experiments (Chapters 5-8) in this study to address constraints encountered in natural pasture improvement.

3.6. ON-STATION TRIALS

3.6.1. Seed harvesting and storage

Ten species that were agreed upon in collaboration with both farmers and extension agents in the study area were propagated in 5 x 5 m plots as pure stands at the Kiboko Forage Research site between 1997 and 1999 as shown in Plate 3.1.

When the grasses were fully established seeds were harvested at the end of two growing seasons using two methods and stored in four types of containers and their viability monitored in the laboratory periodically over 18 months post harvest. More details and results of four grass species, namely *C. ciliaris*, *C. roxburghiana*, *E. macrostachyus* and *E. superba* in this trial constitute Chapter Five.

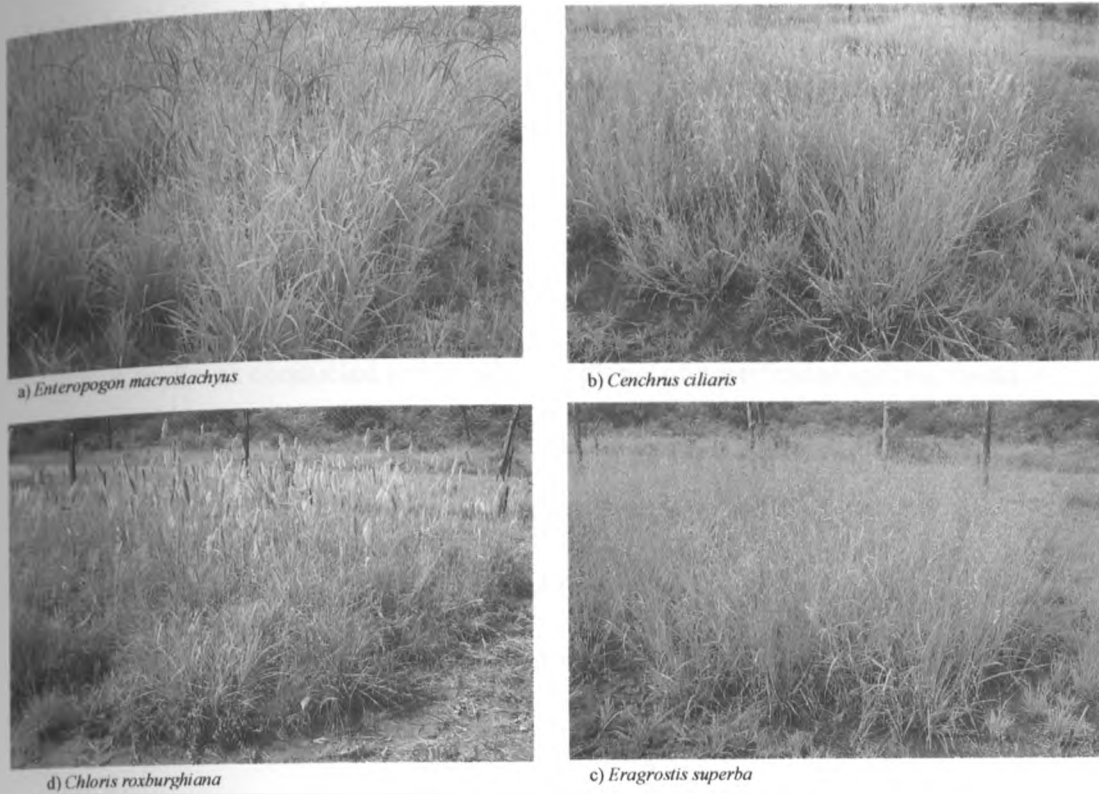


Plate 3.1. Pure stands of the four native grass species used in the re-seeding and seed technology trials by KARI Kiboko during 1999-2002.

Chapter six reports the trial that involved planting the four selected grasses in different soil types and subjecting them to varying regimes of watering. Emergence and subsequent seedling growth and development to maturity were monitored. Above ground biomass was then estimated by clipping and oven drying.

3.7. ON-FARM TRIAL

The only on-farm trial dealt with re-seeding. The field trials employed four treatments of re-seeding with or without pitting. Data on seedling population and biomass production from two sites, one each in Mashuru Division in Kajiado District and Makindu Division in Makueni district, are presented in Chapter Seven. The sites were

Makindu Division in Makueni district, are presented in Chapter Seven. The sites were monitored seasonally to mid-2002, a period covering three short and three long rainy seasons.

3.8. GENOTYPING *CHLORIS ROXBURGHIANA*

A trial was conducted to test whether plants of a particular species found in different localities would be similar genetically. The species selected for the pilot trial was *C. roxburghiana* that had been one of the more difficult ones to establish but usually has a wide ecological adaptation (Pratt and Gwynne, 1977). This trial (details given in Chapter Eight) involved collection of plant materials from the field at four sites namely Kiboko, Merueshi, Kavatini and Kimala and, genotyping them at the International Livestock Research Institute (ILRI) laboratories in Nairobi. RAPD (random amplified polymorphic DNA) marker technique was used.

3.9. EXPERIMENTAL DESIGN AND DATA ANALYSIS

The experimental design for each experiment is detailed in the respective chapters. Different software was used as was found appropriate for different data sets. The main ones, however, were SAS, SPSS and NTSYS. The specific procedures are given under the respective sections where applied.

CHAPTER FOUR

4.0. ASSESSMENT OF COMMUNITY HOUSEHOLD CHARACTERISTICS AND THEIR PERCEPTIONS ON EXTENT AND CAUSES OF NATURAL PASTURE DENUDATION

4.1. INTRODUCTION

The communities inhabiting the semi-arid parts of southern Kenya are varied in their culture and practice different agricultural production systems. Nonetheless, they all can be grouped into two broad categories, i.e. pastoralists who derive over 50% percent of their livelihood from livestock and agro-pastoralists who practice arable farming beside a significant involvement in livestock production (Dietz, 1987; UNDP, 1994; Herlocker, 1999). Land tenure differs between and within the production systems; there are those more inclined towards communal ownership and use of land and others, particularly those who practice arable farming, that have a greater tendency for individual land ownership. Such variations, when interacting with biophysical factors (for instance soil type, rainfall and vegetation) inherent of an area, produce different results in terms livestock production and long term impacts on the land (Pratt and Gwynne, 1977; Bekure *et al.*, 1991; Gitunu 1994; Herlocker, 1999; Galvin, 2003).

Further, external forces such as education, land tenure reform or advent of cash economy, which may alter the behaviour of a community (GEO, 2000; Gitunu, 1994, 1999; Wang'ang'a, 2001; FAO, 2002), would ultimately lead to a shift in the way resources are valued and used. For example, it is more likely for a pastoralist to value forage plants that are important for the survival of grazing or browsing livestock much more so than would a farmer who tills the land for crops. It is also more likely for an

individual with a land title deed to invest in its development (for example on soil erosion control structures, fencing, pasture improvement, etc.) than one living on communal land. In other words, the background and property rights of a people may influence how they relate to the natural resources around them. This implies that, depending on the value placed on natural pasture, degradation may or may not be equally apparent and be of concern to all communities in the semi-arid areas.

In the one decade, diagnostic surveys and study tours had consistently identified feed shortage as a major constraint to livestock production in the rangelands of southern Kenya. Wandera *et al.* (1996) established through PRA that feed shortage was the second most limiting factor (after water) to meat production by small stock in the pastoral districts of Kajiado and Baringo. The feed shortage was attributed to land denudation, which is an advanced stage of natural pasture degradation in extensive livestock production systems (FAO, 2002). Similar results were obtained at different locations in Kajiado District (Mnene and Mbakaya, 1997).

During the above surveys, communities requested for intervention from *inter alia*, KARI in order to alleviate feed shortages. Reseeding ranked second after purchasing of feed supplements among the opportunities identified by PRA towards alleviation of feed shortages (Wandera *et al.*, 1996; Mnene and Mbakaya, 1997). Results of a regional survey of eastern Africa to document impacts of droughts and floods and the coping mechanisms of pastoralists had also highlighted re-vegetation of degraded natural pastures as a viable strategy (Ndikumana *et al.*, 2000). While the previous two surveys were of limited scope, that of Ndikumana *et al.* (2000) had a wide coverage of the

districts in southern and northern Kenya as well as the neighbouring Ethiopia, Tanzania and Uganda.

Re-vegetation of degraded rangelands usually has two targets; bare patches and areas with annuals or noxious plants. In both cases, palatable perennials that are adapted to the local environmental conditions are seeded. However, patches less than 25% bareness may not be considered a problem since rangeland pastures are naturally patchy, especially where bunch as opposed to sod-forming type of grasses is dominant (Wandera, 1993). Patches that are bare are part of a process of land degradation especially if they tend to increase with time (Le Houerou, 1993). Natural patches may also be as a result of other factors such as differences in soil characteristics like pH and nutrient levels / hydrological gradients (Bridge *et al.* 1983; Scholes 1990; Wandera 1993; Nill 1996). Man's activities like spot burning and restrictive livestock grazing could lead to patchiness (Daubenmire 1968; Mott 1987; Willms *et al.* 1988). Wildlife activities, like burrowing and mound building by ant bears and termite are other possible causes of bare patches in natural pastures (Culver and Beattie, 1983).

Reseeding had been introduced in Kenya and demonstrated at various sites in the middle of the last century (Jordan, 1957; Bogdan and Pratt, 1967). More on-station work was done at Kiboko by Too (1995) to test re-seeding as a means to increase forage productivity after bush clearing. This bush management study found that herbage increases were economically feasible (Too *et al.*, 1997). Despite these research technologies, adoption of natural pasture improvement, particularly through re-seeding has barely taken place among communities for unknown reasons. Consequently, in response to the current community demands for research to address the problem of

natural pasture improvement in this region, it was necessary first to carry out a systematic assessment of the target area, which is a standard pre-requisite (Roeleveld 1996).

4.1.1. Hypothesis

The pastoral and agro-pastoral communities in the southern Kenya have similar perceptions about rangeland degradation and they equally know strategies of rehabilitating degraded areas.

4.1.2. Objectives

- (1) To find out from the communities inhabiting these areas baseline information, namely:
 - a) Existence and extent of pastureland denudation,
 - b) Their knowledge of the cause(s) of pastureland denudation,
 - c) Their recognition of pastureland denudation as a problem, and
 - d) What, if anything at all, the communities are already doing to combat the problem of pastureland denudation.
- (2) To identify constraints to community efforts in adopting reseeding and propose intervention measures.

4.2. MATERIALS AND METHODS

4.2.1. Site and household selection

The three districts of Makueni, Taita-Taveta and Kajiado are expansive, measuring 7,966, 17,128 and 21,851 Km², respectively (Jacobs, 1983). Makueni has 16 Divisions while other two districts have five each. Together with Kitui District, they form the research mandate areas for KARI - Kiboko. Although the target in the proposal

for this study was the lowland semi-arid areas, not all divisions could be covered.

Through consensus between the districts' extension service, departmental heads, the provincial administrators and a multi-disciplinary research team the following criteria was agreed upon to assist in both site and household selection and thus form the sampling frame:

1. Three divisions per district that had the most serious pasture degradation in terms of denudation. Three was a working number allowing for at least two degrees of freedom in the data analysis with each division forming a cluster of analysis, resulting in nine clusters.
2. Within each cluster, three locations were then selected purposefully with a preference for those in the dry lowlands where livestock keeping has been the main economic activity over the years. This was to increase the chances of enumerating households with a longer history of the areas and thus a greater possibility of having observed some trend in pasture degradation.
3. Within a location three sub-locations were selected from where five households were systematically picked from a list obtained with the help of the area Assistant Chiefs. This approach was necessary because in each of the three districts there is a project dealing with an early warning system for livestock keepers in pastoral and agro-pastoral production systems (Global Livestock Collaborative Research Support Programme – GL-CRSP/LEWS) whose satellite data was generated within 8 x 8 -km grid. This project had established a collaborative agreement to provide forage-monitoring information to the communities and therefore this meant that selected households be scattered out for a greater coverage of the area.

In addition, under pastoral production systems random selection of households based on a percent of population from a list is expensive and at times not logistically possible and time consuming (McPeak, 2001).

4. Respondents had to be livestock keepers under extensive grazing system, which relies heavily upon natural pastures. A household was also selected on the basis of it being an autonomous family production unit regardless of whether it was female or male headed. This is because decisions on production activities are made at household level and it was therefore the smallest unit of the study.

Bekure *et al.* (1991) used a similar approach in their study in Kajiado.

5. The maximum number of respondents was calculated to be 45 per cluster (Division) derived, thus:

- a) 3 locations
- b) 3 sub-locations
- c) 5 households per sub-location.

Sample sizes of this magnitude have been used elsewhere in similar community studies (Mukhebi *et al.*, 1985b; Gitunu, 1994; Chang'ole *et al.*, 2000; Okuro *et al.*, 2000; McPeak, 2001; Kuria *et al.*, 2003). Further, variation within Divisions in the low land areas was considered minimal.

6. Respondents had to be heads of their respective households in order to capture all the information at once as detailed in the questionnaire. The local area Chiefs assisted where language was a barrier of effective communication.
7. The survey was to be carried out during the dry season so as to get near real situation of pasture constraint to livestock production.

Following the above guidelines, the divisions selected were Taveta, Mwatate and Tausa in Taita-Taveta; Mtito Andei, Kibwezi and Makindu in Makueni; and Mashuru, Central and Magadi in Kajiado.

4.2.2. Questionnaire design, testing and administration

A semi-structured questionnaire was developed after a session of brain storming by a multi-disciplinary technical group at KARI-Kiboko to arrive at the crucial issues to be addressed in the survey. The emerging issues were then grouped into similar components to form sections and sub-sections of a questionnaire (Appendix 4.1). There were three main sections comprising of the background of the household heads; land ownership and status of pasture denudation expressed as a proportion of the pastureland (< 25, 25 to <50 and $\geq$ 50 %). As part of pasture degradation, knowledge of loss of important forage species and causes, means of combating the degradation and constraints encountered were recorded among others.

The questionnaire was first pre-tested on 10 farmers / pastoralists each in Makueni and Kajiado districts by a team of duly trained research scientists and technicians from KARI – Kiboko. The pre-testing served as a practical training session after which the team met to report and share their experiences, especially on difficulties with administering the questionnaire. A number of questions were then either reformulated or reorganized for easier flow of information while conducting the actual interviews thereafter.

This study used the single subject interview approach (Curry *et al.*, 1999). A team of five technicians from KARI-Kiboko and the extension officers at the various locations did the questionnaire administration in March 1999. Where a respondent was

unable to communicate in the official (English) or national (Kiswahili) language, an interpreter was engaged or vernacular language was used if the interviewer understood it. Interviews took place at the respective homesteads or in the farms and lasted approximately 1h 45min. At the end of each interview a walk about in the pastureland was undertaken in order to triangulate the questionnaire information such as land acreage, extent of pasture denudation and others. Photographs were also taken wherever possible to record the actual condition of those pastures.

4.2.3 Sample size

A total of 353 respondents were interviewed across the three districts. The number per district averaged 118 (Table 4.1).

Table 4.1. List of administrative divisions (clusters) and number of respondents in each during the survey in 1999.

District	Division	No. of Respondents	Percent Total
Makueni	Makindu	35	9.9
	Kibwezi	44	12.5
	Mtito Andei	36	11.3
	Total	115	33.0
Kajiado	Magadi	36	10.2
	Mashuru	38	10.8
	Central	34	9.6
	Total	108	31.0
Taita-Taveta	Tausa	46	13.0
	Mwatate	42	11.9
	Taveta	38	10.8
	Total	126	36.0
Total		349	100.0

However, seven of them, mainly from Kajiado were dropped from the analysis since they had large ranches that skewed the data and considered unrepresentative of the community for the purpose of this study. Most households were male-headed, therefore, majority of the respondents were males. Although the target number was 135 respondents per district, it was more difficult to find household heads or mature family members at home in Kajiado than in the other two districts. This was a reflection of the differences in population densities (Table 4.2) and the logistics involved. It was also a social problem; whereas it was easier for any other mature family member to accept to be interviewed in both Makueni and Taita-Taveta, the Kajiado communities insisted on only the household heads being interviewed.

Table 4.2. Human population disaggregated by gender, total and density (No. km⁻²) in various districts in southern Kenya, 2002.

District Name	District Area (Km ²)	Human Population			
		Male	Female	Total	Density
Makueni	7,966	372,639	398,906	771,545	97
Kajiado	21,851	205,399	200,286	405,685	19
Taita- Taveta	17,128	121,684	123,261	246,671	14

NB: Source – Respective statistics officers in the districts.

Cases of household heads being away were numerous especially considering that often they went out with their livestock herds in search of water and pasture, which is a normal nomadic practice. In their absence, the enumerators had to cover long distances before getting a likely replacement household due to sparse population relative to the

other two districts. Therefore, the data was unbalanced with clusters having between 34 and 45 respondents, the least being in Kajiado Central and the most in Tausa divisions.

4.2.4. Data analysis

Data was analyzed using the Statistical Package for Social Sciences ver. 11.5.1 (SPSS, 2002). Qualitative information was coded into either nominal or ordinal scale values, for example a 0 for No and a 1 for Yes; 1=Husband, 2=Wife; 0=informal/no education, 1=primary level, 2=secondary level and 3=tertiary (college/university), etc. Descriptive statistics were generated whereby frequencies were summarized and expressed as percent of total as well as cross-tabulation by District and Divisional levels. Chi-Square test was used to test statistical significance of the difference between the Districts and Divisions. The Chi-square tests of independence are considered appropriate for bivariate and multivariate variables for which frequency observations have been obtained (Ott, 1988). Group statistics were derived for the quantitative data and independent sample tests done using Levene's Test for equality of variances with the assumption of equality of variance or lack of it ($p < 0.05$). Pearson correlation test was used to test statistical significance at 0.05 levels (2-tailed) of possible relationship between a selected set of variables.

4.3. RESULTS AND DISCUSSION

4.3.1. Human population characteristics

Characteristics of the households are presented and discussed in four contexts, namely level of education, occupations, family size and land ownership, farm size and use.

4.3.1.1. Level of Education

Generally, illiteracy was high among the household heads in the study area although differences existed between production system, the districts and divisions at all levels of education (Table 4.3). For example, less than one percent had attained tertiary level while those who had not received any formal education comprised approximately 57% and 30% of the respondents in pastoral and agro-pastoral production systems, respectively. None of the respondents from Kajiado (pastoral production system) had attained tertiary (college) level of education and the few under the agro-pastoral production system; twice as many were in Taita-Taveta compared to Makueni. Among the divisions Central in Kajiado had the lowest level of education with approximately 64% with no formal education and Tausa in Taita-Taveta the highest at both secondary and tertiary. These results fall far short of the national literacy rates for adults which was 70.8% in 1990 and rose to 83.3% in 2001 (UNDP, 2003). High literacy level among communities is important because it is relatively easier to obtain employment and to communicate, for instance when passing messages from research and extension on various agricultural technologies (Guerin and Guerin, 1994). It also enables easier recognition by individuals of what the ramifications of certain actions are especially on natural resources in the fragile ASAL (Lemunyete, 2003).

Table 4.3. Distribution (%) of household heads on the basis of levels of education among and within two production systems, three districts and nine divisions of the research area in southern Kenya in 1999.

Production System / District / Division	Level of education								Pearson Chi-Square Test		
	Within level of education				Within production system / District / Division				Value	df	P Value
	None / Informal	Primary	Secondary	College	None / Informal	Primary	Secondary	College			
Pastoral	45.9	23.2	18.8	0.0	56.9	32.1	11.0	0.0	24.267	3	<0.001
Agro-pastoral	54.1	76.8	81.3	100.0	29.9	47.5	21.3	1.2			
Total	100.0	100.0	100.0	100.0	38.2	42.8	18.1	0.8			
Makueni	32.6	35.1	32.8	33.3	37.0	44.5	17.6	0.8	31.655	6	<0.001
Kajiado	46.7	23.2	18.8	0.0	57.3	31.8	10.9	0.0			
Taita-Taveta	20.7	41.7	48.4	66.7	22.6	50.8	25.0	1.6			
Total	100.0	100.0	100.0	100.0	38.2	42.8	18.1	0.8	46.897	24	0.003
Makindu (Makueni)	11.1	8.6	10.9	0.0	42.9	37.1	20.0	0.0			
Kibwezi (Makueni)	10.4	13.9	12.5	33.3	31.8	47.7	18.2	2.3			
Mtito Andei (Makueni)	11.1	12.6	9.4	0.0	37.5	47.7	15.0	0.0			
Magadi (Kajiado)	15.6	6.6	7.8	0.0	58.3	27.8	13.9	0.0			
Mashuru (Kajiado)	14.1	9.9	6.3	0.0	50.0	39.5	10.5	0.0			
Central (Kajiado)	17.0	6.6	4.7	0.0	63.9	27.8	8.3	0.0			
Tausa (Taita-Taveta)	4.4	13.9	25.0	33.3	13.6	47.7	36.4	2.3			
Mwatate (Taita-Taveta)	7.4	14.6	15.6	0.0	23.8	52.4	23.8	0.0			
Taveta (Taita-Taveta)	8.9	13.2	7.8	33.3	31.6	52.6	13.2	2.6			
Total	100.0	100.0	100.0	100.0	38.2	42.8	18.1	0.8			

4.3.1.2 Other Occupations

Approximately 70% of the respondents derived their livelihoods from pastoral / agro-pastoralism, and had no other sources of income (Fig 4.2). The rest (30%) also engaged either in business (17.6%) or had salaried employment (13.0%) both within and outside their respective divisions and districts (Table 4.4). There was no difference between districts in the number of respondents engaged in business. There was a positive correlation between level of education and engagement in other occupations. Relatively fewer respondents in Makueni and Taita-Taveta districts engaged in salaried employment compared to Kajiado district; these were mostly working in local institutions (government and non-government) or away in towns.



Figure 4.1. Comparative (%) household heads involvement in alternative means of livelihood in Makueni, Kajiado and Taita-Taveta districts in 1999. Bars within a cluster with similar letters are not significantly different.

These results concur with observations of Gitunu (1994) in Kasikeu and Mito Andei in Makueni District that off-farm earnings form an important fraction of family income and thus play a major role in the sustenance of household livelihoods. Therefore,

lack of alternative sources of income implies putting a greater demand on land to support livelihoods of these communities. Such high pressure would subsequently have its toll on the integrity of land leading to degradation.

Table 4.4. Proportion (%) of the respondents that engaged in alternative occupations by divisions during the survey in 1999.

District	Division	None	Business	Salaried employment
Makueni	Makindu	71.43	25.71	2.86
	Kibwezi	72.73	20.45	6.82
	M/Andei	77.50	15.00	7.50
Kajiado	Magadi	72.22	22.22	5.56
	Mashuru	60.53	10.53	28.94
	Central	55.26	23.16	26.32
Taita-Taveta	Tausa	59.10	20.45	20.45
	Mwatate	73.81	16.67	9.52
	Taveta	78.95	13.16	7.89
	Total	69.40	17.60	13.00

However, while heads of households may not be in other occupations, their children usually are as has been found to be the case in other pastoral settings. Gitunu (1994, 2000) reported that households in a community that had settled on small pieces of land in some parts of Makueni were heavily dependent on off-farm sources of income and primary among them was remittances from family members working elsewhere. Predominantly, it was not the household heads that were away but sons and other

relatives. In Kajiado, Peacock *et al.* (1982) and de Leeuw *et al.* (1985) had also observed that off-farm employment of young members of the households contributed significantly to the communities' livelihood. Similarly, in Botswana young family members who have little control over land, draught power and family labour seek employment away from home. Those with a good education head for the urban centres while those without are engaged in mining even outside their country (Gulbrandsen, 1980).

4.3.1.3. *Family size*

Family size varied widely from 2 to 86 members with a mean of 10, excluding relatives but including co-wives and their children. The family sizes varied between Districts and among Divisions. (Table 4.5a and b). The largest family units were in Kajiado with a mean of 15, which was higher than that in Makueni and Taita-Taveta, which were similar with 9 and 8, respectively. Magadi Division had the highest (19) and Tausa the lowest (7) number of family members. Family sizes were negatively correlated with household heads' level of education. Similarity of family sizes between Divisions in Makueni is in agreement with the findings of Gitunu (1994). Disparity in family sizes was mostly attributed to polygamy, which was more prevalent in Kajiado District and Magadi Division in particular. Polygamy is a common feature among pastoral communities who need many children to assist in the husbandry tasks associated with large herds of livestock in a harsh environment (Gulbrandsen, 1980; de Leeuw *et al.* 1985; Bekure *et al.*, 1991). Besides the family unit, households had other people in residence comprising distant relatives and employees.

Table 4.5a. Case summary (mean $\pm$ SE) and analysis of variance family, farm and herd / flock sizes of the 115, 105 and 126 households in Makueni, Kajiado and Taita-Taveta districts, respectively in 1999.

District		Family size	Farm size (ha)	Cattle number	Sheep number	Goat number
Makueni	Mean	8.56	8.90	4.89	1.65	12.80
	$\pm$ SE	0.397	0.913	0.652	0.288	1.259
Kajiado	Mean	15.37	535.07	73.61	69.25	68.56
	$\pm$ SE	1.079	296.674	8.749	9.843	7.741
Taita-Taveta	Mean	7.52	5.61	16.66	5.26	17.88
	$\pm$ SE	0.359	1.381	2.693	2.220	2.772
Total	Mean	10.32	171.71	30.44	23.98	31.96
	SE	0.423	93.076	3.285	3.550	2.939
ANOVA	SS Between Groups	4,144.904 (2) [/]	21,098,695.571	306,213.396	328,292.107	215,660.045
	Within Groups	18,135.923 (350)	100,553,463.412	1,034,373.545	1,237,933.791	857,905.400
	Total	22,280.827 (352)	121,652,158.983	1,340,586.941	1566225.898	1,073,565.445
	MS Between Groups	2072.452	10,549,347.786	153,106.698	164,146.053	107,830.023
	MS Within Groups	51.817	3,015,275.324	2,955.353	3,536.954	2,451.158
	F	39.996	3.499	51.807	46.409	43.991
	Sig.	<0.001	0.031	<0.001	<0.001	<0.001

[/] = Numbers in brackets are the associated degrees of freedom and are the same for all columns.

Table 4.5b. Case summary (mean $\pm$ SE) of some the background information of the respondents in the nine divisions of Makueni, Kajiado and Taita-Taveta districts in 1999.

District	Division	Mean / SE	Family size	Farm size (ha)	Cattle number	Sheep number	Goat number
Makueni	Makindu	Mean	8.63	10.83	5.63	2.31	12.43
		±SE	0.898	2.552	0.990	0.526	2.434
	Kibwezi	Mean	8.61	6.46	3.25	0.82	13.18
		±SE	0.557	0.835	0.710	0.316	2.465
	Mtito Andei	Mean	8.45	9.87	6.05	1.98	12.70
		±SE	0.652	1.186	1.531	0.619	1.539
Kajiado	Magadi	Mean	18.56	603.82	91.75	74.92	74.94
		±SE	1.585	490.930	18.924	14.369	9.292
	Mashuru	Mean	12.61	140.82	83.84	48.76	56.79
		±SE	1.096	13.304	14.548	12.733	8.742
	Central	Mean	15.11	883.156	44.67	85.22	74.61
		±SE	2.589	766.834	9.879	22.664	19.804
Taita-Taveta	Tausa	Mean	6.70	7.52	9.50	7.93	16.68
		±SE	0.690	3.750	2.253	6.109	6.809
	Mwatate	Mean	8.50	4.40	23.88	4.81	18.60
		±SE	0.652	0.787	6.976	1.262	3.382
	Taveta	Mean	7.39	4.74	16.97	2.66	18.47
		±SE	0.431	0.907	3.017	0.938	2.624
	Total	Mean	10.32	171.70	30.44	23.98	31.96
		±SE	0.423	93.076	3.285	3.550	2.939
ANOVA		SS Between Groups	4874.063 (8)	197234733.189	356836.438	355211.170	223820.029
		Within Groups	17406.765 (344)	6530546885.456	983750.503	1211014.728	849745.415
		Total	22280.827 (352)	6727781618.645	1340586.941	1566225.898	1073565.445
		MS Between Groups	609.258	24654341.649	44604.555	44401.396	27977.504
		F	39.996	3.499	51.807	46.409	43.991
		Sig.	<0.001	0.031	<0.001	<0.001	<0.001

4.3.2. Land tenure

Individual land ownership was the most common system (Figure 4.3). In Makueni all respondents had pieces of land that they could refer to as their own because they not only had access but also control over them. Some of these had individual title deeds but the majority had only allotment numbers given after land adjudication. Nearly 40% of the respondents in Kajiado had individual land ownership while the rest shared land under the communal Group Ranches. Cooperative land holdings were negligible and existed only in Taita-Taveta. Divisions also varied in the types of land ownership, particularly within Kajiado whereby Central had fewer households with individual land ownership (Table 4.6).

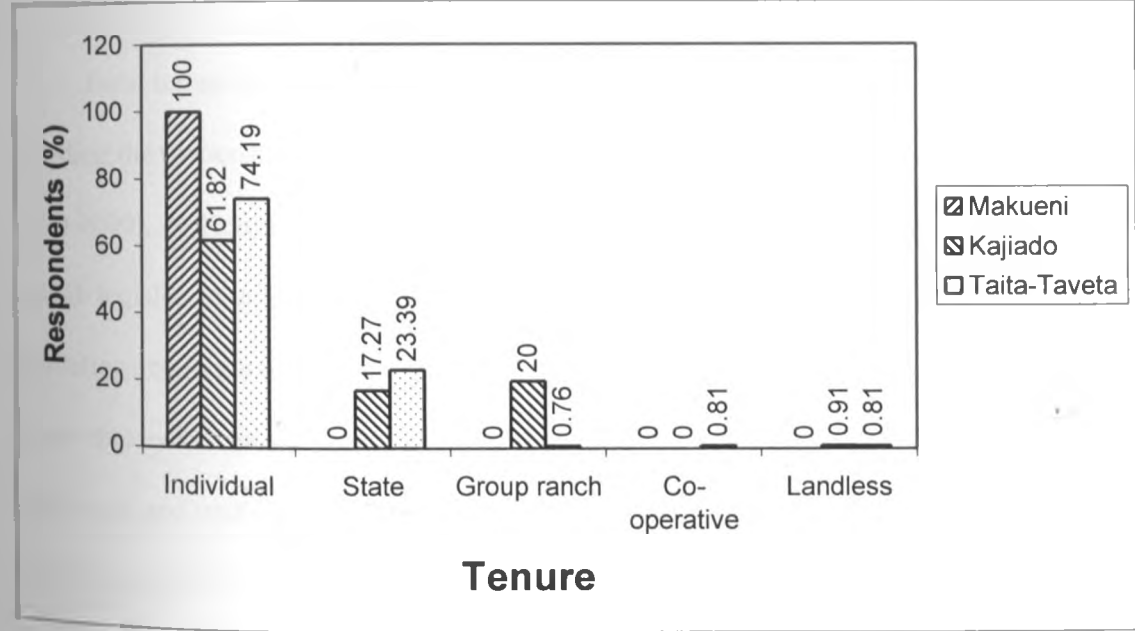


Figure 4.2. Mean distribution (%) of respondents according to land tenure system in the three study area districts in 1999.

Table 4.6. Relative distribution (%) of respondents in terms of land ownership in the nine divisions of Makueni, Kajiado and Taita-Taveta district in 1999.

District	Division	N	None	Individual	State	Group ranch	Co-operative
Makueni	Makindu	35	0.00	100.00	0.00	0.00	0.00
	Kibwezi	44	0.00	100.00	0.00	0.00	0.00
	M/Andei	40	0.00	100.00	0.00	0.00	0.00
Kajiado	Magadi	36	0.00	88.89	5.55	5.55	0.00
	Mashuru	38	0.00	78.95	2.63	18.42	0.00
	Central	36	2.78	16.67	44.44	36.11	0.00
Taita-Taveta	Tausa	44	2.27	79.54	15.91	2.27	0.00
	Mwatate	42	0.00	76.19	21.43	0.00	2.38
	Taveta	38	0.00	65.79	34.21	0.00	0.00
	Total	353	0.81	74.19	23.39	0.76	0.81

Land tenure systems are the laws and regulations – modern and traditional – regarding the ownership and accessibility of land resources in any given country or area (GEO 2000). In Kenya, group ranches were established by the government in 1970 through legislation under Section 287 of Land (Group Representative) Act as a means of facilitating economic activities in communally held rangelands. The act provides for group representatives as owners of the land whereby all members of the particular ranch claim equal and undivided share of the ranch areas and any other resources. The ranch members appoint 3 to 10 representatives who jointly act as trustees in the ownership of the property and thus can transact any business on their behalf. Every group ranch has a constitution specifying its name and area owned according to the boundary defined under the Land Adjudication Act (Cap. 284 of 1970). This legislation supersedes the traditional property rights of pastoralists (Galaty, 1992; Scoones, 1994; McCarthy *et al.*, 2003)

which allows for flexible tenure arrangements to be recognized. Where the secular law protects land rights it is expected that owners find it less risky to invest in the development and proper use for posterity (Galaty, 1992; Herlocker, 1999; RELMA, 1999; Kimani and Pickard, 2002). As such, uncontrolled over-exploitation of natural resources such as pastures should be prevalent in communally than individually owned land.

However, over the years the group ranches countrywide have been undergoing subdivision after members were dissatisfied with the group ranching system (RELMA, 1999; Kimani and Pickard, 2002). Land subdivision continues to be the thinking and belief among all the communities in the study area today. This is a threat to pastoralism because even though some parts of the ranches are good enough even for arable farming, these constitute only a very small proportion (Pratt and Gwynne, 1977; Herlocker, 1999). Areas with the potential for arable farming usually serve as dry season grazing reserves (Grandin *et al.*, 1989; Galvin *et al.*, 2001; Kimani and Pickard, 2002). Otherwise, the greater part of these ranches is fragile. It cannot sustain sedentarization with the attendant continuous grazing. This is usually the case whenever communal land is partitioned into individual holdings and livestock mobility is curtailed (Lusigi, 1987; Galaty, 1992; Grandin *et al.*, 1989; Kristjanson *et al.*, 2001; Kimani and Pickard, 2002; Galvin *et al.*, 2003). Where livestock mobility is restricted, conflicts are likely to occur as herds seek to move in and out in search for forage and water, particularly during drought (Kristjanson *et al.*, 2001; Galvin *et al.*, 2003).

Nonetheless, the tempo is such that it will be hard to reverse the subdivision process and therefore realistic ways of managing the issues arising out of individuation of

land must be worked out. One of the ways is for individuals with access and control over land to invest in improving the land (e.g. reseeded) for greater productivity. The other alternative is for such individuals to form common interest groups / associations under which they can jointly plan and exploit the natural resources on the basis of equitable share capital. This will allow a fair sharing of benefits such as dividends that will in turn serve as incentive to continue investing in proper resource management. Examples of this kind of approach are found in Laikipia (Muthiani, 2000) and southern Ethiopia (McCarthy *et al.*, 2002). Still, fragmentation of rangelands and its consequences are debatable issues that are yet to be understood fully at local, regional and international levels. This is evident from the many presentations at the VII International Rangeland Congress (Hobbs and Galvin, 2003; Ash *et al.*, 2003; Boone and Hobbs, 2003; Kerven *et al.*, 2003; Coughenour, 2003 and Reid *et al.*, 2003).

4.3.3. Acreage and diversity of land use

The average farm size was about 171.70 ± 93.076 hectares (Table 4.5a, b) with variations between the districts (Fig. 4.4), ranging from 0 to a ranch of 27,440 hectares. However, there was no significant difference between farm sizes for divisions within districts (Table 4.5b). The smallest farms were found in Taita-Taveta (mean 5.61 ± 1.380 ha) while the largest were in Kajiado (mean 535.07 ± 296.67 ha). The small farm acreage in Makueni and Taita-Taveta presents a case for both intensification and diversification to optimize production per unit of land area and increase the chances of sustainable support to the households. One form of intensification is reseeded to increase the carrying capacity of the land available (Herlocker 1999).

Approximately 90% of the land owned by the respondents was under natural pasture. However, this varied between districts with Kajiado having the largest natural pasture sizes and Makueni the smallest (Fig. 4.4). This result was expected, especially for Kajiado where farming on less arable land is not as wide spread as in the other two districts. On average, 68.62% of the respondents in Kajiado, 97.60% in Taita-Taveta and 98.32% in Makueni were practicing crop cultivation on 3.75, 5.85 and 8.44 ha, respectively. On the other hand about 5.7% of the respondents did not have any part of their land under pasture. They instead relied upon neighbours' land, crop residues and fallow land between seasons to sustain their livestock.

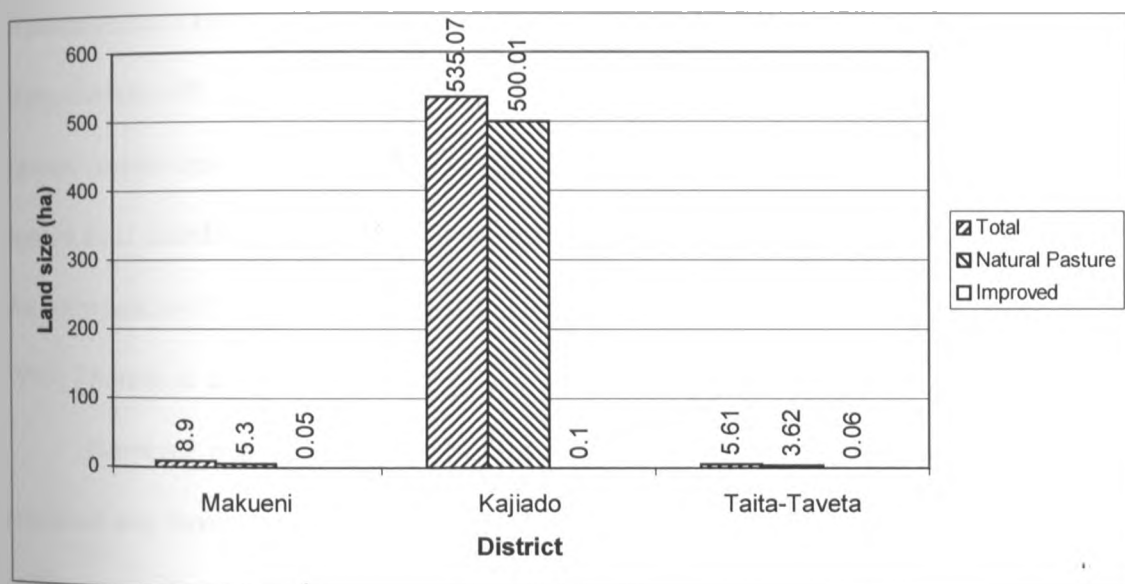


Figure 4.3. Comparative acreages of land under natural pasture to improved portions in the three study area districts in 1999.

Cultivation in Kajiado results from many factors, most important of which are individuation of previously communal land and the need to diversify to better mitigate food deficiency arising from the effects of droughts (Ndikumana *et al.*, 2000; SNV, 2000;

Kimani and Pickard, 2002). This is, therefore, a community in transition from pure pastoralism to a greater reliance on arable farming. Similar scenarios have been observed elsewhere; in West Pokot (Jaetzold and Schmidt, 1982; RELMA, 1999), in the Borana region of Ethiopia (Kamara, 2001), and among the Maasai of Narok in Kenya and across the border in Tanzania (McCarthy *et al.*, 2002; Thompson and Homewood, 2002).

Multiple use of the little land, already inadequate for the number of livestock currently present, further implies that the land is exposed to a greater risk of degradation. It also suggests that the animals are often under low plane of nutrition and thus under-producing besides being highly likely to succumb to the harsh environmental challenges characteristic of these areas (Ndikumana *et al.*, 2000; Galvin *et al.*, 2001). This phenomenon will come about unless high levels of supplementary feeding are done or pasture improvement is practiced. The role of crop residues and fallows in meeting annual feed shortfalls is recognized and practiced in many parts of the tropics including the communities in this area (Jaetzold and Schmidt 1982; RELMA, 1999; Herlocker, 1999; Thorton *et al.*, 2003).

However, approximately 93% of the respondents across the districts had not practiced any form of pasture improvement for lack of awareness on the need to do so and / or lack of technical know-how. Pasture improvement was positively correlated with family size suggesting that it is a labour intensive undertaking. For the few farmers who had done some pasture improvement, it was in the form of bush clearing by slashing, burning, terracing, manure application and reseedling most of which are manual operations.

4.3.4. Livestock population and grazing

Data were collected for all types of livestock kept by the four communities but only that for cattle, sheep and goats are presented and discussed here. This is because out of all domestic animals these are present in greater numbers and are considered of greater economic importance to the people in this study area (Gitunu, 1994; Herlocker, 1999; Scarpa *et al.*, 2003). Notably, however, there were approximately 800 head of camels in Kajiado, a non-camel district, arising from an introduction of 110 heads in 1989 for experimental purposes to hedge against the effects of drought (Evans *et al.* 1995); SNV Annon.). On average, each household had 30 cattle, 32 goats and 24 sheep heads (Table 4.5a, b). Nonetheless, the total numbers and kinds of species kept varied both between the districts and between divisions. Most livestock numbers were reported in Kajiado than in the other districts, regardless of type, while Makueni had the least (Fig. 4.5).

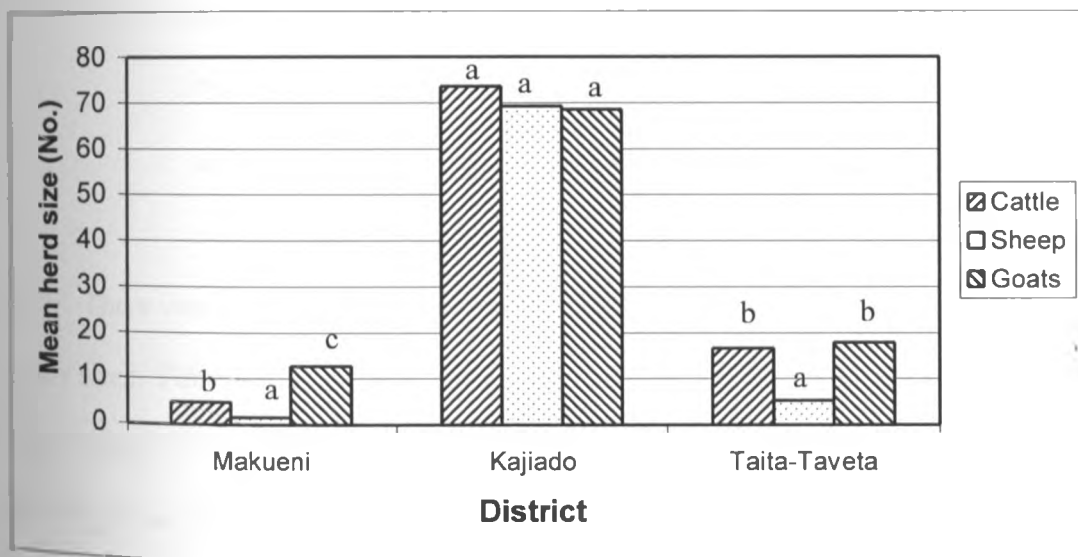


Figure 4.4. Comparative livestock herd sizes per household by species (cattle, sheep and goats) in the three study area districts in 1999. Bars within a cluster with different letters are significantly different ($p < 0.05$).

For example, there were almost 4 and 15 times as many cattle in an average Kajiado household than in Taita-Taveta and Makueni, respectively. Among the divisions, Magadi had the largest numbers and Kibwezi the least. It was noted that an area with high numbers of say, cattle did not necessarily have high numbers of the other two species. Further probing revealed that this is due to two main reasons:

- i) A large scale cattle owner is considered wealthy and as such he / she do not need to keep large flocks of sheep or goats which are considered a poor person's kind of animal. The wealthy farmers thus keep only a few heads of sheep and goats for home consumption or petty cash.
- ii) Areas that are suitable for cattle rearing are not equally suitable for goats. This is in agreement with the common understanding that there is a difference in foraging behaviour of different livestock; cattle are largely grazers while goats are browsers (Lusigi *et al.*, 1984; Huston and Pinchak, 1991; Stuth, 1991; Mnene and Kibet, 1995). Therefore, cattle are mostly found in open grassland and goats in bushed grassland and scrublands.

There was also a close association of herd/flock numbers per household and family sizes. For example Kajiado District had both the largest family units and cattle heads among the three districts (Table 4,5b). Within Kajiado, Magadi Division also had both the largest family units (19) and cattle heads (92).

Cattle and sheep are both largely grazers while goats are mainly browsers, adjusting their preference according to availability, which in turn is influenced by site and season (Stuth and Kamau, 1990; Stuth, 1991; Huston and Pinchak, 1991; Schwartz and

Shultka, 1995; Mnene and Kibet, 1995; Mnene *et al.*, 1996; Herlocker, 1999). The result is a more efficient utilization of the range resources and a higher carrying capacity (Huston and Pinchak 1991; Behnke and Scoones 1992; Herlocker 1999). It is thus advantageous to have a mixed species livestock herd that takes advantage of plant species diversity and heterogeneity that characterizes most natural pastures.

However, the relative numbers of the different livestock species in a given area have different impacts on vegetation composition. During an earlier survey in these areas (Mnene and Mbakaya, 1997) sheep and donkeys were reported to be responsible for pasture denudation in parts of Kajiado where they were abundant. In the present study, although Kajiado Central Division had the highest number of sheep, it is Magadi Division, which is more at risk because it has the second largest number plus the largest cattle herds. The combined demand by the two species of livestock for herbaceous forage is bound to have greater impact in terms of depletion and subsequent denudation. For an area with both low rainfall and high temperatures (Pratt and Gwynne, 1977) the situation is more delicate and could be more prone to feed shortages even with mild drought; Magadi Division is one such area as shown by recent studies (Otieno, 2001; Muthiani and Mnene 2003, 2004).

The differences in livestock herd sizes were a reflection of the different levels of importance placed on livestock by different communities. Communities in Kajiado are traditionally pastoralists while arable farming plays a greater role in the livelihoods of the communities in Makueni and Taita-Taveta Districts. So, with greater reliance on livestock, larger herds are necessary (unless more productive breeds are kept) to sustain a household's needs. Large families that characterize most households as discussed above

as well as low levels of education (Table 4.3) and lack of alternative sources of income (Table 4.4) for household heads compound the problem. In addition, without control over land due to inherent tenure systems, livestock are the main if not the only asset for pastoralists, and naturally accumulation of large herds depicts wealth (Valdivia *et al.*, 2001).

Regardless of district, the predominant cattle breeds were the Small East African Shorthorn Zebu and its crosses with Boran and (or) Sahiwal cattle. Goats were mostly the East African, Galla or their crosses. Red Maasai, Dorper, Blackhead Persian and their crosses were the main breed types of sheep. A number of pastoralists have taken up the keeping of exotic breed types which they use to crossbreed with the indigenous zebu. Although production has been high in good years, when a severe drought occurs (there have been about five in the last 20 years) they lose most of these introduced animals through mortality. For example, during the 1996-1997 and 1999-2000 droughts, pastoralists in this area incurred severe losses (up to 60%) of their herds (Ndikumana *et al.*, 2000; Kristjanson *et al.*, 2001; Otieno, 2001; Wang'ang'a, 2001). Even in good seasons there is always the challenge to strictly adhere to disease control measures, timely and proper diagnosis and treatment of disease outbreaks for these exotic breed types to survive in the harsh environment. In a situation where veterinary health delivery infrastructure is poorly developed, this has been a big challenge and often losses have been high (ILCA, 1991; Ndikumana *et al.*, 2000; S. Karimi – personal communication). Therefore, because the lure for better market prices for crossbreds is irresistible, farmers must be provided with the necessary site and user specific management guidelines given the environmental and household diversity. Further, since severe droughts are now a

common occurrence, a timely (early) and accurate warning system targeting livestock keepers is vital (GL-CRSP 2002; Galvin *et al.*, 2003).

However, within this state of potential and at times real crisis of livestock losses is an opportunity for range recovery, depending on its resilience capacity. This is because, while high continuous stocking encourages degradation, natural calamities of massive livestock losses through deaths impose a high off-take. The result would be range recovery before re-stocking reaches damaging levels again (Behnke and Scoones, 1992; Scoones, 1995; Sidahmed, 1996).

While sheep numbers were the same as those of goats in Kajiado, they were very few in the other two districts, especially Makueni where sheep are not kept for food but for other purposes, mostly cultural (Muthiani, 1973; Gitunu, 1994). In Makueni and to a lesser extent Taita-Taveta, cattle are used for traction, mostly drawing carts and ploughing; a function rarely practiced in Kajiado. The purpose for keeping certain kinds of livestock thus determines a herd's species composition. This in turn determines the utility from and impact on the range. Different kinds of livestock have different foraging behaviour (Kamau, 1986; Huston and Pinchack, 1991; Stuth, 1991; Sidahmed, 1996; Mnene and Kibet, 1995; Mnene *et al.*, 1996; Herlocker, 1999).

Generally, rangeland with a history of continuous heavy grazing tends to be dominated by unpalatable herbs as the more preferred species are selected out. In some heavily grazed cases bush invade such areas. It is hypothesized that because of less herb layer, more soil moisture and nutrients are able to get deeper down beyond the grass root zone to nourish the woody species. This phenomenon has been used to explain bush encroachment in Botswana (Perkins and Thomas, 1993a; Dougill and Cox, 1995). On the

other hand, presence of a large number of browsers tends to suppress the woody species (Ludwig *et al.*, 2003). Where both the grazer and browser populations are too large and continuously utilize an area, then it is more likely to lead to land denudation. Despite range having some degree of resilience (Behnke and Scoones, 1992; Scoones, 1995; Mworira *et al.*, 1997), proper management of the growing vegetation and a period of rest between heavy utilization is needed. It is particularly more critical where droughts occur frequently such as in the ecological zone V of the study districts (Behnke, 1993; Hiernaux, 1993; Milchunas and Lauenroth, 1993; Keya, 1997).

Feed availability was reported to be inadequate in all districts and in deed all divisions. The most critical time was during the dry season when for instance, 43% of Makueni community reported that livestock graze not only within their own farm but also in hired / neighbours' pasture. This is much higher than what was found in Kajiado (29%) and Taita-Taveta (31%). The impac6t of this is that more than a third of the livestock in the study area cannot be sustained *in situ* and that impoverishment of the feed resources is highly likely to occur in such situations due to continuous overgrazing unless there are strategies to fall back on. In this regard, it was observed that most of the divisions are in close proximity to state lands, for example Chyulu Game Reserve, KARI– Kiboko, University of Nairobi farm at Kibwezi, Chyulu Forest, and Tsavo National Parks (Chapter Three, Fig. 3.2). These areas provide feed security to livestock during periods of shortage.

However, this system is only sustainable if the current use and ownership of these state lands remain the same. Even then, the rules and regulations governing different

land uses such as forest and game parks prohibit livestock grazing and whatever is happening is a breach of the current laws. The way forward is to:

- a) Amend the laws to cater for formal arrangements between parties during emergency periods of feed shortage as a way of mitigation against livestock losses, conflicts and human suffering.
- b) Device a policy that ensures that within the rapidly changing land tenure, households are allocated economically viable land units.
- c) Develop, test and promote appropriate land management techniques, such as natural pasture improvement through re-seeding.

4.3.5. Land denudation as a form of natural pasture degradation

4.3.5.1. *Awareness, causes and extent of degradation*

Awareness about pasture degradation was high among the communities since an overall majority (78.5%) of the respondents across the districts acknowledged the existence of extensive bare patches of land without grasses. The highest level of awareness was among communities in Magadi division (97%) and least among those in Taveta (16%). Level of awareness had a positive correlation both with herd / flock and family sizes.

Although it was not possible to determine when the bare patches had started in each area, there was a general consensus among the communities that these bare patches have been increasing over the years. There was also a vernacular name for such bare areas, implying that bare patches in natural pastures are not a new occurrence. The Maasai call the patches *Olbora* or *Oori*; the Taita *Makangarashu*; the Taveta *Mapura* and

the Kamba *Mang'alata*. In deed, poor ground cover appears to have been in these study areas for decades.

For instance, previous low altitude aerial reconnaissance had showed that sparsely covered land occupied at least half of some of the parts in eastern Kajiado including Mashuru Division (Peacock *et al.*, 1982). The situation has been getting worse and these results agree with earlier perceptions based on decades-long trend lines (Lelo *et al.*, 1995) drawn by some of the communities in participatory assessment sessions (Mnene and Mbakaya, 1997). The extent to which denudation had taken place varied from less than 25% to more than 50% of the natural pasture land. Over 35% of the respondents that were aware of denudation estimated that denuded areas constituted more than 50% of their pasture although this varied among districts and clusters (Fig. 4.6).

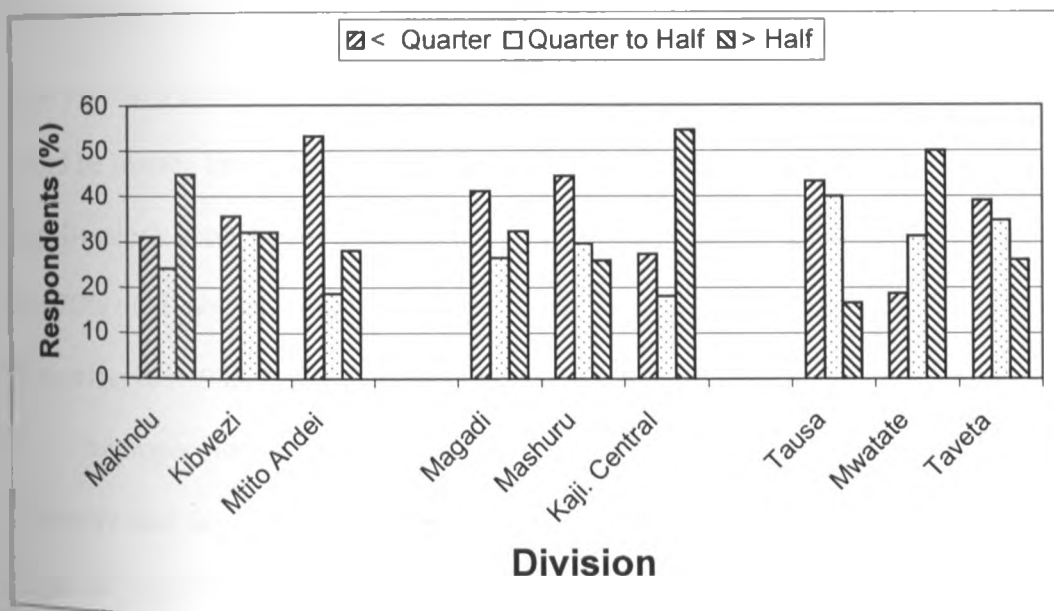


Figure 4.5. Community perceptions of the extent (%) of natural pasture denudation in the nine divisions within Makueni, Kajiado and Taita-Taveta districts in 1999.

Under the 25-50% extent of denudation, Taita-Taveta district ranked highest while Kajiado was highest in the over 50% denudation category. In this study, there were many causes of denudation that were enumerated (Table 4.7). Continuous overgrazing was the major factor but matters are worsened by other factors like drought. In deed, overgrazing was implicit in that an average household owned 7.5, 97.5 and 21 tropical livestock units (TLU; where 1 TLU = 250 kg live-weight of a mature cow, Herlocker, 1999; RELMA, 1999) in Makueni, Kajiado and Taita-Taveta, respectively. The recommended stocking rate is 3-5 hectares per TLU in ecological zones 4 - 5 (Pratt and Gwynne, 1977). Therefore, the ideal natural pasture requirements are 22.5 - 37.5 ha, 63 - 105 ha and 292.5 - 487.5 ha in Makueni, Taita-Taveta and Kajiado, respectively in order to sustainably support the current livestock units. However, considering that much of the pastureland was bare, then there is definitely a high grazing pressure in these study areas even in a normal year. Without access to neighbouring grazing resources, the crisis would be worse. From the survey, it was established that nearly every household with large livestock herds hires pasture or uses neighbouring grazing land. During drought, over 70% of all households in Kajiado have had to move at least part of their livestock (Peacock *et al.*, 1982; Ndikumana *et al.*, 2000; GL-CRSP, 2002).

Improper stocking rates are recognized as major contributors to pasture and eventually land degradation and this anthropogenic influence is exacerbated by abiotic factors such as drought (Pratt and Gwynne, 1977; Boonman, 1993; Herlocker, 1999; FAO, 2002; Galvin *et al.*, 2002). Herbaceous ground cover does not necessarily imply high forage biomass; especially if it comprises short grass or forbs of low dry matter content or even unpalatable vegetation (Stuth, 1991; Herlocker, 1999).

Table 4.7. Responses (%) of the respondents' perception of causes of denudation in natural pastures in nine divisions of three districts in southern Kenya in 1999.

No.	CAUSE	MAKUENI			KAJIADO			TAITA-TAVETA		
		Makindu (35)*	Kibwezi (42)	Mtito Andei (39)	Magadi (36)	Mashuru (36)	Central (36)	Tausa (44)	Mwatate (41)	Taveta (38)
1.	Natural occurrence	20.00	33.33	20.51	8.33	19.44	8.33	38.64	29.27	39.47
2.	Bush infestation	5.71	4.76	2.56	2.78	2.78	0.00	2.27	0.00	0.00
3.	Drought	5.71	7.14	2.56	0.00	0.00	5.55	4.54	4.88	2.63
4.	Overgrazing	0.00	2.38	0.00	0.00	8.33	5.55	2.27	2.44	2.63
5.	Soil erosion	0.00	0.00	0.00	0.00	2.78	5.55	0.00	0.00	0.00
6.	Burrowing animals and insects	0.00	0.00	5.13	5.56	0.00	0.00	0.00	0.00	5.26
7.	Problematic soils	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.19	2.63
8.	Charcoal burning	0.00	0.00	0.00	0.00	2.78	0.00	4.54	2.44	0.00
9.	Combination of factors [/]	68.57	52.38	69.23	83.33	63.89	75.00	47.72	48.78	47.36

* Figures in brackets are numbers of respondents in the respective divisions.

[/] Unspecified number of factors.

Continuous high grazing pressure results in loss of palatable vegetation and reduced ground cover leading to soil erosion and impaired livestock production. This happens especially when severe droughts occur (Mbakaya, 1986; Leisinger *et al.*, 1995; Sidahmed, 1996; Nill, 1996; Herlocker, 1999).

Large herbivores have been reported to consume an average of 66% and a maximum of 95% of above ground biomass (McNaughton, 1979). Under heavy grazing when only 5% of the biomass is left and a drought sets in, as is frequently experienced in the study areas (example 1974-5, 1984-85, 1996-97, 2000), the plants are likely to die off. While studying the effects of frequent and intensive clipping of six grasses at Kiboko, Woie (1984) observed that lack of effective rainfall in 1983 caused a significant reduction in forage yield, tillering and re-growth height especially in plants clipped most frequently and intensely. Keya (1997) reported similar results in Marsabit in northern Kenya. However, in a grazing situation, intensity and frequency applied to different plant species would depend on their palatability and preference by the animal, which first leads to loss of the more preferred ones (Sanford, 1983; WRI, 1994; FAO, 2002).

Moreover, under heavy continuous grazing where selection is minimal (Mnene and Kibet, 1995; Mnene *et al.*, 1996) most plants would be consumed and eventually disappear thus leaving the land bare. However, in this study, a plant species reported to have disappeared from one grazing area would be found elsewhere mostly within the same locality with a different history of land use. Despite possible depletion of the soil seed bank of desirable forage species, establishment may be possible through seed dispersal agents such as wind, water runoff and foraging livestock if the areas are rested from grazing long enough (Ahmed, 1986; Lusigi, 1986; Keya, 1998).

Bush thickets were considered equally important in Makueni and Taita-Taveta and much less in Kajiado in contributing to pastureland denudation (Table 4.7). However, 50% of the respondents indicated that not all woody species are undesirable for livestock production. In Makueni a number of woody species provide valuable browse during times of herbage shortage. But, throughout the study area there are woody species that do not allow herbaceous under-story to establish wherever they dominate. Examples of such species are *A. mellifera*, *A. brevispica*, *Premna oligostrica* and *Commiphora* spp. It is an established fact that bush thickets impede herbage production (Scifres, 1980; Too, 1995). Therefore, a good balance between the various forms of vegetation is necessary to be able to maintain mixed species livestock herds on the range (Huston and Pinchack, 1991; Stuth, 1991).

Soil erosion was cited as a major cause of land denudation, particularly in Makueni and Taita-Taveta districts (Table 4.7). However, it is possible that long before it becomes a problem there must be some predisposing factors. Once established, erosion then exacerbates the process of denudation. This survey did not establish what led to erosion of various sites. However, research has found that once land is depleted of its vegetation cover, rain drops and runoff as well as wind will erode it more readily (Mbakaya, 1985; Sharpley and Williams, 1990; Williams *et al.*, 1990; Nill *et al.*, 1996; Olukoye *et al.*, 2003). According to Nill *et al.* (1996) soil erosion is a process acting over tens and hundreds of years and its cause-effect factors encompass social, economic and political contexts beside those of biophysical nature.

Drought is considered a major cause of denudation although different communities perceived its role differently (Table 4.7). In Kajiado, it was not considered a major issue despite the large number of livestock in this district. This is because the traditional practice of shifting in search of pasture whenever a severe drought occurs is still used to escape the impact of drought. Usually herd movement begins before the vegetation is severely affected. Drought did not seem to be a major problem in most of Taita-Taveta either due to a strategy of combining herd movement, access to fallow, wet and park lands and use of crop residues that lessens the pressure on normal grazing areas (Ndikumana *et al.*, 2000).

In Makueni, however, drought ranked second only to erosion as the main cause of land denudation. Discounting for the argument advanced against erosion then drought may well be the number one problem in Makueni. In deed, despite having put much of the land (> 98% of the households cultivates 95% of their land) into crop production, Makueni district has perennially experienced food shortage due to prevalent droughts resulting in crop failure. It appears, therefore, that there is less risk in nomadic pastoralism in this study area compared to sedentarization in terms of food security and range degradation, which is in agreement with observations made in northern Kenya (McPeak, 2001) and the Sahel (Sidahmed, 1996).

However, it is yet to be understood why communities in Makueni and Taita-Taveta differ in their perception of drought as a major cause of pastureland denudation. Perhaps, this is related to the fact that unlike Taita-Taveta, most Makueni residents within the study area settled there recently (40-60 years) from the highlands of Machakos. As such they might not have adequately developed and or adapted strategies to deal with the

droughts which are more severe. Nonetheless, in all these study areas, the community perceptions of pasture land denudation require empirical data involving both cross-sectional and longitudinal site monitoring to be able to draw concrete conclusions about the relative impacts of sedenterization.

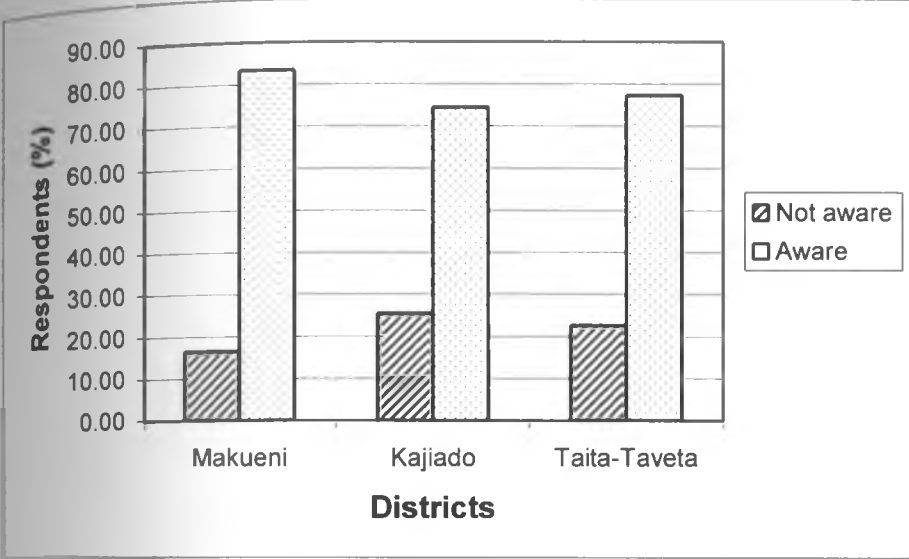
4.3.5.2. *Pastureland denudation control and attendant constraints*

On average, over 70% of the households were aware of one or more techniques to control denudation. The highest degree of awareness was in Makueni while the lowest was in Kajiado (Fig. 4.7a), the difference between the two Districts being significant ($p < 0.01$). Between divisions, the highest level of awareness was in Magadi and the lowest in Central, both in Kajiado (Fig. 4.7b). In Taita-Taveta, Tausa Division had greater awareness than Mwatate, which was again greater than Taveta. There was less variation between the Divisions in Makueni. Differential awareness among these communities had been created through both formal and informal training by extension and research organizations both from the government and private sector. The training covered diverse subjects related to crop and livestock as well as environmental issues. Table 4.8 shows that among the household members, the husbands alone attended such training 53.3% of the time compared to 12.2% for the wives. At times husband and the wife as well as children had been trained.

Different communities knew and practiced different methods of natural pasture improvement. These included re-seeding, terracing, use of thorny branches to cover bare patches, pitting, deferment and application of manure among others (Table 4.9 and Fig. 4.14a, b). About 62% of them had tried at least one method and nearly half of them had applied only one of the methods and the rest had used a combination of two or more. Re-

seeding was the most known technique of reducing bare patches in natural pastureland and about 14% of the respondents had used it alone. This is the option used by the majority of respondents in Makueni district, particularly in Makindu and least in Kajiado.

a) Awareness in the districts



b) Awareness in the divisions

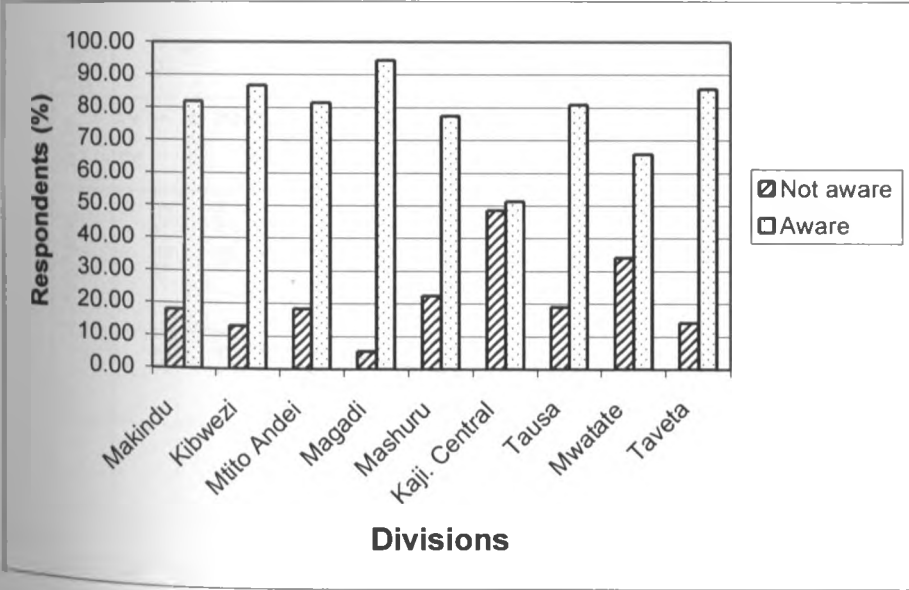


Figure 4.6. Level of awareness of strategies to alleviate natural pasture degradation in (a) district and (b) divisions within the study area in 1999.

Table 4.8. Proportion (%) among respondents who had been trained on various techniques of pasture management in 1999.

District	Division	N	Husband	Wife	Both	Children	Parent & Child	Un-married F	Un-married M	None
Makueni	Makindu	33	45.45	21.2 1	9.09	3.03	3.03	0.00	0.00	18.18
	Kibwezi	39	58.97	12.8 2	15.3 8	0.00	0.00	0.00	0.00	12.82
	Mtito Andei	39	48.72	23.0 8	5.13	0.00	2.56	2.56	0.00	17.95
	Total	111	51.35	18.9 2	9.91	0.90	1.80	0.90	0.00	16.22
Kajiado	Magadi	36	83.33	5.56	0.00	0.00	0.00	2.78	2.78	5.56
	Mashuru	31	74.19	3.23	0.00	0.00	0.00	0.00	0.00	22.58
	Central	34	44.12	5.88	0.00	0.00	0.00	0.00	0.00	50.00
	Total	101	67.33	4.95	0.00	0.00	0.00	0.99	0.99	25.74
Taita-Taveta	Tausa	42	59.52	9.52	4.76	0.00	0.00	2.38	4.76	19.05
	Mwatate	38	55.26	7.89	2.63	0.00	0.00	0.00	0.00	34.21
	Taveta	35	48.57	28.5 7	5.71	0.00	0.00	0.00	2.86	14.29
	Total	115	54.78	14.7 8	4.35	0.00	0.00	0.87	2.61	22.61

Table 4.9. Proportion (%) of the respondents that had attempted various strategies to improve natural pastures in nine divisions of three districts in southern Kenya in 1999.

No.	METHODS	MAKUENI			KAJIADO			TAITA-TAVETA		
		Makindu (33)*	Kibwezi (39)	Mtito Andei (40)	Magadi (36)	Mashuru (31)	Central (35)	Tausa (42)	Mwatate (38)	Taveta (35)
1.	None	39.39	33.33	42.50	22.22	38.71	65.71	30.95	47.37	25.71
2.	Covering bare ground with thorny branches	0.00	0.00	0.00	38.89	29.03	14.29	7.14	2.63	5.71
3.	Construction of soil erosion control structures	3.03	12.82	5.00	2.74	0.00	2.86	7.14	5.26	14.29
4.	Deferred grazing	0.00	5.13	0.00	5.56	3.23	8.57	0.00	0.00	2.86
5.	Re-seeding	21.21	10.26	20.00	0.00	0.00	5.71	30.95	13.16	20.00
6.	Controlled burning	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	0.00
7.	Combination of methods	36.36	38.46	30.00	30.56	29.03	2.86	23.81	31.58	31.43

Table 4.10. Problems of re-seeding and the proportion (%) of respondents who presented them in 1999.

No.	Problems in re-seeding	MAKUENI			KAJIADO			TAITA-TAVETA		
		Makindu (33)*	Kibwezi (39)	Mtito Andei (40)	Magadi (36)	Mashuru (31)	Central (35)	Tausa (42)	Mwatate (38)	Taveta (35)
1.	Lack of seed	0.00	7.69	17.5	0.00	3.23	2.94	0.00	0.00	2.86
2.	Poor seed	3.03	0.00	0.00	0.00	3.23	0.00	0.00	0.00	0.00
3.	Labour	0.00	20.51	2.50	2.78	6.45	5.88	2.38	2.63	0.00
4.	Loss of seed	0.00	0.00	0.00	0.00	0.00	0.00	4.76	0.00	0.00
5.	Drought	6.06	17.95	5.00	19.44	22.58	8.89	7.14	13.16	11.43
6.	Low persistence	0.00	0.00	0.00	2.78	0.00	0.00	11.90	0.00	0.00
7.	Combination of problems	54.55	12.82	45.00	36.11	32.26	5.88	23.81	10.53	14.29
8.	None	36.36	41.03	30.50	38.89	32.26	76.47	50.00	73.68	71.43

Covering bare ground with thorny branches came second with 10.3% and was the most known approach in all divisions in Kajiado. Soil and water control structures, especially terracing ranked third, and was the most common method known in Taita-Taveta, especially in Tausa and Mwatate. The most practiced methods were terracing, manure application, re-seeding and use of thorny branches in that order. Again, this varied from district to district. Although manure application ranked highly among the practices in use, many households did not know about it while re-seeding (the most known) ranked third in adoption due to a number of constraints.

Those who attempted re-seeding encountered several problems, including:

- a) *Drought* - About 50% of the respondents cited this as a major set back. Drought led to low or poor germination. However, most respondents felt it was a combination of problems that makes re-seeding difficult (Table 4.10). Poor germination can be caused by a number of other factors. For example, use of immature seeds, seed hardness, improper sowing (depth, timing etc.) and removal by harvester ants or other seed predators (Bogdan, 1977; Boonman, 1993; HSU, 1994; Loch and Ferguson, 1999). Also, use of species that require high soil moisture leads to poor germination and subsequent establishment, which is a likely to be the case in these arid and semi-arid areas.
- b) *Unavailability of appropriate seed in the market* – Rangeland grass seeds needed for pasture improvement and general range rehabilitation are not readily available in the market. Therefore, whatever kind of seed is obtained by farmers is used, often leading to poor establishment. When forage seed is not correctly matched with local environmental conditions where it is being sown / introduced, chances

of failure to establish are high (Boonman, 1993; Loch 1999). Since benefits from reseeding are not usually direct as with food crops, then chances of repeat attempts in subsequent seasons are low. Therefore, ways of improving success of pasture establishment are needed. According to Boonman (1993) and Loch (1999) some of the key factors influencing establishment of a forage species in the semi-arid tropics are soil and water.

- c) *Inappropriate grass species* - The most commonly used grass species were *C. ciliaris*, *E. superba* and *C. plectostachyus*. These are not only local species but they are considered most appropriate for re-seeding rangelands due to a variety of qualities including drought tolerance, fast establishment of cover and high seed production (Bogdan 1977; Pratt and Gwynne, 1977). However, a few cases of reseeding with *C. gayana* were encountered; this grass normally has low persistence (Boonman 1993).
- d) *Lack of control over land* - These was another important constraint to reseeding and pasture improvement in general. This was a problem in Kajiado, especially Magadi and Mashuru, where subdivision of ranches has not taken place yet. This result tends to reaffirm earlier observations that communal use of land is a disincentive to one's investment of resources to protect let alone developing it (Kimani and Pickard, 2002). The fear that the portion of land one develops now may not be allocated to them when sub-division is finally effected is real. What is more, a freshly reseeded area requires a period of deferment and in a free range grazing system fencing is necessary yet expensive. The mere fact that one can not fence what does not belong to them, and therefore, neighbourhood herds have

equal access to any part of the land practically precludes re-seeding as a development option (IFAD, 2004). RELMA's (1999) experience in Pokot also attests to this, but the problem was resolved through community empowerment by forming common interest groups / associations and recognizing their traditional local laws to enforce decisions.

- e) *Termites* – Damage by termites is a general concern in the study areas since they also affect crops and farm structures. For instance in Makueni, particularly Makindu Division, it was estimated that loss of forage could be as high as 30% of the standing crops. Ways and means to deal with them must, however, be in management to minimize the losses and not total control because termites play an important ecological role, especially nutrient cycling (Richards, 1974; FAO, 2001).
- f) *Poor seed material* - Use of poor seed material arises from lack of appropriate certified seed in the market. Farmers therefore do their own collections locally without following proper techniques. Storage is another likely stage at which seed could get damaged, especially if moisture and temperature are not well controlled (HSU, 1994). However, it is not certain whether the procedures recommended for harvesting and storage of commercial pasture seed varieties work for the unimproved local range types. As such, pertinent trials and demonstrations are necessary.
- g) *Labour costs and general uncertainty of returns to investment*. This is an issue of economic worthiness of reseeded as a land improvement tool (IFAD, 2004) and can be demonstrated through on-farm trials. It requires proper record keeping of

all inputs, including the opportunity cost on deferred grazing and the value of the increased pasture's potential to support sustainable extra livestock units.

- h) *Low persistence* – This is due to a number of factors principal of which are frequent drought and mismanagement, especially pre-mature and / or continuous heavy grazing as has been demonstrated and argued earlier (Woie, 1986; McNaughton, 1979; Sidahmed, 1996).

In combating range degradation, there are two broad approaches; grazing management and land improvement (IFAD, 2004). However, while much has been done about grazing management, land improvement technologies have received little donor support mainly because of cost and sustainability. This generally explains, at least in part, why re-seeding which is one of the land improvement strategies has had little adoption. However, it can be argued that encouragement of communities to form common interest groups / associations and training groups can ensure greater impacts.

Adoption entails putting resources to practice and where one stands a higher risk through say, lack of control, less resource is likely to be allocated (Galaty, 1992; Lesorogol, 1998; Kimani and Pickard, 2002). For example, in reseedling and terracing, more resources are needed than cutting tree branches to place on bare patches. So, this may explain why in Kajiado where there is less control of land use, the cheaper technique is opted for.

Further, practice of different methods also tended to be influenced by the existing extension practices. For example, the Taita-Taveta ASAL Programme (TTAP) advocated terracing, stabilizing them with valuable forage species. In Makueni the German Agro-Action (GAA) programme emphasized re-seeding while, no particular message about

natural pasture improvement existed in Kajiado (SNV, undated). This brings to the fore the fact that until recently (GoK, 2004) Kenya had weak and non-specific policy guidelines regarding management of natural pastures in ASAL (Mr. Ishmael – Chief, Range Management Division, personal communication). As such, extension agents (both GoK and NGOs) have had to come up with what seems to work for them in their target areas.

4.3.5.3. *Gender and cultural considerations in natural pastureland improvement*

Nearly all members of the household did some rehabilitation work on denuded natural pasture in the three districts. However, it was mostly a husband's task irrespective of which technique was employed. Exceptions were in Kajiado where women more than men did the cutting of thorny branches to cover bare ground patches more than 70% of the time. This was rather surprising since mainly men and male children did herding of cattle and they would be expected to do the work while out in the pastures with the livestock. The women use the thorny branches resulting from cutting fuel wood and construction materials. In the Maasai culture, it is the responsibility of women to build houses. This variation in gender roles was an important observation since in most cases the gender roles among the communities are misunderstood or unknown to outsiders such as researchers, extension and development agents, not only in Kenya but in other countries as well (Kamara, 2001; Valdivia *et al.*, 2001). Whereas men may own the cattle it would seem women play an important role in their very survival. In designing interventions, therefore, it would be desirable to tailor them such that they are in line with the socio-cultural norms of the target community.

4.3.6. Conclusions and recommendations

The assessment of community perception on the extent of pasture denudation in pastoral and agro-pastoral areas was achieved in this survey. The different communities had diverse backgrounds in terms of education, other sources of income and family sizes. There was also disparity in household endowment with various resources such as herd and land sizes.

There was a close association between large families and ownership of large herds. Both of these were negatively correlated to the level of education of household heads. Attainment of higher levels of education was positively correlated to engagement in other means of income generation implying less reliance on the land for earning a livelihood.

The larger the farm size the larger the portion that would be set aside for pasture. However, under the agro-pastoral production system, priority is given to crop production. Therefore, fragmentation of communally owned land into small parcels in Kajiado is a threat to the future of extensive livestock production since much of the land would be tilled for crop production.

Despite their diversity, the majority of the communities in the study areas were conscious about natural pasture degradation, which is in terms of not only loss of important forage species but also loss of land through denudation. The causative agents of natural pasture degradation were known to some of the communities. The survey identified several causes, the major ones being continuous overgrazing and drought. However, it is understood that the two factors above had a greater damaging effect on

natural pastures when they act in association with other factors such as termite, opportunistic cultivation and charcoal burning.

Although this study found out that in nearly all divisions sampled, overstocking is evident and drought incidences are documented, the manner of their interaction with other factors to effect degradation of natural pastures is not well understood. A greater insight into this phenomenon could be gained through experimentation and a long-term longitudinal survey along permanent transects.

Nonetheless, from this study various reasons may explain why nearly all divisions surveyed are overstocked. One is over-population with livestock, especially in the agro-pastoral districts where very little land is set-aside for pasture. This is exacerbated by the government practice of allocating small pieces (2-4 ha) of land per household in settlement schemes. The other reason is a change in land tenure in traditionally pastoral areas, particularly individuation of ranches without concomitant change in the culture of equating large herds to wealth. This means nearly the same animal numbers are accessing even more limited grazing areas. The third reason of overstocking is the very existence of state lands such as forests, idle research farms and parks since they serve as an informal grazing reserve. A clear policy guideline needs to be put in place concerning how these 'grazing reserves' are to be managed to benefit the livestock keepers in their immediate vicinity.

Different communities know a number of technologies depending largely on what extension programmes were promoted in those areas. Some of these technologies were deferred grazing, controlled burning, covering bare ground with thorny branches, terracing and re-seeding.

A large number of men, women and children in that order were aware of how to alleviate the problem of pasture degradation. However, studies are needed to better understand the different gender roles in increasing the adoption of natural pasture improvement technologies.

Only a few individuals were actually practicing the technologies of natural pasture improvement. Lack of control over the land, lack of technical know-how, lack of inputs, and unpredictable weather were some of the reasons behind the low level of adoption.

Most households with large families practiced natural pasture improvement. This is because of the laborious nature of most techniques, which thus employed family labour. These techniques should be made less labour intensive and more efficient methods developed.

Lastly, the survey found out that re-seeding was the most known of the many technologies for natural pasture improvement. However, its practice is low owing to a number of constraints. These include low availability of seeds in the market, poor quality of whatever seed is available and inefficient re-seeding techniques. As a result, establishment was poor and persistence low. Therefore, research on seed harvesting, storage and propagation approaches was necessary so as to refine recommendations applicable at community level. Results from studies addressing some of these reseeded constraints form the content of the next four chapters.

CHAPTER FIVE

5.0. EFFECT OF METHOD OF SEED HARVESTING AND STORAGE ON GERMINATION OF FOUR SEMI-ARID RANGELAND GRASSES

5.1. INTRODUCTION

Pasture seed is not readily available in developing countries, especially in the in the arid and semi-arid lands, and this has been a major limitation to increased food production (Hanson, 1994; ICARDA, 2000). In Kenya, whatever is in the market comprise of species considered of commercial value, mostly the type that does well in the humid and sub-humid areas such as *S. sphacelata* and *C. gayana*. Mbogoh and Shaabani (1999) observed that one of the major constraints to natural pasture improvement in the southern Kenya rangelands is seed inadequacy. Similar conclusions were drawn earlier in Chapter Four from the community survey. As such it is difficult to obtain seeds of the typical semi-arid and arid rangeland pasture species, for example *C. roxburghiana*, *C. ciliaris*, *E. superba* and *E. macrostachyus* (Bogdan, 1977; Boonman, 1993; Herlocker, 1999). From the previous chapter it was evident that natural pastures are degraded. The need for improvement exists possibly by over-sowing, while some actually require rehabilitation through reseeding.

From concerted efforts of various stakeholders, communities in parts of Makueni, Kajiado and Taita-Taveta districts have been sensitized on natural pasture improvement (Gitunu *et al.*, 2003). This has led to an increased demand for pasture seed. For instance, at KARI – Kiboko in 1992 the annual demand was approximately 100 kg and by 2003 it had risen to over 1,000 kg of assorted species of grass and legumes. Most of the demand

comes from individual farmers and organized community common interest groups. Others have been NGOs involved in development and extension as well as officials of the ministries of Agriculture and Livestock and Fisheries Development. At no one time in any year has this demand for seed been met. Foreexample, in 2003 the total seed supply at Kiboko was only 150 kg. Consequently, individuals or organizations including government institutions have had to harvest whatever they need wherever they can get it, mostly in the wild. This practice is likely to continue until commercial seed dealers step in and satisfy this demand.

The methodology of seed harvesting by smallholder farmers has not been well documented and disseminated (Hanson, 1994). Worse still, appropriate storage conditions, especially at farm level are not well known (ISTA, 1999; Loch, 1999). Anything under storage has to have a labeled shelf life, lest huge if not total losses are incurred at the end when all is trashed after discovering that the materials have long expired. This implies also that there has to be a form of routine testing of stored seeds as required by the International Seed Testing Association (ISTA, 1999).

ISTA requires that before seeds are packed and sold, they must be tested for germination rate and purity. Public seed testing agencies normally do the testing and certification. The germination rate must meet a known standard value in order for the seed lot to be certified. Germination test reports show the percentage number of seedlings that have developed normally under optimum laboratory conditions. In addition, proportions of abnormal seedlings, un-germinated fresh / dormant seeds and dead seeds are also reported. Germination testing is the standard method most accepted

for seed viability. However, this method is not designed to assess the many factors that influence seed vigour (Perry, 1978; Seed Labs, 2003).

In Kenya, the Kenya Plant Health Inspectorate Service (KEPHIS) has the onus to test and control the quality of all plant materials including seeds, both inland and at the ports of entry into the country. KEPHIS headquarters is in Nairobi but it has regional offices in Nakuru, Mombasa, Eldoret and Kisumu. However, the inspectorate's scope of accreditation has very limited capacity to test the quality of the typical rangeland grasses. For instance, out of a list of 12 grasses that KEPHIS could test in 2001, there were only two of such species, namely *C. ciliaris* and *E. superba*. The main constraint has been lack of established germination standards for these grasses. Therefore, the main aim of this study was to recommend appropriate grass seed harvesting and storage techniques for farmers that would result in superior seeds for four commonly preferred semi-arid rangeland grasses, namely *C. roxburghiana*, *C. ciliaris*, *E. superba* and *E. macrostachyus*. The results from this study could be used in setting the necessary standards by KEPHIS. Additionally, because commercial seed dealers are yet to show much interest in these grasses, one option to alleviate shortage of forage seed availability would be to encourage the farmers / pastoralists to harvest seeds from their own localities. Thus information pertinent to seed handling at farm level is needed especially on rangeland grass seed harvesting, processing, storage and viability testing. This would be similar to approaches taken for the commercial types (HSU, 1994; Chin and Hanson, 1999; ISTA, 1999).

5.1.1. Hypothesis

Methods of harvesting range forage seeds, seed storage material and duration of storage affect seed viability.

5.1.2. Objective

To test a number of selected techniques of pasture seed harvesting and storage suitable for on-farm use.

5.2. MATERIAL AND METHODS

5.2.1. Species selection

Four grass species were selected for this study on the basis that:

1. They ranked highest in a list that communities had identified as being important for local pasture re-establishment in the study area (Chapter Four).
2. They are perennials (Bogdan, 1977; Boonman, 1993) and as such they would be more appropriate for reseeding when considering the persistence factor.
3. They had been used elsewhere before in reseeding trials (Jordan, 1957; Pratt, 1963; Pratt and Knight, 1964; Bogdan and Pratt, 1967; Freddenslug and Cassady, 1969; Pratt and Gwynne, 1977; Too, 1995; Keya, 1998; Herlocker, 1999)
4. Literature indicates that some of them are good seed producers (Bogdan, 1977; Boonman, 1993) which is advantageous in many respects such as:
 - Self-seeding (autochorous) by seed falling off the mature plants (Green and Johnson 1989; Briske, 1991).

- Seed dispersal (allochorous) by agents like wind, animals (including grazing livestock) and water runoff (Agnew and Flux, 1969; Okubo and Levin, 1989; Veenendaal, 1991).
- Once established and well managed, the pilot areas will act as source of seeds to be used for expansion of the work on natural pasture improvement and / or
- Provide an income through sales.

The description of the four selected grasses was presented earlier in the general materials and methods (Chapter Two, Table 2.1).

5.2.2. Seed collection and storage

Two seed lots were harvested, one during the short rainy season in 2000 and the other during the long rainy season in 2001 and stored under similar conditions. Seeds were collected from natural stands of the grasses occurring at KARI centre at Kiboko. Seeds were harvested using two methods (Plate 5.1) according to recommended procedures (Boonman, 1993; HSU, 1994 and ISTA, 1999). The two harvesting methods were:

1. Stripping (milking) the seeds by hand from the panicles when dry.
2. Cutting the stalk bearing the panicle with mature seeds together with the flag leaf at the last node.



(a) Stripping



(b) Cutting with stalks

Plate 5.1. Demonstration of two grass seed harvesting methods

The harvested material was spread on a canvass under shade to air dry. After air-drying for 5 days the seeds were threshed by shaking and beating on a canvass manually to dislodge any seeds that were still attached to the stalks. They were cleaned by hand to remove leaves and stalks and other chaff.

Clean seed of each species was heaped together and five handful grabs were taken from the outer and the inner parts of the heap. These grab samples were for immediate germination testing as per schedule below. The rest of the seed lot was put, each species separately, in four well-labeled different types of containers (Plate 5.2), namely:

1. Brown paper bags, usually used for baling maize / wheat flour in Kenya.
2. White cotton cloth bags, tailor made with strapping.
3. Woven synthetic sacks commonly used for wholesales of sugar and animal feeds in Kenya.
4. Aluminium metal open-top tins with well fitting lids fabricated by the informal sector (*jua kali*) artisans at Gikomba and Kamukunji sheds in Nairobi.

The information on the labels included forage species, date and method of harvest.

A traditional crib, similar to those used by agro-pastoral communities (Kamba and Taita) for food grain storage, was constructed on-station for the purpose of seed storage (Plate No. 5.3). It was assumed that such a facility would meet the minimum requirements for seed storage in terms of temperature and humidity (HSU, 1994; Chin and Hanson, 1999; ISTA, 1999). This is because such cribs have always served different communities in the storage of food grains since time immemorial (Al-ani and Ouda, 1969, Burtler, 1985). Crib temperature and humidity, the two most crucial conditions to observe in seed storage (HSU, 1994) were monitored daily at 3.00 pm throughout the study. This was to provide an indication as to what extent the crib was modifying the ambient weather parameters. In addition, a max / min temperature thermometer was placed in a Stevenson's screen outside about 25 m away from the crib to record ambient temperatures daily at 3.00 p.m. in order to provide a comparison with the crib data.

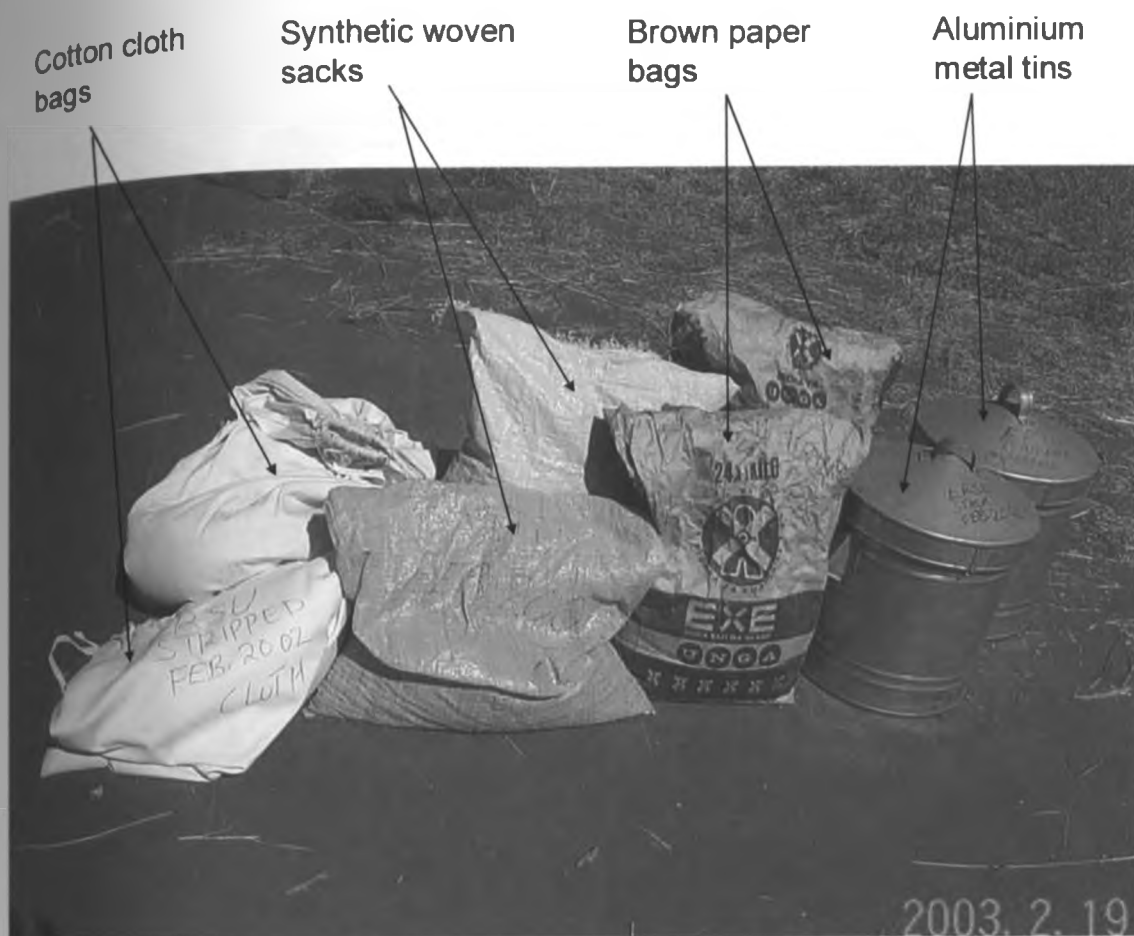


Plate 5.2. Example of the types of containers used to store experimental grass seeds.



Plate 5.3. A traditional grain store (crib) used to store the experimental grass seeds.

5.2.3. Seed viability testing by germination

Periodically from 0 to 72 weeks post-harvest germination tests were conducted. Altogether, 10 germination tests were conducted per seed lot as shown in Table 5.1. At each sampling period, primary samples consisting of five-handful grab samples of each grass species were drawn at random from different positions in the seed lot in the store and combined and mixed thoroughly to make a uniform composite sample. The composite samples were taken to the laboratory where working samples were drawn for processing to extract caryopses.

Table 5.1. Schedule for the germination tests of two seed lots from four grass species during 2001-02 at KARI – Kiboko.

Test No.	Storage duration (weeks)	Germination test dates	
		Seed lot No.1 (Harvested Jan 24, 2001)	Seed lot No.2 (Harvested Jun 5, 2001)
1.	0	Jan 30 – Feb 13, 2001	Jun 12 – Jun 27, 2001
2.	2	Feb 14 – Feb 28, 2001	Jun 27 – Jul 10, 2001
3.	4	Feb 23 – Mar 8, 2001	Jul 15 – Jul 28, 2001
4.	8	Apr 1 - Apr 14, 2001	Aug 10 – Aug 23, 2001
5.	12	Apr 28 – may 11, 2001	Sep 5 – Sep 18, 2001
6.	18	Jun 8 – Jun 21, 2001	Oct 19 – Oct 30, 2001
7.	24	Jul 20 – Aug 2, 2001	Nov 29 – Dec 12, 2001
8.	36	Oct 12 – Oct 23, 2001	Feb 23 – Mar 8, 2002
9.	48	Jan 4 – Jan 17, 2002	May 24 – Jun 6, 2002
10.	72	Jun 21 – Jul 4, 2002	Nov 13 – Nov 26, 2002

Seeds were processed by use of sandpaper to extract caryopses. Since sandpaper in the market is available in various grades of coarseness and different grass species have different seed sizes, it was assumed that to apply the same sandpaper grade, say No. 2 on all of them would be inappropriate. Smaller seeds may require less abrasive sandpaper lest the caryopses are damaged. On the other hand, large seeds probably would require rough sandpaper to effectively extract the caryopses. So, a preliminary trial was

conducted using sandpaper grades 0, 1, 2, 3 and P80 that are usually readily available in the local market to select the appropriate one(s) for use in this study.

Standard laboratory petri dishes and filter paper No. 91 were used under room conditions as per the ILRI seed manual (HSU, 1994). The room had side benches set against the wall. On one side of the room the walls had large fixed glass windows with smaller ones higher up close to the ceiling, which were permanently kept open. This allowed natural but indirect light and air into the room. These are laboratory conditions needed in germination trials since direct sunlight would result in high temperatures and desiccation of the seedlings (HSU 1994).

In both the preliminary and actual studies, 100 caryopses were obtained from the working samples of seeds per species. Although the appropriate number recommended for seed quality testing through the percent germination method is 400, where stocks are small fewer numbers are acceptable (Veenendaal, 1991; HSU, 1994; ISTA, 1999). The procedure for extracting the caryopses is detailed in HSU (1994) and the main steps followed in this study were:

1. A sheet of sandpaper measuring about size A5 (148 mm x 210 mm) was placed flat on a stable bench with the abrasive side of the paper facing up.
2. A pinch of the grass seeds was placed at the centre of the sandpaper.
3. A second piece of sandpaper was placed on top of the seeds with its abrasive side facing down.
4. Then, while holding the lower piece of sandpaper down with one hand, gently but firmly the second sandpaper was used to rub against the other sandpaper in circular motions.

5. By checking now and then the caryopses, which were mostly yellowish brown, were removed using a fine point pair of forceps without squeezing too hard to minimize chances of them getting damaged. The caryospes were placed in a petri dish. Additional seeds were added and rubbed until the desired number (100) was obtained.

The 100 caryopses were divided into four sub-samples of 25 and each sub-sample was spread out evenly in rows on moist filter paper placed flat in a petri dish, which was then covered (Plate 5.4). Petri dishes were labeled and laid out on side benches by sets of lot number, species, harvesting method, and container type and storage period. A small amount of water was added regularly to maintain the paper in moist status throughout the experiment. Daily counts were made of the number of seeds germinated for a period of 21 days. Presence of an emergent radical was used as the measure of germination (HSU, 1994) given that germination is defined as the emergence of the radicle through the seed coat (Koning, 1994). Those counted as germinated were removed from the petri dish. Later, due to clouding of caryopses by fungal growth, the observation period was reduced to 14 days. This was after preliminary data analysis and further review of literature (Koning, 1994; Keya, 1997; Loch and Ferguson, 1999; ISU, 2000; Dahliquist - Annon; Shaman, 2004; Kennell, 2004; IRRI, 2004; HSTA, 2004) it was realized that the study objective would still be achieved with a shorter test period.

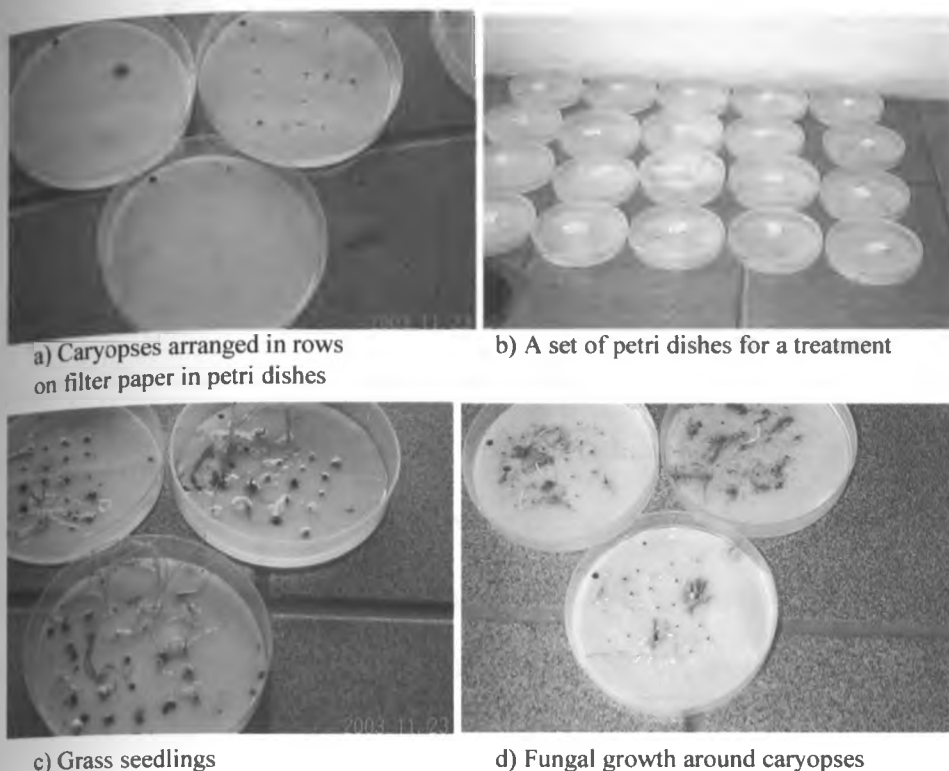


Plate 5.4. Illustration of a) caryopses arrangements b) Petri dish set per treatment c) grass seedlings d) fungal growth during seed germination trials in the laboratory at KARI – Kiboko.

Fungal growth affected all the seed regardless of species although the most affected was *C. ciliaris* and the least was *E. macrostachyus*. Because of fungal problem, seed samples were taken to KEPHIS's Plant Quarantine laboratory at Muguga for analysis. Also submitted were samples of the water that was used in the germination trial. The results showed that the most common fungi were *Fusarium moniliforma*, *F. graminearum* and *Phoma sorghina*; these affected all the seeds. Altogether there were nine different micro-organisms identified from the germinating seeds, the full list of which is shown in Appendix Table 5.1. The *C. ciliaris* seeds had the highest intensity and diversity of microbial infestation with nine species while *E. macrostachyus* had the least with five species. Infestation with microbes of this kind is an indication that seeds

were not harvested properly or the storage conditions are poor. High levels of infestation results in seed damage (HSU 1994).

5.2.4. Data analysis

All data on seed germination were converted into percentages and analyzed using Statistical Analysis Systems (SAS, 1990) procedures. For the initial test for effects of sandpaper grade on percent germination date of observation, grass species and petri dish number were also included in the model. The latter was to ascertain that the laboratory room conditions were uniform and wherever a petri dish was placed it was exposed to the same conditions. After the preliminary run to select the appropriate grade of sandpaper to use, the main effects retained in the multivariate ANOVA analysis were method of harvesting, container type, period of storage and seed lot. Both data on period of storage and day of observation was subjected to partial correlation analysis. To test for within subject effects on germination univariate tests were done.

5.3. RESULTS AND DISCUSSION

5.3.1. Preliminary sandpaper trial

Sandpaper grade had a significant ($p < 0.05$) effect on percent seed germination as did day of observation and species. However, percent seed germination was not affected by petri dish number. Figure 5.1 shows that for each grass species there was a particular grade of sandpaper that produced caryopses with the highest germination potential.

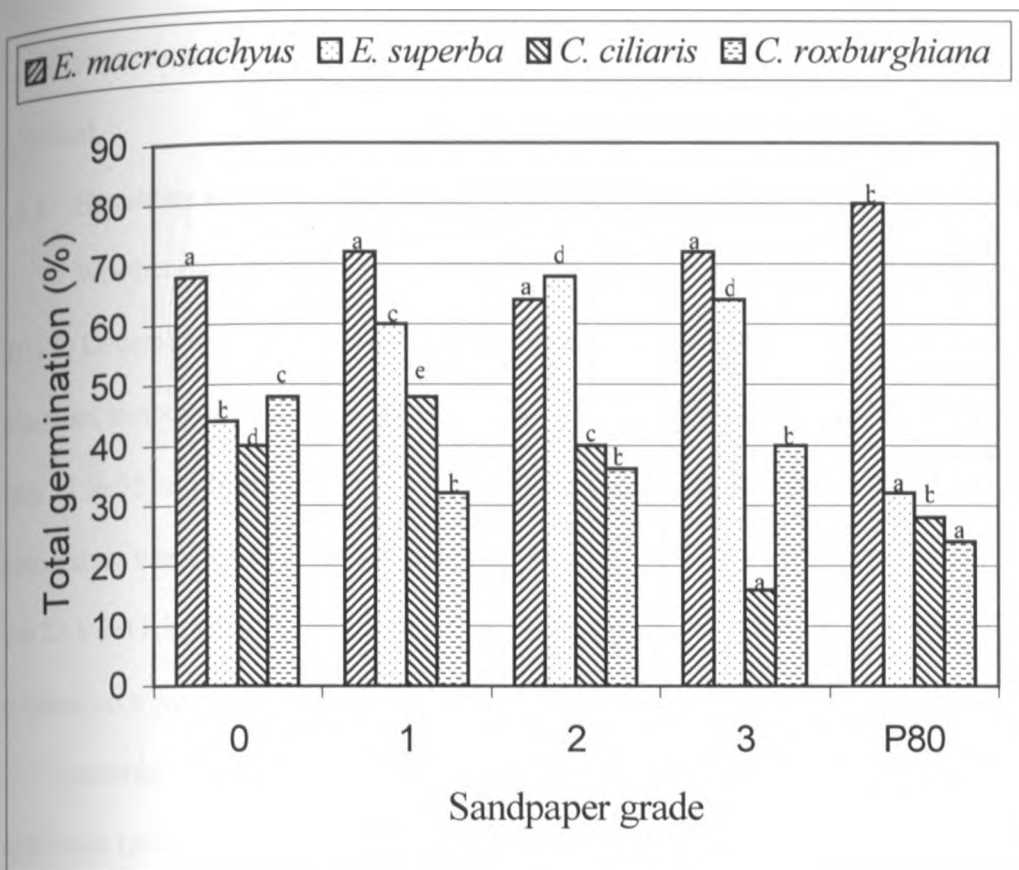


Figure 5.1 Comparative effect of coarseness of sandpaper used to extract caryopses for quality testing by the Petri dish method on percent seed germination of four grasses at KARI – Kiboko. Bars of the same species with similar lettering are not significantly ($p > 0.05$) different.

Accordingly, therefore, the best results were obtained with grade:

- No. P80 for *E. macrostachyus*,
- No. 2 for *E. superba*,
- No. 1 for *C. ciliaris*, and
- No. 0 for *C. roxburghiana*.

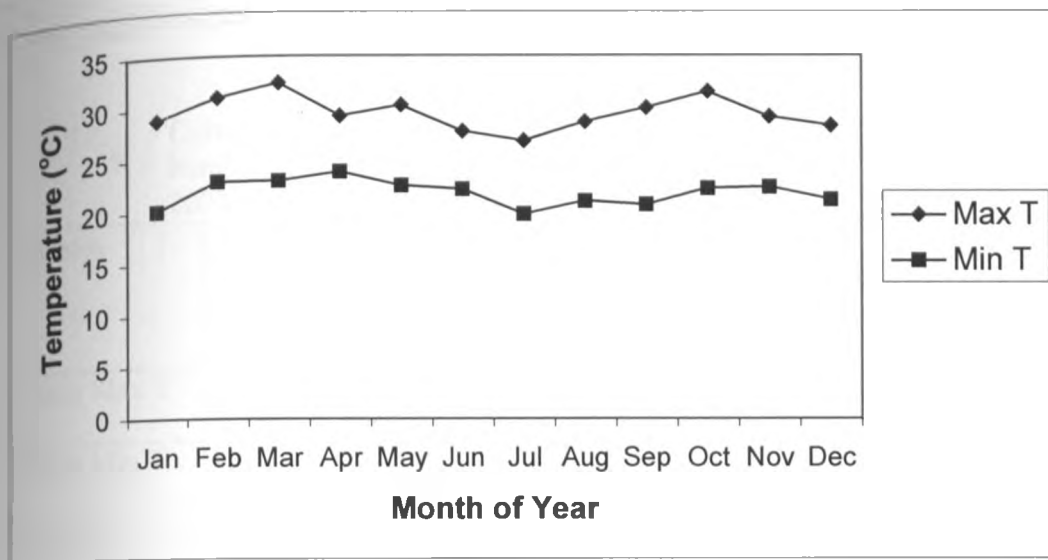
The results are a confirmation to the hypothesis that there is possible mechanical damage of caryopses in the extraction process since sandpaper P80 was physically the coarsest while 0 was the least. In terms of seed size, *C. roxburghiana* has the smallest while *E.*

macrostachyus has the largest. So, the smaller the seed the greater the damage would be when extracting with more coarse sandpaper thus lowering the seed's germination potential.

5.3.2. Humidity and temperature

Weather data was recorded daily for a total of 730 days beginning January 1, 2001 to December 31, 2002. During this period the mean (and $\pm$ SD) maximum and minimum temperatures outside the store were 29.4 ($\pm$ 2.25) and 21.8 ($\pm$ 2.44), ranging from 21 to 35 and from 11 to 30°C, respectively (Fig. 5.2a). Inside the store the mean temperature was 28.4 ($\pm$ 2.44) and ranged from 19 to 34°C while the relative humidity was 23.5 ($\pm$ 11.31) and ranged from 0.9 to 84.0% (Fig.5.2b). One-way analysis of variance on a weekly (total 104 weeks) basis showed that the variations with time of both the temperatures outside and inside the store as well as the relative humidity were highly significant ($p < 0.001$). Not only were temperature and humidity fluctuating over time they were also correlated. The ambient temperatures were within the range for the long term annual mean (Michieka and van der Pouw 1977; Musembi, 1986).

a) Temperature (Max and Min °C) outside



b) Storage weather

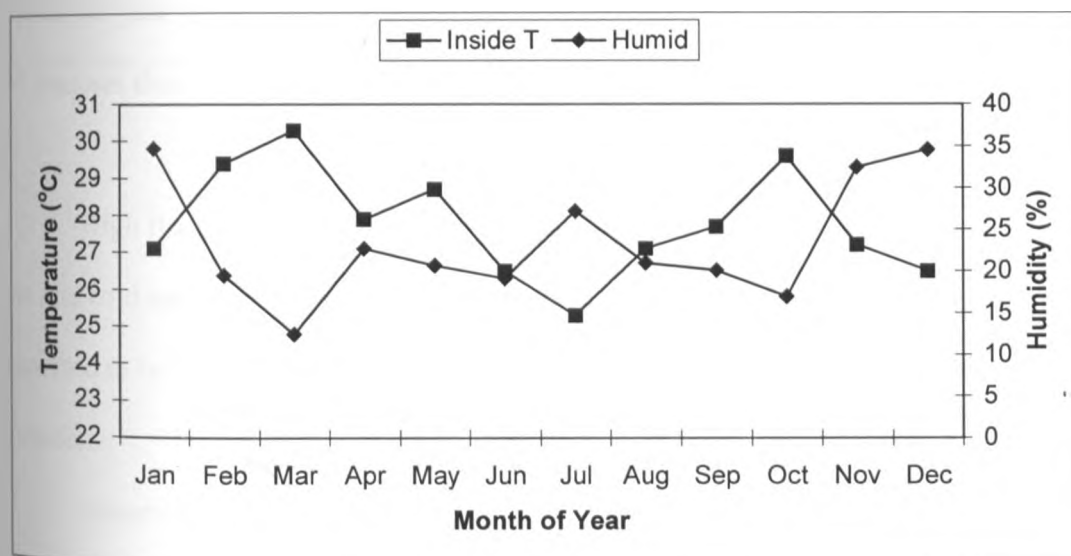


Figure 5.2. Weather conditions a) mean maximum and mean minimum temperature (°C) outside and b) temperature and relative humidity inside the seed store at the forage experimental plots at KARI Kiboko during the study years 2001-2002.

Table 5.2 shows coefficients from multivariate correlation analyses, which suggest a strong but negative correlation, particularly between maximum temperature outside and the relative humidity inside the store.

Table 5.2. Correlation matrix of temperature (T) (max/min °C) outside and relative humidity (%) and temperature inside the seed store during the study period 2001/2002.

Variables	Variables				
	Outside Max T	Outside Min T	Inside Humidity	Inside T	Month of year
Outside Max T	1.000	0.325*	-0.553**	0.208**	-0.185**
Outside Min T		1.000	-0.306**	0.133**	-0.106**
Inside Humidity			1.000	-0.169**	0.148**
Inside T				1.000	-0.002
Month of year					1.000

** Denotes that correlation is significant at 0.001 and * significance at 0.05.

High fluctuations of temperature outside the store reflected the usual pattern of hot and cold months in a normal year. However, inside the store temperatures were expected to be cooler but they were only a degree or two lower than the maximum outside.

However, the high levels of humidity in the store were more than had been expected although they reflected the wet and at times foggy weather conditions outside. Both high temperature and high relative humidity are undesirable storage conditions (HSU, 1994; Chin and Hanson, 1999) and would most likely have a negative effect on the stored seeds, by lowering the shelf life. Lack of a clear relationship between

temperature inside the store and time of year (Table 5.2) is a further reflection of the cyclic weather patterns. High humidity in the store was attributed to excessive baggage and the orientation or arrangement of storage containers that may have curtailed free air movement.

5.3.3. Mean daily and total germination

Mean daily percent seed germination was 3.61 ± 0.060 . The daily variation in seed germination was significant ($p < 0.001$) with a higher rate at the beginning than towards the end of the trial. Most seeds germinated in the first 1-4 days and the trends were curvilinear with subsequent daily germination occurring at a diminishing rate (Fig.5.3).

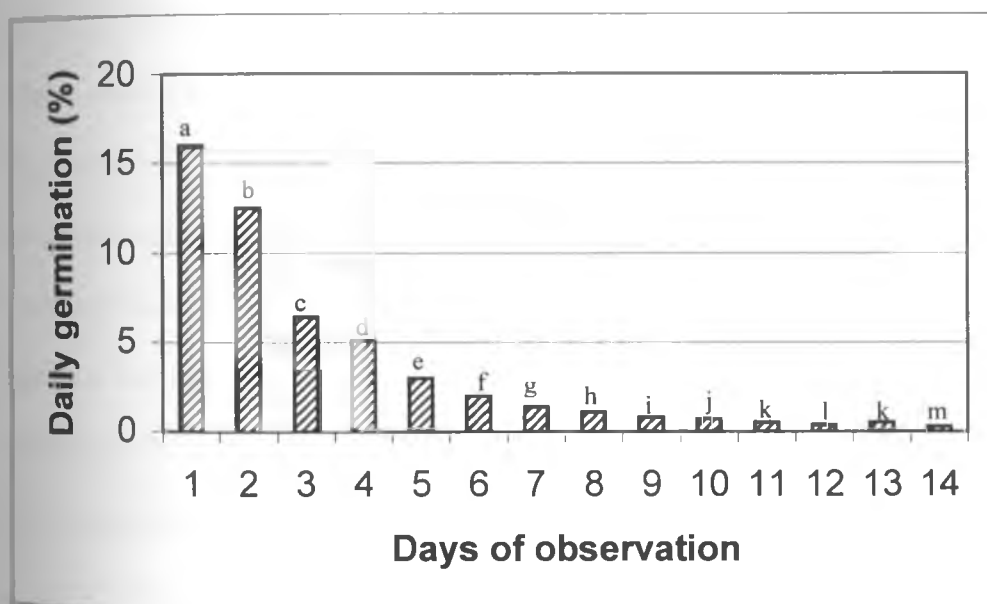


Figure 5.3. Overall mean daily seed germination (%) for the entire study comprising 2 seasonal seed lots of 4 grass species harvested using two methods, stored in 4 container types for ten periods (0-72 weeks) at KARI Kiboko during 2001-02. Bars with different lettering are significantly ($p < 0.05$) different.

This suggests that generally the seeds had low dormancy and that conditions in the laboratory were favourable to their germination. At 3.60 percent daily germination total germination after 14 days would be 50.54%. While this appears to be low, it has been observed that freshly harvested seeds of most grasses show low germination percentage, often less than 10% while dormancy is released after 6-12 months of storage (Veneendaal, 1991; HSU, 1994; Chin and Hanson, 1999; HSTA, 2001).

Usually naked caryopses have a lower dormancy than whole seeds because the removed integument does impart some of the dormancy and as such probably the mean performance of these grasses is higher than it would have been with whole seeds. For example, Veenendaal (1991) reported that naked caryopses of *E. superba* had 18% greater germination than whole seeds. However, this varies from species to species and in some cases dormancy is chemically built into the embryo (Esau, 1960; Koning, 2004). The concentration of these chemicals in the seeds get reduced with time and in some cases seeds would require a longer period to imbibe water before germination could occur since most of the chemicals are water-soluble (HSTA, 2001). Temperature and light have also been known to accelerate germination of some species (HSTA, 2001). It should be interesting, therefore, to examine how some of these factors affected the percent germination of the four grasses.

Grass seeds are reported to depict a variable induction time of germination but this is not known to be a fixed character in any given species (Elberse and Breman, 1989). This is the time required by a seed to adjust to the new environment that has triggers for germination and thus allow the germination process to begin. Induction time

has been observed to change among accessions of the same species and with continued ripening of the seed (Elberse and Breman, 1989; Veenendaal, 1991; Keya, 1997).

5.3.4. Effect of Petri dish placement on seed germination

The effect of petri dish location was done to test the hypothesis that location and placement of individual petri dishes may be a factor influencing seed germination due to possible differences in laboratory room conditions. Such differences may arise from varying degrees of exposure to sun light in the morning and afternoon, air circulation which is influenced by the position of vents, windows and doors, proximity to walls, etc. The test results showed that percent seed germination ranged from 3.55 ± 0.144 to 3.67 ± 0.115 and was not significantly different ($p > 0.05$). This implies that the distribution and placement of the petri dishes was uniform and / or that the room conditions in the laboratory were essentially the same at each trial as is required in seed testing (HSU, 1994; ISTA, 1999).

5.3.5. Effect of harvesting method on seed viability

Methods used in harvesting the seeds had a significant ($p < 0.05$) effect on the subsequent total germination. The trend of daily rate of seed germination was similar but significantly different for the first two days (Fig.5.4). The overall mean percent germinations were 3.51 ± 0.077 and 3.67 ± 0.084 for the stripping and cutting with stalks methods, respectively. However, while the statistical difference is significant the variation is so small that it may not show much difference in practice. Generally it does not matter whether the dry seeds are stripped from the panicles or mature ones are cut with the stalks, unless other advantages are to be derived from the method of cutting with the stalks (HSU, 1994).

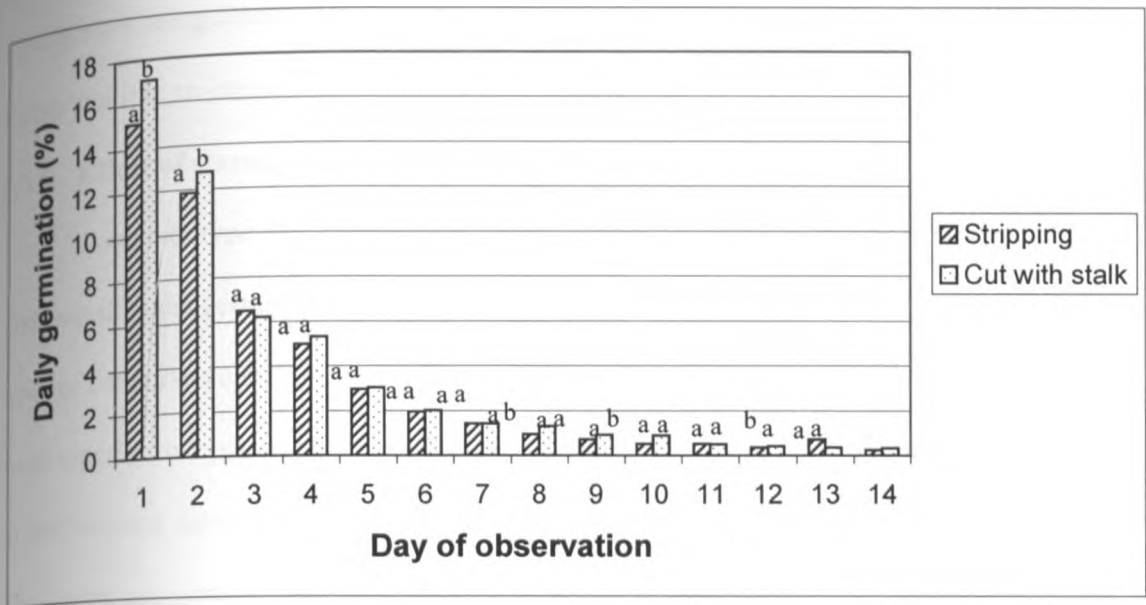


Figure 5.4. Overall mean daily seed germination (%) as affected by method of harvesting four rangeland grasses (regardless of season of harvesting, container and duration of storage) at KARI Kiboko during 2001-02. Bars in a cluster with different letters are significantly ($p < 0.05$) different.

The stripping method is not only faster but also less laborious (personal experience of the author at Kiboko). This may make the communities take it up much more easily. However, there may be merits in harvesting by cutting with stalks especially when evaluating these methods at species level for gene banks and where quality puts premium on the price of seeds (Loch and de Souza, 1999).

In addition, most soils in dry environments tend to lose moisture rapidly especially at the onset of the rains. Therefore, seeds that are quick to germinate may take advantage of the available soil moisture to develop a root system early before the moisture limits its growth. Such seedlings are likely to establish better than those from seeds with delayed germination. Keya (1998) observed such phenomenon with

Leptothrium senegalense and *C. roxburghiana* in the arid environments of northern Kenya and it is an important adaptation mechanism.

5.3.6. Effect of storage container type on seed viability

Container type had a significant ($p < 0.05$) effect on the overall seed germination.

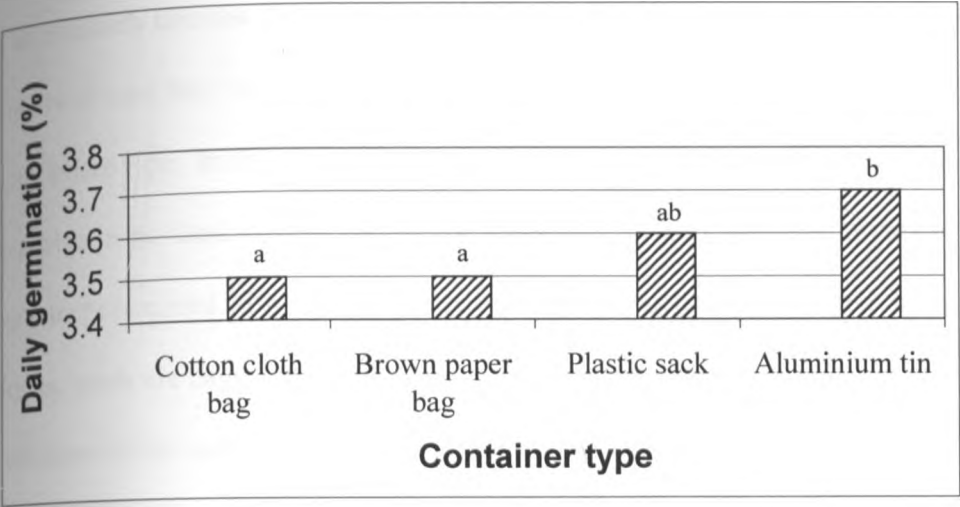
The overall mean germination percentages and daily rates of germination for the four types of containers are illustrated in Figure 5.5a and b. Seeds stored in aluminum tins were superior to those in other types of containers, with a more rapid rate of germination in the first four days. They were, however; almost similar to those stored in plastic sacks. The lowest germination was by seeds stored in brown paper bags.

The four types of containers differed mainly in the kind of materials used to make them. Ideal storage containers should be waterproof, which in this case was the aluminum tins and plastic sacks although both were not closed to be air-tight. Further, plastic is not 100% moisture proof and as discussed earlier it is the gauge that determines its porosity (Arvier, 1983).

Therefore, the seeds may have absorbed some moisture in the air that could have entered the containers and reach moisture levels above those recommended for proper storage (8-12%) thereby lowering their germination potential (HSU, 1994; ISTA, 1999). This possibility is even more apparent considering that the daily relative humidity in the store at times rose to 84% (Fig. 5.2b). Dry seeds, particularly those of grass are highly hygroscopic (HSU, 1994; Chin and Hanson, 1999) and exposure of dormant seeds to moisture has been reported to worsen seed germination (Groves *et al.*, 1982; Ernst and Tolsma, 1988) and often leads to fungal infection (HSU, 1994; Chin and Hanson, 1999).

In this study fungal growth was evident but there was no data collected to correlate infestation with particular container(s).

a) Overall mean daily germination



Bars with different letters are significantly ($p < 0.05$) different.

b) Daily germination rate

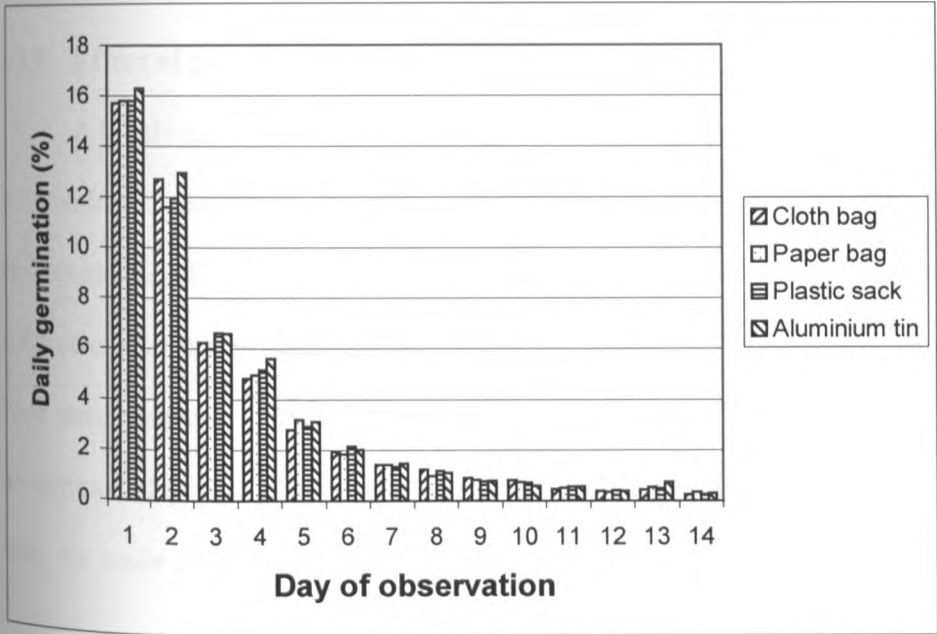


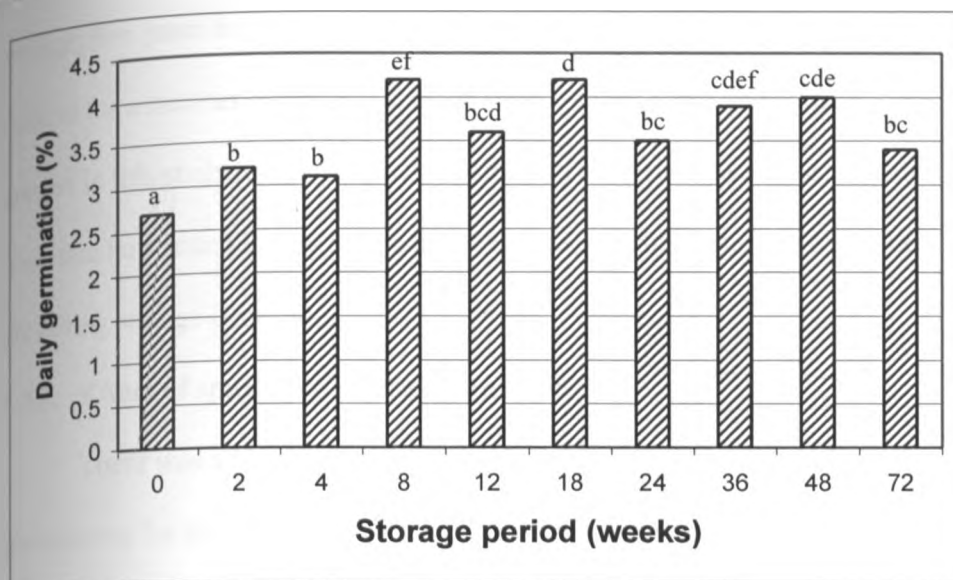
Figure 5.5. a) Overall mean daily seed germination b) rate as affected by storage container type for four rangeland grasses (regardless of season of harvesting and method of harvesting and duration of storage) at KARI Kiboko during 2001-02.

The rationale of including container type in the study was based on the fact that farmers have a tendency to use whatever receptacle that is available to store seeds in. This is mostly because they either do not know what effect a container would have on the quality of seed they store and for those who know, they may not be able to afford the appropriate type. In this case, simple aluminium tins, which are cheap and readily available in the local market, should come in handy as the more appropriate seed storage container compared with the bags tested. It has also been recommended that after proper drying, seeds are bagged in thick gauge polythene and then put in stainless steel containers (Chin and Hanson, 1999). Such containers are not readily available and are beyond the reach of resource poor rural communities. However, it is proposed that grass seeds be wrapped in thick polythene bags and then put in aluminium containers with lids that fit as tightly as possible.

5.3.7. Effect of period of storage

A highly significant difference ($p < 0.001$) was observed between daily germination of seeds stored for different periods of time (Fig. 5.6a, b). The trend was of low germination for those seeds stored for a shorter period with the highest germination at 8 weeks after which there was no clear pattern, since both a downward and an upward trend were observed. The variations in germination for seeds in storage may be related to environmental factors particularly changes in temperature and humidity. After attaining a peak, the seeds maintained this germination potential up to one and a half year.

a) Overall mean germination



Bars with different lettering are significantly ($p < 0.05$) different.

b) Daily rate of germination

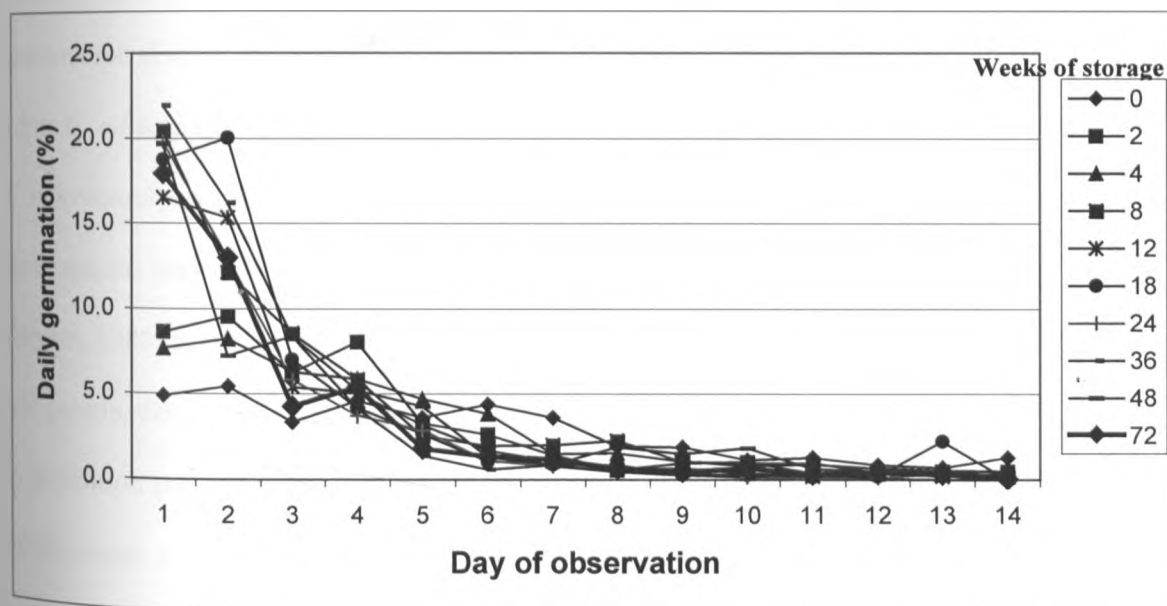


Figure 5.6.

a) Overall mean b) daily seed germination rate as affected by period of storage for four rangeland grasses (regardless of season of harvesting and method of harvesting and storage container) at KARI Kiboko during 2001-02.

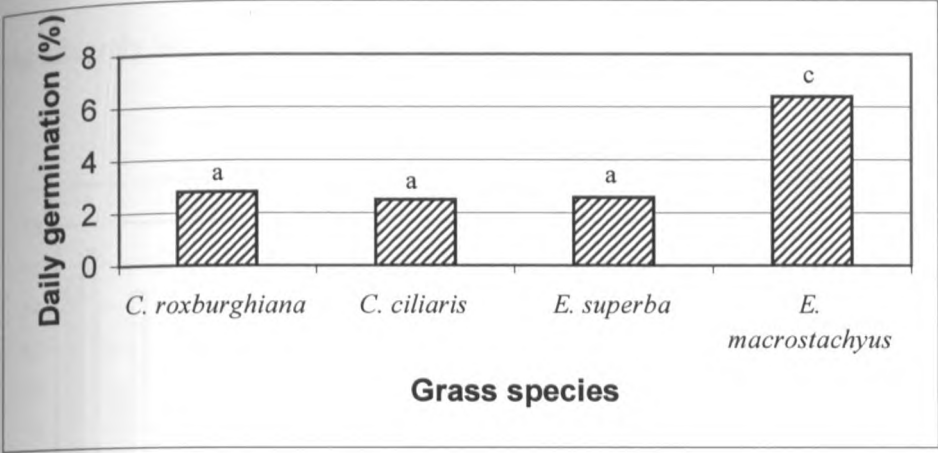
Grass seeds can maintain high viability and germination for a long time while in storage; five years have been possible with low temperature (20°C) and low moisture content for a number of tropical species (HSU, 1994; Chin and Hanson, 1999). The four grasses in this study are therefore in conformity with previous observations although it is uncertain how much longer they will retain this germination potential under the prevailing storage conditions.

5.3.8. Effect of species on seed germination

There was a highly significant ($p < 0.0001$) difference between mean daily seed germination for the four grass species (Fig. 5.7a). Whereas *E. macrostachyus* begun with a peak on day one followed by a rapid decline, the other three species started very low, peaked quickly and had a slower rate of decline in daily seed germination. Similarly, there was significant ($p < 0.001$) differences between the four grass species in their overall germination (Fig. 5.7b). Seeds of *E. macrostachyus* had the highest percent germination while *C. ciliaris* and *E. superba* had the lowest but similar germination. It is likely that *E. macrostachyus*'s dormancy mechanism involves only the integument while the other three species may have both the embryo and /or the integument related dormancy (Bryant, 1985; Simpson, 1990; Keya, 1998). This would explain the rapid imbibitions and germination by the former species relative to the other three grass species. The delay in imbibition is advantageous in that in areas where rainfall patterns are such that the initial storms are followed by a long dry period, there would, hence, be fewer seedlings to be affected by the drought. However, species with delayed germination much later in the season would be at a disadvantage since the rains would end while the seedlings are still

too young. In which case, faster germination is desirable since it will give the seedlings a head start in normal plant competition (Kadman and Shmida, 1990).

a) Overall species germination



Bars with different lettering are significantly ($p<0.05$) different.

b) Daily rates of germination

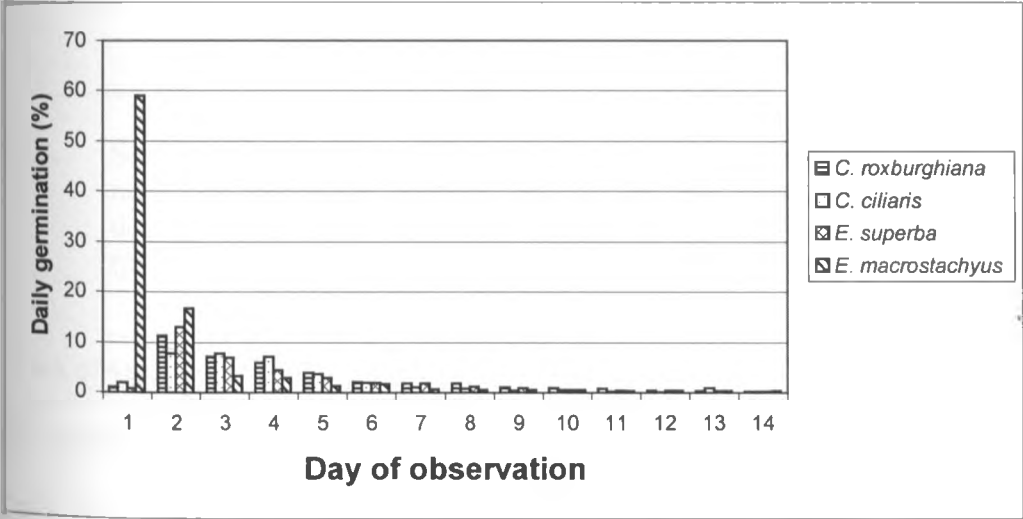


Figure 5.7 a) Overall mean seed germination by species and b) their daily rate regardless of season and method of harvesting, container and storage period at KARI Kiboko during 2001-02.

5.3.9. Effect of seed lot on seed germination

Mean daily seed germination did not vary significantly ($p>0.05$) between seed lots.

Lot 1, harvested from the year 2000 short rainy season had a mean of 3.46 ± 0.073 while lot 2 from the 2001 long rainy season had a mean of 3.73 ± 0.88 . The rate of germination was significantly higher for lot 2, especially in the first 3 days (Fig.5.8).

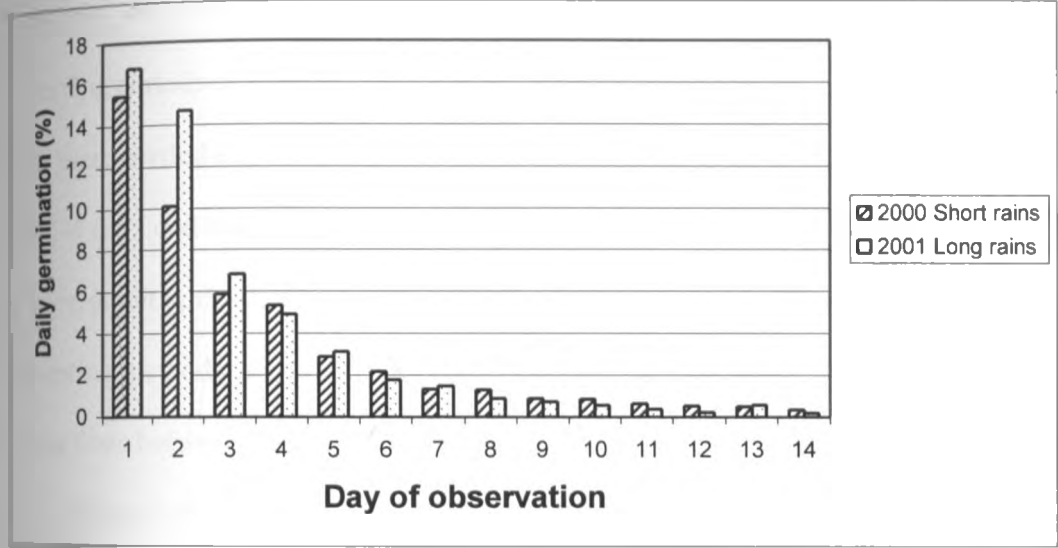


Figure 5.8. Seed lot effect on mean daily rate of seed germination (regardless of method of harvesting, container and storage period) at KARI Kiboko during 2001-02. Bars in a cluster with different lettering are significantly ($p<0.05$) different.

Lack of variation between the seed lots could be explained by the timing of seed harvests relative to the seasons. Between the short and the long rainy seasons there are only 2-3 months which perhaps were not sufficient to impart a major stress on the vegetation and generally affect seed quality as has been reported elsewhere (Veenendaal, 1991; Hacker, 1999; Lock *et al.*, 1999). However, this may not be the case with individual grass species since the ability to withstand moisture stress and weather

conditions varies among plants species (Esau, 1953; Briske, 1991). Veenendaal (1991) reported significant variation in seed germination between seed accessions from different seasons in Botswana in an area that has unimodal rains compared to southern Kenya with bimodal rainfall.

5.3.10. Inter-relationships between factors influencing seed germination

The main objective of this study was to not only assess grass seed germination potential when seeds are harvested and stored in different ways but also when subjected to varying periods of storage. Four species were involved and ten 14-day germination trials were carried out. The overall pattern was for most seeds to germinate within the first 1-4 days and only a few germinating afterwards. This general trend applied to all species, albeit with variations. The overall mean germination differed between species, harvesting methods, and storage containers storage periods, hence the need to look at interactions between and among these factors.

Method of harvesting was a factor among species since seeds of *E. superba* harvested by cutting with the stalks had significantly ($p < 0.01$) higher germination than those harvested by stripping (Fig. 5.9). The interactive effect of harvesting method and grass species was significant ($p < 0.05$) even at the fourth level of interaction with container type and storage period. So, while it is not advantageous to harvest all four grasses by stripping, better quality seed of *E. superba* are obtained with this method.

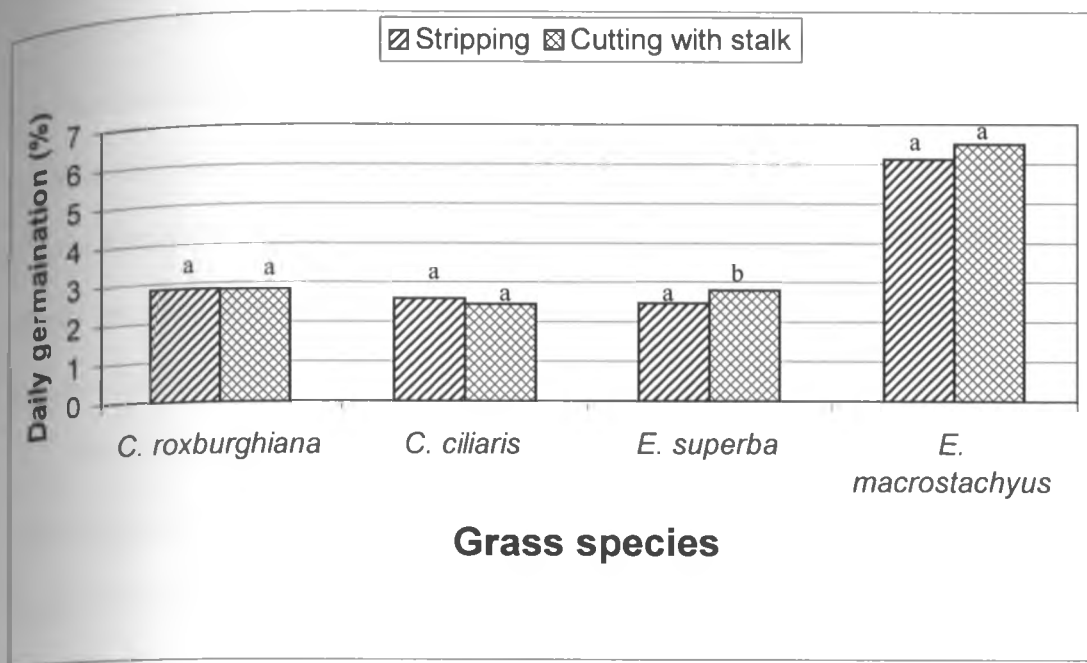


Figure 5.9. Harvesting method and species effect on mean daily seed germination (regardless of season, container and period of storage) at KARI Kiboko during 2001-02. Bars in a cluster with different lettering are significantly ($p < 0.05$) different.

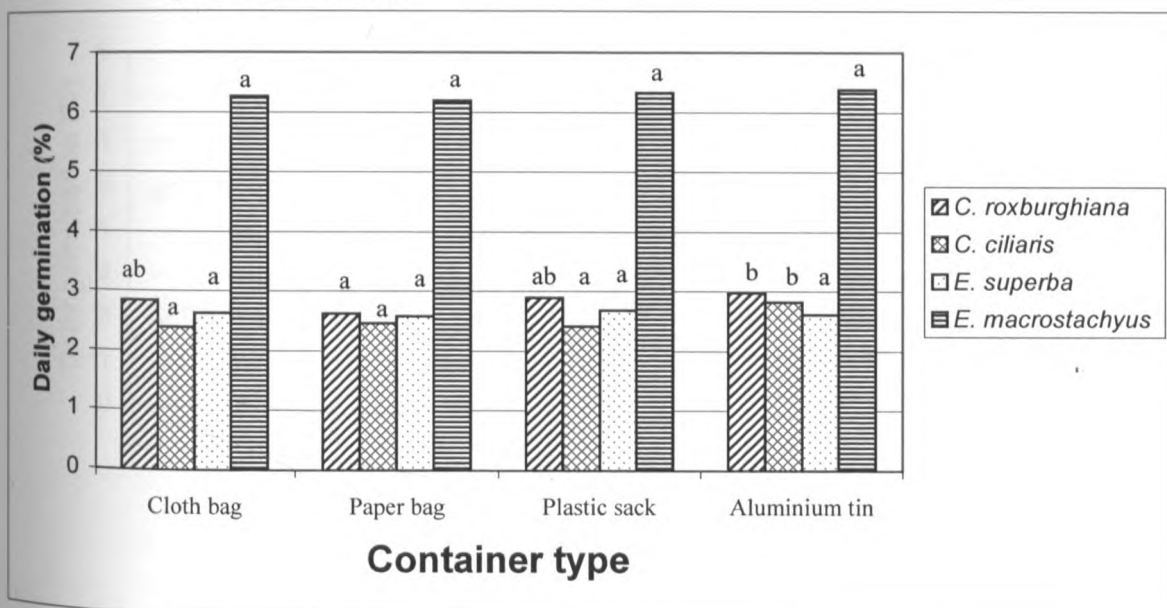


Figure 5.10. Container type and species effect on mean daily seed germination regardless of harvesting method, season and period of storage at KARI Kiboko during 2002-02. Similar bars between clusters with different letters are significantly ($p < 0.05$) different.

Interaction between container type and species was significant ($p < 0.05$). Seeds of *C. roxburghiana* and *C. ciliaris* had a higher germination percentage when stored in aluminium tins than in both paper and cloth bags. The other two species were unaffected by container type (Fig.5.10). The two affected species have relatively smaller seed sizes and thus are affected more by the high temperature and high relative humidity existing in the store (Chin and Hanson, 1999).

There was a significant ($p < 0.001$) species by storage period interaction effect, implying that different species attained peak germination after different periods of storage. Both *C. roxburghiana* and *E. macrostachyus* peaked after 8 weeks, *C. ciliaris* after 18 weeks and *E. superba* after 36 weeks (Fig. 5.11).

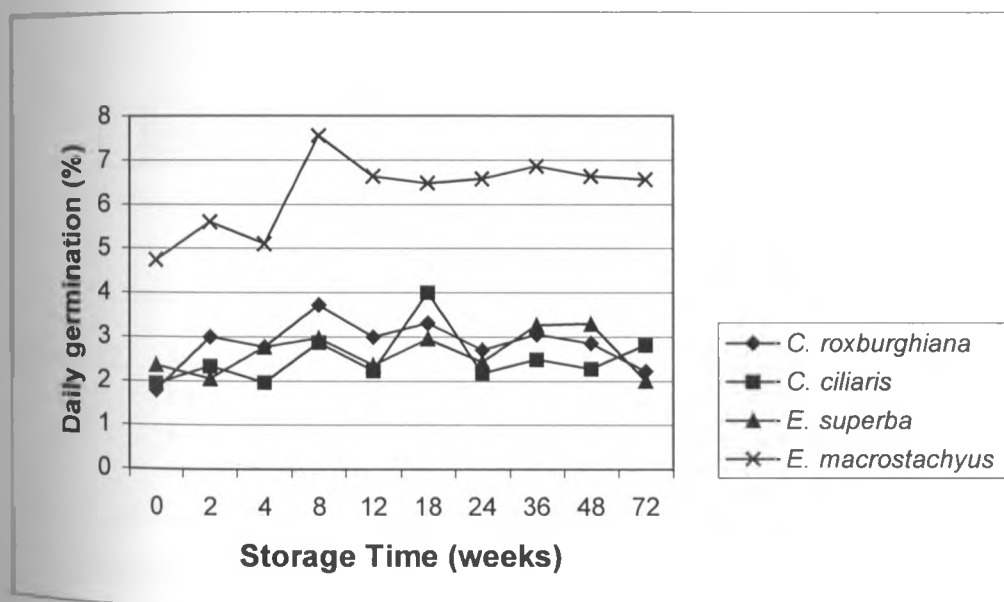


Figure 5.11. Period of storage and species effect on mean daily seed germination regardless of season, harvesting method and container type storage at KARI Kiboko during 2001-02.

These results explain the multiple peaks observed earlier (Fig. 5.6). The results also agree with earlier reports that seeds require an after-ripening period before they attain optimal germination potential due to dormancy which varies with species (Bogdan, 1977; Harty *et al.*, 1983; Burtler; 1985; Boonman, 1993; HSU, 1994; Chin and Hanson, 1999).

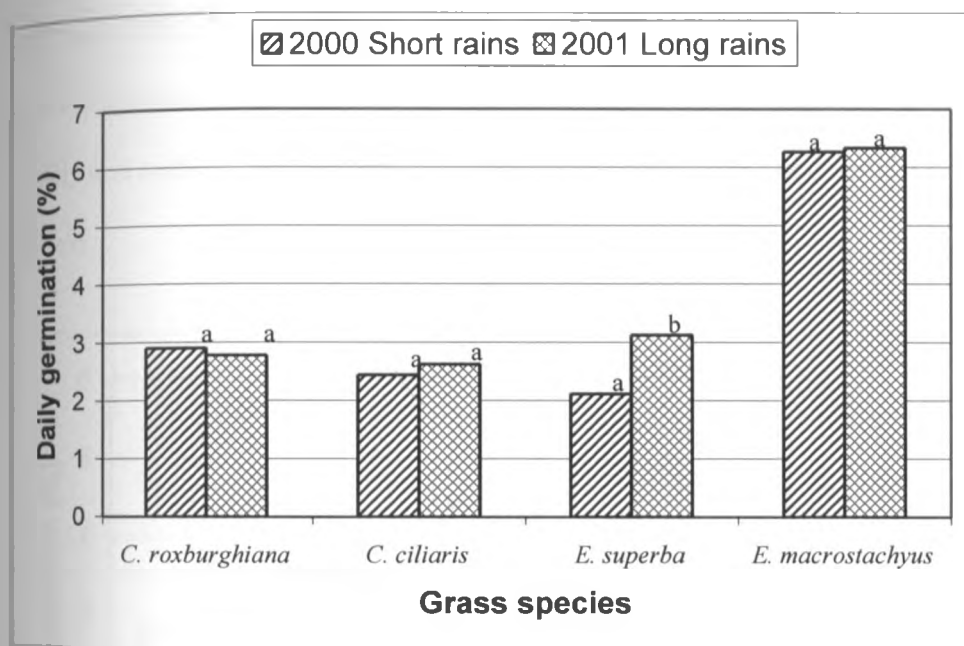


Figure 5.12. Seed lot and species effect on mean daily seed germination (regardless harvesting method, and container type and period of storage) at KARI Kiboko during 2001-02. Bars in a cluster with different lettering are significantly ($p < 0.05$) different.

Further, in some of the situations cited above, higher temperature tended to hasten the break down of seed dormancy. For instance, *P. maximum*, which is found in similar environments as some of the grasses in this study, has dormancy that disappears within 7-13 weeks with the shorter periods attained at 22°C than at 10°C (Simpson, 1990; Chin and Hanson, 1999). The storage temperature was on average above 28°C throughout this

study and as such possibility exists of extending the shelf lives of the seeds through lowering the temperature farther down.

Species by seed lot interaction had a significant ($p < 0.001$) effect on daily germination. The second lot of *E. superba* had a faster germination rate than the lot one but the other three grasses were unaffected by season of harvest (Fig. 5.12). Additionally, a significant seed lot by storage period interaction effect was observed (Fig. 5.13 and Appendix Table 5.2). Growth and development requirements of plants are different for different species and vary depending on a season, thus soil moisture interaction with fertility and ambient temperature may favour one species one season and a different one the next.

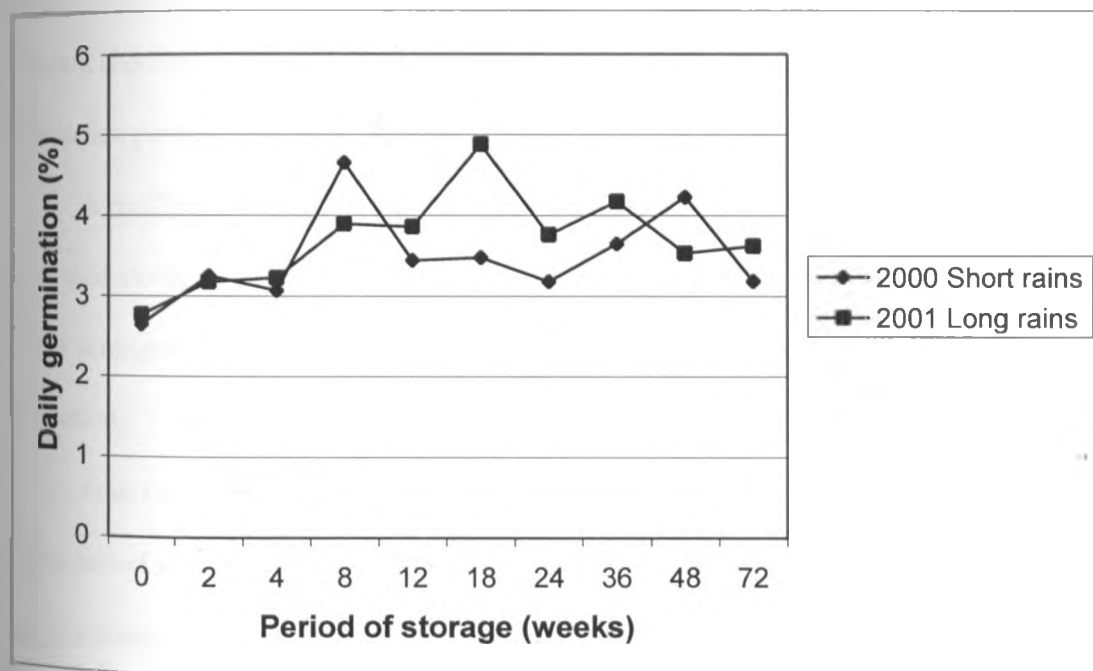


Figure 5.13. Storage period and seed lot effect on mean daily seed germination (regardless season, species, method of harvesting and container type) at KARI Kiboko during 2001-02.

Mnene (1997) reported preliminary results on work at Bachuma that showed variations between grass species in terms of on-set of growth, flowering and eventual die-back. Seven grasses growing in a natural association were studied including all but one (*C. ciliaris*) in this study. The results showed that grass species display a relay and sometime partial overlap in the onset and end of various pheno-phases, including flowering and seed shedding. Therefore, the differential effect on plant phenology by season among species apparently begins at infancy.

5.3.11. Conclusion

The specific objective of this study was to test selected techniques of pasture seed harvesting and storage suitable for on-farm use. Harvesting grass seed by stripping and cutting with stalks was done and the two methods were found to yield significantly different seedling numbers in terms of germination. Stripping was superior to cutting with stalks, particularly for *E. superba*.

A traditional store normally used for grain storage served well the purpose of grass seed storage, keeping them in good germination condition for 72 weeks. However, proper arrangement of bags and avoiding over-stuffing is necessary to allow adequate ventilation.

Four types of containers were evaluated for their suitability to keep grass seed for a long period without spoilage and subsequent loss of viability. The metal containers, and to a lesser extent polythene one, were better than ordinary brown paper and cloth bags, but differences were not great. In particular, two grasses, *C. roxburghiana* and *C. ciliaris* tended to be more sensitive to the type of container used for storage and their

seeds had better germination when kept in aluminium containers. These containers may also protect against rodent use of seeds.

All four grasses showed an inborn dormancy characteristic, losing it gradually while under storage. Peak germination was attained after a period of storage which varied with species, ranging from 8 weeks for both *C. roxburghiana* and *E. macrostachyus* to 36 weeks for *E. superba*. Generally, therefore, the hypothesis that method of harvesting range forage grass seeds and duration of storage improves their viability was proven valid.

Further research is necessary to address a number of issues:

- i. Temperature treatment. More work should be done with respect to making the stores cooler and less humid,
- ii. Chemical treatment to break dormancy at planting time,
- iii. Application of fungicides in the storage of range forage seeds,
- iv. More trials are necessary to identify containers that would keep the seeds even better, and
- v. Simultaneous germination tests with naked and whole seeds.

Lastly, even though the use of petri dishes and filter paper is a convenient and accepted standard way of evaluating seeds, relative species superiority in terms of seed germination may change when evaluated under field conditions. In the field great variations prevail mostly due to soil types and soils moisture availability. This is the subject of the study reported in the next chapter.

CHAPTER SIX

EFFECTS OF SOIL TYPE AND WATERING FREQUENCY ON THE ESTABLISHMENT OF FOUR RANGELAND GRASSES

6.0.

6.1. INTRODUCTION

Soils are the body of matter consisting of solids, liquid and gases at the land surface which may or may not contain horizons or layers, penetrating typically to 200 cm below the surface (FAO, 1998; USDA, 1999). Rangelands are endowed with a wide variety of soil types as described in the notes on the major soils of the world (FAO, 2001). Soils are broadly grouped into organic and mineral soils. Organic soils (HISTOSOLS) are formed from organic materials and include those developed in peat and swamps. Therefore, HISTOSOLS occur predominantly in lowlands. A greater variation occurs among mineral soils depending on parent materials (volcanic, sand or clay), topography (lowlands, uplands or glacia) and climate (humid or sub-humid tropics, and or semi-arid tropics etc.).

In southern Kenya, landscapes range from hill slopes through the plains and bottom lands that influence distribution of soil types. The soils at Kiboko, the study site, were described and mapped by the Kenya Soil Survey in the early 1970s and some of the dominant soils were found to be FERRALSOL and GLEYSOL (Michieka and van der Pouw, 1977). The former is mainly on the plains and the latter in the lowlands.

GLEYSOLS have a typical gleyic colour pattern made up of reddish, brownish or yellowish soils and include such soils like, for example ENTISOLS, INCEPTISOLS and MOLLISOLS. FERRALSOLS have diffuse horizon boundaries; a clay assemblage dominated by low activity clays (mainly kaolinite) and a high content of sesquioxides

which are oxides containing three atoms of oxygen with two atoms (or radicals) of some other substance e.g. iron, aluminium, etc (FAO, 2001). Local names usually refer to the color of the soil, the connotation being red and yellow due to iron (Latin *ferrum*) and alum (Latin *aluminium*). Internationally, FERRALSOLS are also known as 'OXISOLS' (USA) among others.

Variation in soils interacts with rainfall to determine soil moisture and subsequently the type of vegetation to be found in a particular area. Generally, sandy soils tend to allow fast water infiltration and percolation. They also lose water rapidly through evaporation. Clay soils behave nearly the opposite, and as a result, small rain showers may boost clay moisture content sufficiently to trigger and sustain plant growth while heavy rain storms may lead to water logging (Nill, 1996). These characteristics are part of what distinguishes soil types, and for a plant to grow in any one kind of soil it would need the ability to adapt to the inherent characteristics. Otherwise a particular plant species seed may be viable but, without the right growing conditions, fail to produce a healthy and vigorous crop (Loch *et al.*, 1999). These conditions are mainly the substrate (in this case soil), moisture (here determined by rainfall), day length, air and temperature (Esau, 1953; Hacker, 1999).

In the previous discussions (Chapter Four), it became apparent that commercial range forage seed is largely unavailable in the country and one of the options to alleviate this problem is community based seed multiplication. Although there is little a farmer can do except to provide these optimal plant growth conditions, more information is needed as to what is suitable under different circumstances that may aid the farmer in making the right management choices. This is particularly the case considering that

different districts in Kenya are endowed with different soils (Sombriek *et al.*, 1980) and in deed, often farmers within the same location have different soils in their ranches or farms. It is not uncommon to find more than one soil type within a farm of one ha (personal experience during the survey – Chapter Four). The soil of an area is a reflection of climate, parent material, topography, time and living organisms (Brady, 1974; Nill, 1996; FAO, 2001).

In addition, in typical Kenya rangelands, rainfall varies in spatial distribution and amount (Pratt and Gwynne, 1977; Herlocker, 1999) and as long-term data demonstrates (Chapter Three). Such variation in soils and rainfall presents all kinds of possible scenarios particularly when the two interact on the farm to influence the nature and distribution of vegetation (Walker, 1993; Herlocker, 1999). For instance, one species thrives under water logging whereas another perishes because it is more adapted to well-drained soils. So, what forage species should be recommended to a farmer for reseeding purposes must be based on the possible outcomes that the interactions of the above environmental conditions may produce. Therefore, this study was conducted to investigate the interactive effect of type of soil and moisture on seed emergence and seedling development for different plant species.

6.1.1. Hypothesis

Soil types and soils moisture contents are important factors influencing grass seed germination and subsequent plant development.

6.1.2. Objective

To describe and compare growth characteristics of four forage species in relation to soil type and moisture availability.

Results from the study will assist in making recommendations targeting specific soil types and appropriate forage species in the endeavour to improve natural pastures in semi-arid areas.

6.2. MATERIALS AND METHODS

6.2.1. Soil type selection and preparation

Polythene tubing (30 cm diameter, 1000-G) material was cut into lengths of 50 cm each and one end sealed to form 50 x 30 cm (4.71 litre) potting packets. The packets were perforated to allow drainage at the bottom.

Three major soil types at Kiboko as classified and mapped by Michieka and van der Pouw (1977) were selected for this study, henceforth to be referred also as soil type 1, 2 and 3 or simply ST1, ST2 and ST3. The soils were orthic (brown) FERRASOL, rhodic (red) FERRASOL and histic GLEYSOL. Histic soil units are those consisting of 75% or more, by volume, sphagnum fibres or have a bulk density when moist of less than 0.1 (Fitzpatrick, 1983). The three soils formed a major part of the soils found in the study area (Michieka and van der Pouw, 1977; Sombriek *et al.*, 1980). The top 0-15 cm soil was collected from the field and cleaned of large sized debris, stones, roots and litter so as not to damage the pots during soil compaction. A total of 240 packets were filled with the soil up to 40-cm height (3.77 litre, thus allowing sufficient room for watering) with moderate compacting using a pointed stick. Sub-samples of the soil were analyzed for pH and nutrient content at KARI's National Agricultural Research Laboratories (NARL) and results are shown in Table 6.1.

Twelve shallow pits measuring 240 cm long, 60 cm wide and 15-cm deep cm were dug in the ground in which the pots were placed in lots of 16 according to the

experimental design below. The pits were inlaid with dump proof sheets. The purpose of the pits was to provide support to the pots while the dump proof sheets were to minimize entry of ground soil moisture into the pots.

Table 6.1. Comparative fertility analysis (mean $\pm$ SE) of three soils types used in potting for germination of four grasses at KARI Kiboko in 2001.

Soil property / element	Soil type		
	Orthic FERRALSOL	Rhodic FERRALSOL	Histic GLEYSOL
pH	6.25 $\pm$ 0.050	6.5	7.5
Nitrogen (%)	0.12 $\pm$ 0.025	0.12 $\pm$ 0.100	0.12 $\pm$ 0.090
Organic carbon	1.74 $\pm$ 0.005	1.60 $\pm$ 0.065	2.75 $\pm$ 0.090
Phosphorous (ppm) (O)	42.00 $\pm$ 2.000	36.50 $\pm$ 1.500	15.4 $\pm$ 5.011
Potassium (me %)	1.09 $\pm$ 0.010	1.08 $\pm$ 0.020	0.75 $\pm$ 0.005
Calcium (me %)	3.60 $\pm$ 0.200	3.35 $\pm$ 0.050	20.00 $\pm$ 2.000
Magnesium (me %)	2.30 $\pm$ 0.050	2.38 $\pm$ 0.750	3.35 $\pm$ 0.050
Manganese (me %)	0.28 $\pm$ 0.025	0.39 $\pm$ 0.010	Trace
Copper (ppm)	1.74 $\pm$ 0.010	1.30 $\pm$ 0.035	0.44 $\pm$ 0.185
Iron (ppm)	27.67 $\pm$ 3.675	19.71 $\pm$ 1.350	2.62 $\pm$ 0.185
Zinc (ppm)	1.90 $\pm$ 0.015	3.31 $\pm$ 0.490	0.23 $\pm$ 0.055
Sodium (me %)	0.44 $\pm$ 0.060	0.42	0.63 $\pm$ 0.010

Generally, the two FERRALSOLS were more acidic and richer in most nutrients, particularly iron while GLEYSOL was richer in organic carbon, calcium and magnesium but had no manganese. There was, however, more zinc in rhodic FERRALSOL soil than in orthic FERRALSOL and much less in histic GLEYSOL. Topsoil organic carbon content greater than 2.5% is considered high (Sys *et al.*, 1991) and when combined with a high nitrogen content then the soil is said to be rich in organic matter, for example the

histic GLEYSOL in Table 6.1 above. Organic matter is the main source of plant nutrients and microbial energy beneficial to plant growth (Allison, 1973; Sanchez, 1976; Esilaba *et al.*, 2002). Usually, organic matter and total nitrogen in the soil are mostly derived from living organisms and are highly correlated (Unger, 1968; Esilaba *et al.*, 2002), particularly within one soil type. Despite the significant differences in organic carbon content between the three soils, the nitrogen content was however not significantly different (Allison, 1973; Sanchez, 1976)

Phosphorous and magnesium levels also varied significantly in the experimental soils. The levels of magnesium were similar for the FERRALSOLS, which was almost 43% higher than that in the histic GLEYSOL. On the hand, the amount of phosphorous in two FERRALSOLS was different and 2-3 times higher than that in the histic GLEYSOL. An abundance of essential elements, phosphorous being one of them, stimulates root growth but shoot growth is stimulated even more resulting in a lower root/shoot ratio in fertile than infertile soils (Kramer, 1969; Fitzpatrick, 1983).

6.2.2. Seed preparation and sowing

Seeds of *C. ciliaris*, *C. roxburghiana*, *E. macrostachyus* and *E. superba* were obtained from previously harvested stock in a related study (Chapter Five). The stock was harvested from natural stands at KARI - Kiboko during January and February 2000 and was in storage for more than three months. This is the minimum time required for most grass seeds to lose natural dormancy and thus show a high germination rate (HSU, 1994). Pure germinating seed (PGS) expressed as a percentage of total (HSU, 1994) was determined at planting according to the laboratory procedures as described in Chapter Four. The respective seed rates are shown in Table 6.2. Whole seeds as dispersal units

were sown by spreading them on the surface of potted soil in the pots. Each grass species was sown in separate pots.

Table 6.2. Number of seeds of four grasses planted with a target of 100 caryopses per pot.

Weight / Number of Seeds	Species			
	<i>C. ciliaris</i>	<i>C. roxburghiana</i>	<i>E. macrostachyus</i>	<i>E. superba</i>
Seeds sample 1 Wt. (g)	0.09	0.02	0.22	0.52
Seeds sample 2 Wt. (g)	0.09	0.02	0.24	0.43
Av. Wt. (g)	0.09	0.02	0.23	0.47
No. Caryopsis 1	40	36	42	68
No. Caryopsis 2	31	39	49	46
Avg. No. Caryopses	35.50	37.5	45.50	57
Weight (g) planted	0.25	0.05	0.50	0.83
No. seeds Planted	141	133	109	88

6.2.3. Water type and irrigation frequency

Watering of the pots was done immediately after sowing using shower-rose fitted watering buckets with fine holes to provide a fine spray. The buckets were filled pre-measured volumes for the respective treatments. Delivery height was maintained at 15

cm to minimize undue disturbance of the seeds and young seedlings. Watering was done between 0700 and 0900 h when it was cool in order to reduce evaporative losses.

Tap water, drawn fresh as and when required, was used to irrigate the pots. Its source was a natural spring near the study site. In the course of the experiment, water samples were submitted four times to KARI – NARL for analysis of mineral content whose results are shown in Table 6.3. Apart from the sulphates, all water components remained the same throughout the study period. According to the laboratory report the carbonate, chloride and sulphate levels were considered too high and unsuitable for horticulture purposes. However, according to standards elsewhere, irrigation water should not have an electrical conductivity (EC) that exceeds 3,000 mmhos/cm or a sodium adsorption ratio (SAR) greater than 10 (Scherer et al., 1996). In which case therefore, the tap water at Kiboko with an EC of 1,600-1,650 mmhos/cm and SAR of <0.5 was considered safe for this grass trial experiment.

Four watering regimes each lasting 70 days were applied:

1. Daily with 250 ml.,
2. Every other day with 500 ml.
3. Every third day with 750 ml.
4. Every fourth day with 1,000 ml.

Henceforth the watering regimes will also be referred to as WR1, WR2, WR3 and WR4, respectively. The watering regimes were a simulation of seasons that usually last 70 days with rainstorms that may be heavy but far apart or light but frequent (Pratt and Gwynne 1977; Musembi 1986; Herlocker 1999).

Table 6.3. Results of the quality of tap water used to irrigate potted plants in 2001 at KARI – Kiboko.

Water component	Early August	Mid August	Late August	Early September
pH	7.5 ± 0.050	7.5 ± 0.050	7.5 ± 0.050	7.5 ± 0.050
Electrical conductivity (micro. mhos/cm)	$1,600 \pm 0$	$1,600 \pm 0$	$1,650 \pm 0$	$1,625 \pm 25.000$
Sodium (me/litre)	0.39 ± 0	0.39 ± 0.010	0.38 ± 0.010	0.39 ± 0
Potassium (me/litre)	0.74 ± 0	0.74 ± 0.005	0.74 ± 0.005	0.76 ± 0.005
Calcium (me/litre)	0.48 ± 0.015	0.50 ± 0.015	0.45 ± 0.015	0.52 ± 0
Magnesium (me/litre)	3.95 ± 0.105	4.15 ± 0.130	3.69 ± 0.125	3.79 ± 0.005
Carbonates (me/litre)	0.50 ± 0.025	0.47 ± 0.015	0.51 ± 0.065	0.54 ± 0.005
Bicarbonates (me/litre)	5.86 ± 0.240	5.66 ± 0.045	5.42 ± 0.005	5.22 ± 0.011
Chlorides (me/litre)	11.15 ± 0.450	12.55 ± 0.150	11.55 ± 0.050	11.80 ± 0.100
Sulphates (me/litre)	74.95 ± 0.550	76.25 ± 2.050	82.05 ± 0.150	79.40 ± 2.800
Sodium adsorption ratio	0.27 ± 0.005	0.26 ± 0.005	0.27 ± 0.015	0.27 ± 0

In a similar experiment, Keya (1998) had simulated rainstorms with three regimes of varying combinations of light, moderate and heavy and observed that germination was

difficult to achieve with any of them. In that study, it appeared as if there were other stronger factors triggering germination and so, the focus in this study was to vary soil moisture *per se* by using the different amounts and frequency of watering

To convert the amount of water (l) to mm of rainfall equivalent, the following calculation was done:

$$(706.5/10,000) \times 1 = 14.15 \text{ mm},$$

Where the numerator is the cross-sectional area of each pot in cm^2 , the denominator is the cm^2 equivalent to 1 m^2 and the multiplier is a mm of rainfall.

This calculation was based on the understanding that applying a litre of water per m^2 corresponds to 1 mm of rain (Keya, 1997). It therefore, implies that applying the same 1 litre of water to the pot amounted to 14.15 mm. If this amount is applied 18 times over 70 days, the total is 254.7 mm. This amount is equivalent to an average seasonal rainfall at Kiboko (Musembi, 1986). The other regimes were then convenient choices for lower amounts but with higher frequency such that by day 70, the same total amount of water had been applied.

For each watering regime, four gypsum blocks (Eijkelpkamp Agrisearch Equipment, Netherlands) were randomly placed in four pots per soil type, at approximately 10 cm below soil surface. The blocks were covered completely with moist soil of the same kind used in the respective treatments. This was to improve the blocks' contact with the soils as per the manufacturer's and other practitioners' recommendations (Al-Kaisi, 2000; Sneekloth *et al.*, 2002; Werner, 2002; CCRS, 2003).

6.2.4. Experimental Design

The experimental design was a split-split plot design in a factorial arrangement of treatments. The pots were laid out in 4 x 3 x 4 blocks. Each of the four species was assigned four pots at random for each of the three soil types in each of the four watering regimes. The four watering regimes formed the main plots each with 48 pots. The three soil types were the sub-plots each with 16 pots. The total number of pots was 192 with additional 48 pots, (4 per subplot) included as checks for potential soil seed bank. The seedling populations observed in the check pots provided a correction factor for those in the seeded pots.

6.2.5. Data Collection

The experiment was conducted between July 30th and October 8th 2001 at the KARI Kiboko center. Data were collected on soil moisture, seedling population and their growth parameters (phenometry - height, leaves, tillers, flowering, senescence and biomass).

6.2.5.1. *Soil moisture estimation*

Soil moisture was estimated daily between 0800 and 0900 hours throughout the experiment. A soil moisture metre (Eijkelkamp Agrisearch Equipment, Netherlands) was used. Prior calibration was done to derive readings of percent field capacity (FC) as per manufacturer's instructions.

6.2.5.2. *Seedling emergence*

All pots were monitored for seedling emergence from the soil substrate. This commenced on Day 1 post sowing and seedling counts were done every day for the initial

3 weeks of the experiment. Seedlings were considered emerged with the appearance of the first germination leaf above the soil surface. This was similar to the method used by Keya (1997) in Marsabit. Since it was difficult to differentiate seedlings by species at such an early stage, they were thus classified as either mono- or dicotyledonous. After seedling counts, dicots were uprooted leaving monocots since the main concern of the study was on monocots, and specifically the four perennial grasses.

6.2.5.3. *Seedling height measurement*

Seedling height (cm) was measured using a stainless steel 1.5-meter rule starting from Day 12 of the experiment. Data were recorded on alternate days from 4 seedlings for the first 11 days. Thereafter, weekly measurements were taken up to Day 65 for a total of 16 days of observation.

6.2.5.4. *Seedling leafiness*

Leaf counts were recorded from the same 4 plants (per pot) that were monitored for plant height. The sampling schedule followed that described for seedling height measurement above.

6.2.5.5. *Seedling population thinning*

Thinning is a common practice, whereby a reasonable number of healthy specimens of similar size in each pot are left well spaced out (Roberts *et al.*, 1993 Sweeney and Hopkinson, 1995). Therefore, on Day 21, the monocot seedlings were further identified and isolated into either one of the four experimental species or other monocot. The seedling counts were adjusted using a factor derived from the observations from the control pots. Thereafter, the seedlings were thinned down to 4 plants per grass species in their respective pots. Coyne and Bradford (1985) used a similar number of

plants while studying growth characteristics of *Bothriocloa spp* in the USA. The four remaining seedlings were further monitored to the end of the experiment, including taking count of number of leaves, tillers and inflorescence / seed heads.

6.2.5.6. *Seedling tiller production*

Tillers on grass seedlings were counted and length measured (cm). This observation commenced post thinning from Day 28 and continued intermittently to Day 65, for a total of 16 observations. Of the 16 tiller observations, eight included recording counts of leaves of the tillers and tiller length. However, for the last three observations for tiller length and leaf count, two seedlings per pot were used since most of them had formed several tillers making the whole exercise too cumbersome.

6.2.5.7. *Seedling maturation monitoring*

Observations on seedling maturity as represented by inflorescence setting, started before thinning by counting flower heads per pot daily. However, because of logistics, this was changed to every two days counting post thinning for another three weeks and weekly thereafter to Day 70.

6.2.5.8. *Plant senescence assessment*

Twice, on Days 53 and 70 of the experiment, an inventory was made for senescent / dry leaves from each plant of every pot. All those leaves with signs of yellowing or browning, in part or whole, were considered senescent (Roberts *et al.*, 1993).

6.2.5.9. *Standing crop estimation and partitioning*

Clipping for above ground biomass estimation was done at 75 days post sowing. This was 5 days after cessation of the watering treatment. All plants in half the number

of pots were clipped and the other half was left for further monitoring (Plate 6.1). Clipped materials were weighed separately while fresh and then oven dried at 100°C to derive dry matter production (g DM) per pot. Thereafter, separation was done by hand to obtain the respective weights of the leaf, stem and inflorescence components.

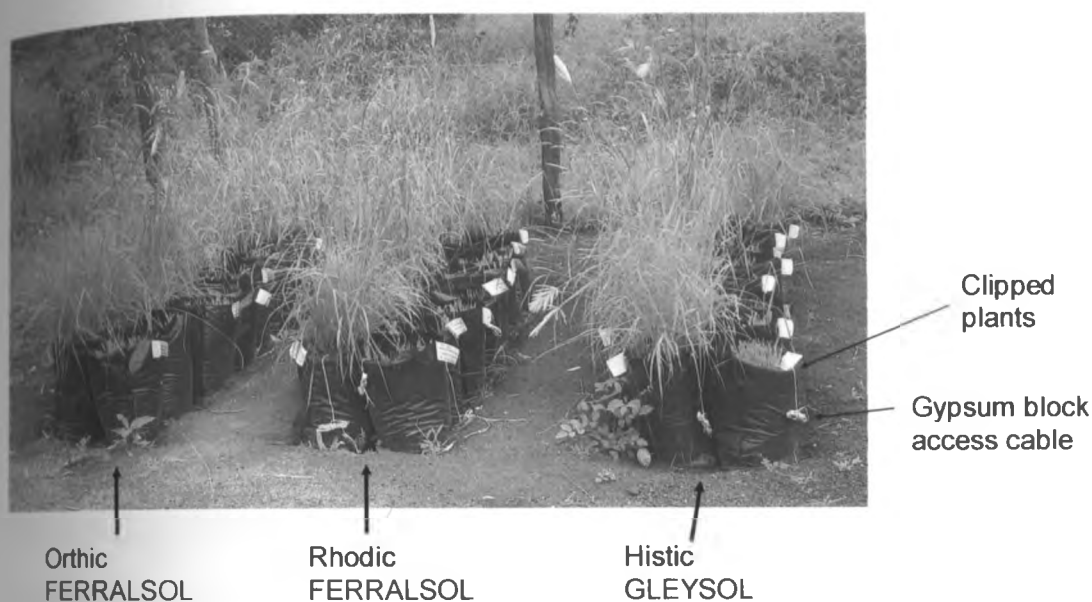


Plate 6.1 Illustration of experimental layout at six months post sowing showing three sets of 16 pots per soil types for one watering regime. Note: some of the plants in half the number of pots were clipped for biomass estimation.

6.2.6. Data analysis

Analysis involved a comparison of the measured and calculated parameters of the species by watering regime and soil type within watering regime using the GLM procedures. The Statistical Analysis Systems (SAS, 1990) software was used for the evaluation of the data. The outline below for soil moisture (SM) is an example of the models fitted for the various parameters by substituting the dependent variable accordingly:

```

PROC GLM;
CLASS DAY WATER SOIL POT;
MODEL SM=POT DAY|WATER|SOIL/SS3;
      MEANS DAY|WATER|SOIL;

```

Duncan's Multiple Range Test was used to separate significant ($p < 0.05$) means.

6.3. RESULTS AND DISCUSSION

6.3.1. Soil moisture

Daily soil moisture index over the 70 days of the experiment had a mean of $47.24 \pm 0.88\%$ with a range of 0 – 98. Soil moisture content fluctuated significantly ($p < 0.001$) from day to day. Generally, soil moisture during the initial 5 days was low followed by a high rate of increase up to Day 14, after which the rate of increase slowed down and oscillated between 60 and 70% up to Day 45. Thereafter there was a general rapid decline to Day 60 followed by a slight increase to the end of the observation period (Fig. 6.1). The trends were similar for all the three soils although orthic FERRALSOL had both a higher rate of increase and a slower rate of decrease than the other soils (Fig. 6.2). Mean soil moisture content varied significantly ($p < 0.001$) between the soil types, the highest being in orthic FERRALSOL (63.27 ± 1.136) followed by rhodic FERRALSOL (58.11 ± 1.211) and the least in the histic GLEYSOL (19.38 ± 0.633).

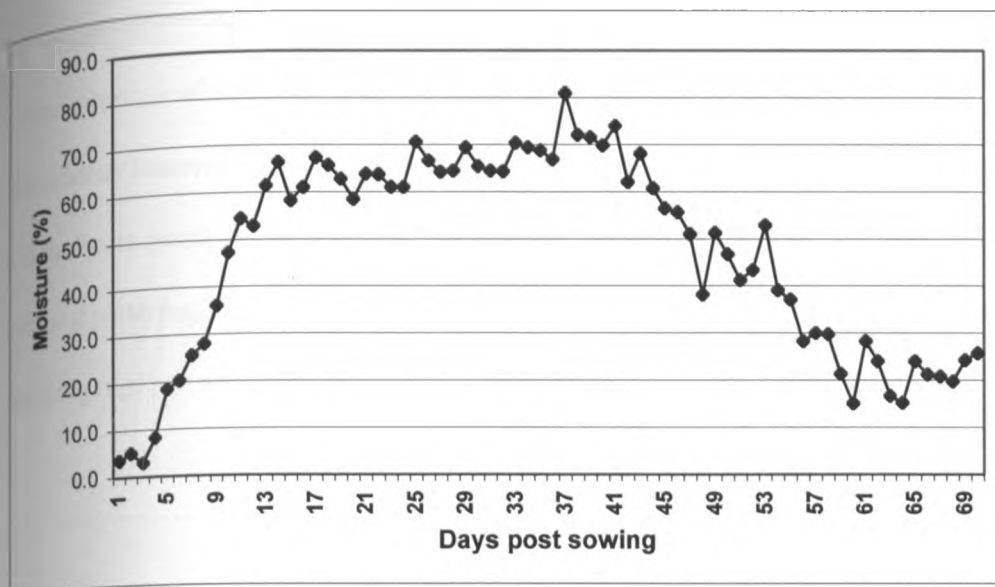


Figure 6.1. Mean daily soil moisture (%FC) for the entire study involving four grasses sown in three soil types in polythene pots and subjected to four watering regimes at KARI – Kiboko during July – October 2001.

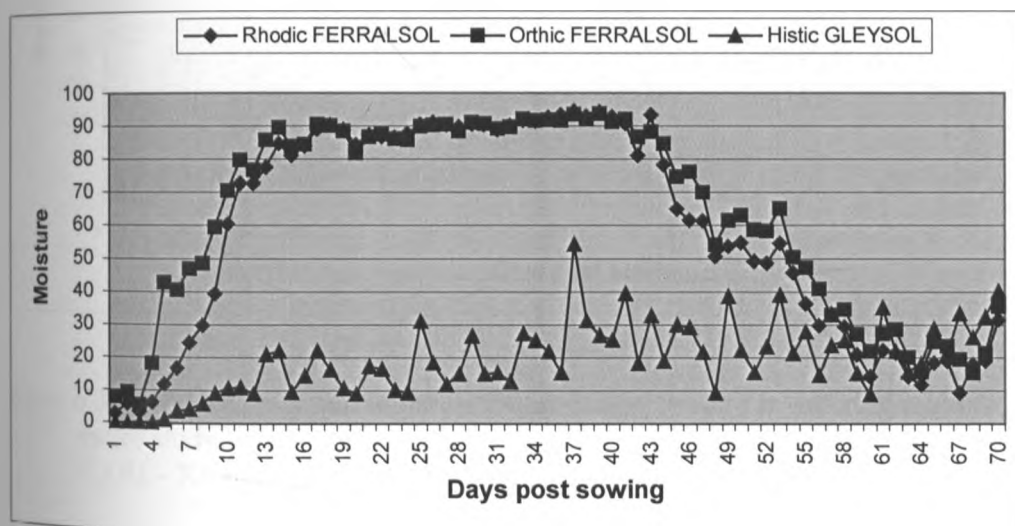


Figure 6.2. Mean daily soil moisture (%FC) in three soil types for the entire study involving four grasses sown in polythene pots and subjected to four watering regimes at KARI – Kiboko during July – October 2001.

Watering regimes had a significant ($p < 0.01$) effect on daily soil moisture content; longer intervals of watering with higher volumes resulted in higher soil moisture content than shorter intervals with low volumes (Fig. 6.3). Watering created a pulse effect on the soil moisture trend, becoming more pronounced with higher amounts of water but less frequent watering. There was however, a significant ($p < 0.01$) interaction between the watering regimes and soil types, particularly the FERRALSOLS (Fig. 6.4).

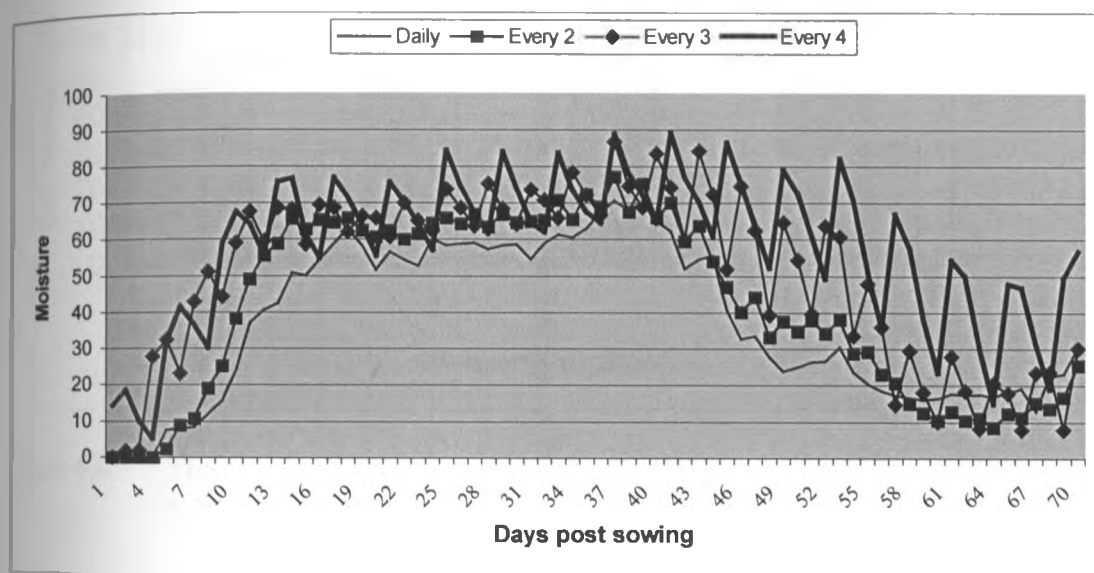


Figure 6.3. Mean daily soil moisture (%) resulting from four watering regimes for the entire study involving four grasses sown in three soil types in polythene pots at KARI – Kiboko during July – October 2001.

The mean soil moisture of 47.2% attained in this study was similar to that observed by Keya (1997) in a study in northern Kenya. In that study, a range of 17-46% was attained with different regimes of watering. The effect of soil type on moisture observed in this study is due to variation between the soils in terms of permeability and hence infiltration and also moisture holding capacity. The subsequent drop coincided

with peak of tiller production, which was also approaching the flowering stage thus placing a greater demand on soil moisture through transpiration. Thinning of the seedlings, which meant reduced cover, may also have led to greater evaporation from the exposed soil surface, gradually lowering the soil moisture.

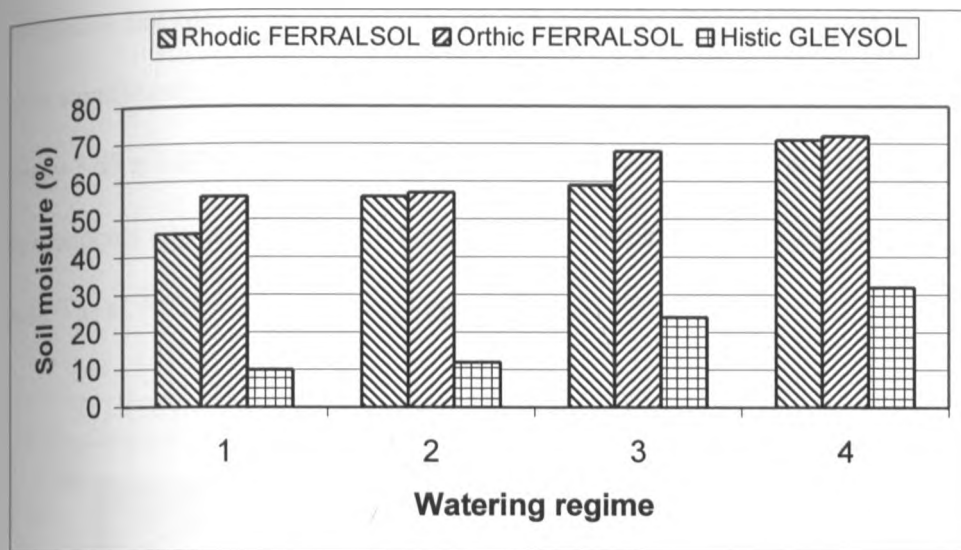


Figure 6.4. The effect on soil moisture (%) by the interaction between watering regime and soil type.

Generally, the plant's physiological processes and external factors such as temperature, humidity and air movement control transpiration (Larcher *et al.*, 1983). As plants use water for growth, soil moisture is depleted and the depletion rates vary with soil types (Larcher *et al.*, 1983; Keya, 1998; Hacker, 1999; Bauder and Carlson, 2004). The amount of moisture retained by the soil is important because different plant species start to suffer stress at different soil moisture levels. For example, alfalfa can use 65% of the available water before becoming stressed while beans and potatoes become stressed at 40% (Bauder and Carlson, 2004). This results from intrinsic variations among species in

their ability to extract water from the soil, a feature that is vital for survival in ASAL environments.

6.3.2: Seedling population

Monocotyledonous seedlings were the first to emerge on Day 6 after sowing in the orthic FERRALSOL soils watered every other day. Dicotyledonous seedlings emerged a day later in the same soil type but under the daily watering regime. There were significantly ($p < 0.001$) more monocot seedlings (mean 11.31 ± 0.295) than dicots (mean 3.68 ± 0.075). Thus a relatively higher peak of seedling population was attained by monocots two weeks after first emergence (3 weeks post sowing) whereas the dicots' peak was at 10 days after first emergence (Figure 6.5).

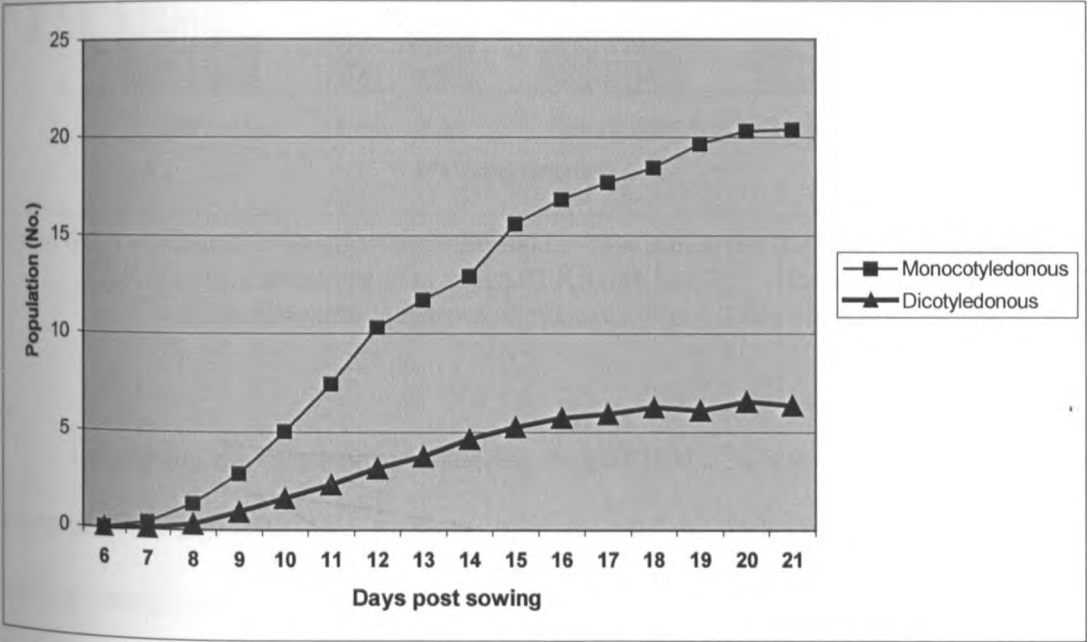


Figure 6.5. Mean daily seedling emergence in three soil types that were subjected to four watering regimes in 2001 at KARI – Kiboko.

Total monocot seedlings were approximately three times those of dicots, with a total of 46,061 seedlings counted. Monocot seedling population was significantly ($p < 0.001$) affected by both soil type and watering regime (Figure 6.6). More seedlings were recorded in the two FERRALSOL soils than histic GLEYSOL. Further, daily watering resulted in fewer seedlings than the number in the other three watering regimes regardless of soil type.

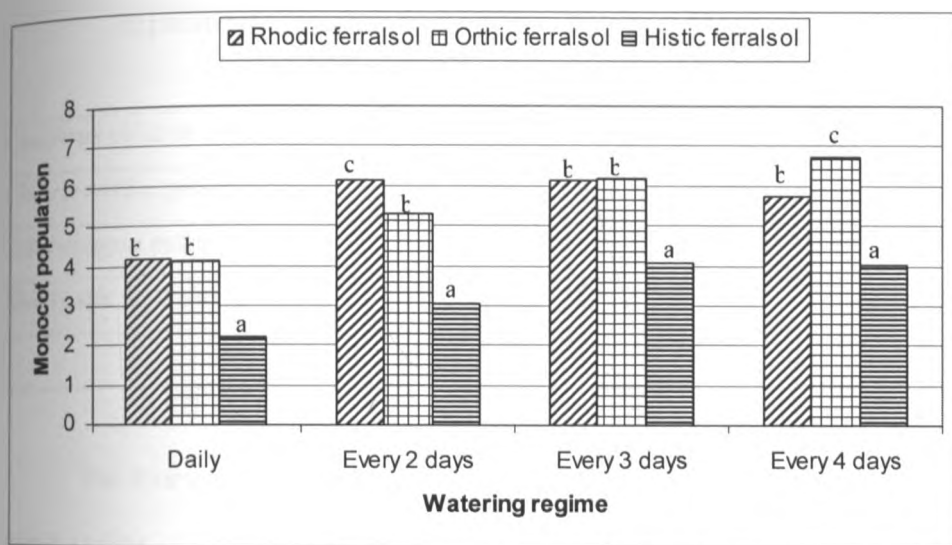


Figure 6.6. Monocot seedling populations in three soil types that were subjected to four watering regimes at KARI Kiboko in 2001. Bars within a cluster with similar letters are not significantly ($p > 0.05$) different.

Decreasing the frequency of watering the FERRALSOLS favoured monocot emergence with a peak at every three-day watering. While, with histic GLEYSOL seedling emergence was highest with daily watering. On the other hand, emergence of dicots peaked at every other day watering in the FERRALSOLS and every three-day watering in the histic GLEYSOL. Daily seedling populations had a positive correlation with daily soil moisture levels.

Mean seedling population per pot was 15.66 ± 1.263 . Seedling populations varied significantly ($p < 0.001$) between grass species. Of these, majority were *E. macrostachyus* which were approximately twice as many as *C. ciliaris*, the next most abundant and over four times those of *C. roxburghiana*, the least abundant (Table 6.4).

Table 6.4. Mean ($\pm$ SE) seedling populations of four grass species sown in three soil types put in polythene pots and subjected to four watering regimes in 2001 at KARI – Kiboko.

Experimental species	N	Mean	Std. Error of Mean
<i>Cenchrus ciliaris</i>	48	15.69	2.011
<i>Chloris roxburghiana</i>	48	7.63	1.009
<i>Enteropogon macrostachyus</i>	48	31.27	3.493
<i>Eragrostis superba</i>	48	8.06	.930
Total	192	15.66	1.263

The four grass species' seedlings were affected by soil type with orthic FERRALSOL and rhodic FERRALSOL having similar populations (20.61 ± 1.566 and 22.38 ± 2.865 , respectively), which, on average, were more than 5-fold those on histic GLEYSOLS (Table 6.5). Significantly ($p < 0.001$) more *E. macrostachyus* seedlings emerged in all soils than the other species, the highest number being in orthic FERRALSOL. Similarly, orthic FERRALSOLS had the highest number of *C. ciliaris* and *Chloris roxburghiana* seedlings. In the rhodic FERRALSOL, *E. superba* was more abundant but together with *C. roxburghiana*, they had negligible seedling emergence in the histic GLEYSOL.

Table 6.5.

Mean ($\pm$ SE) seedling populations of four grass species within three soil types (N=64) in polythene pots average across four watering regimes in 2001 at KARI Kiboko.

Species		Soil Type		
		Rhodic FERRALSOL	Orthic FERRALSOL	Histic GLEYSOL
<i>Cenchrus ciliaris</i>	Mean	21.81	22.38	2.88
	SE	± 2.470	± 3.844	± 0.841
<i>Chloris roxburghiana</i>	Mean	12.38	9.94	0.56
	SE	± 1.612	± 1.318	± 0.203
<i>Enteropogon macrostachyus</i>	Mean	36.06	46.63	11.13
	SE	± 2.351	± 7.796	± 2.020
<i>Eragrostis superba</i>	Mean	12.19	10.56	1.44
	SE	± 1.308	± 1.354	± 0.341
Total	Mean	20.61	22.38	4.00
	SE	± 1.566	± 2.865	± 0.758

Seedling populations also varied significantly ($p < 0.05$) among watering regimes. The highest seedling population, 23.94 ± 3.612 , was observed under the every third day watering and the lowest, 8.02 ± 1.243 under daily regimes for all species (Table 6.6). The second was every fourth day watering regime except *C. roxburghiana* for which every other day watering ranked second.

The interaction between soil type and watering regime had the greatest effect in orthic FERRALSOL with watering every third day for all grasses except *E. superba*, which had the highest number of seedlings in rhodic FERRALSOL with every fourth day watering. In the histic GLEYSOL, both *E. macrostachyus* and *C. ciliaris* performed relatively well but only under infrequent watering regime.

Table 6.6.

Mean ($\pm$ SE) species seedling populations of four grass species within watering regimes (N=48) averaged across three soil types in polythene pots in 2001 at KARI kiboko.

Species		Watering regime			
		Daily	Every 2 days	Every 3 days	Every 4 days
<i>Cenchrus ciliaris</i>	Mean	7.92	11.83	26.50	16.50
	SE	± 1.811	± 2.386	± 6.045	± 2.463
<i>Chloris roxburghiana</i>	Mean	3.67	8.75	11.50	6.58
	SE	± 0.772	± 2.038	± 2.569	± 1.743
<i>Interopogon macrostachyus</i>	Mean	16.75	23.42	47.42	37.50
	SE	± 3.398	± 3.573	± 9.711	± 6.158
<i>ragrostis superba</i>	Mean	3.75	7.75	10.33	10.42
	SE	± 0.827	± 1.741	± 1.990	± 2.109
Total	Mean	8.02	12.94	23.94	17.75
	SE	± 1.243	± 1.526	± 3.612	± 2.458

Weeds in crop production systems compete with the desirable plant species thereby reducing their performance, and this is critical especially if the objective is seed production (Humphreys and Riveros, 1986; HSU, 1994; Loch, 1999). The competition occurs not only above the ground but also in the root zone for water, nutrients and physical space. If soil moisture is limited, competitive effect from weeds will have a greater impact on the crop. As observed here, both timing of water recharge and soil type determined soil moisture status and should be important considerations in site selection. In this study, it was also noted that monocot weeds were more abundant in the same growing conditions as most of the four sown grass species, and they preferred orthic FERRALSOL watered every three days. This is not surprising because they are members of the same family as opposed to dicots, which may prefer other conditions. However,

numbers may not be the only consideration in weed competition because dicots have broad leaves whose shading effect may smother the monocots, particularly those with a slow germination rate. In this case, *E. macrostachyus* with a rapid germination may have a greater chance of out-competing the dicot weeds.

Further, a high rate of seed germination ensures that the grass takes advantage of available soil moisture and grows to maturity by the end of the season, resulting in successful pasture establishment desired by the farmer. Early season forage is linearly related to plant density in the seedling stage (Humphreys and Riveros, 1986). However, for seed production, a lower plant density is more desirable (Humphreys and Riveros, 1986; Loch *et al.*, 1999). On the other hand, where rainfall distribution is poor, young seedlings may die thus requiring a repeat sowing in the next season. In which case, the grass species like *E. superba* may still have seed in the soil that could germinate in subsequent favourable rainy seasons.

6.3.3. Seedling vegetational characteristics

6.3.3.1. Seedling growth and height

The rate of seedling growth was high with significant ($p < 0.05$) variation among species, soils and watering regimes. The overall trend of daily seedling height measurements for the four grasses is shown in Figure 6.7. From Day 12, seedlings gained height at the rate of 0.67 cm / day to attain 35.67 ± 1.367 cm by 65 days post sowing. The overall mean seedling height at Day 65 was 11.06 ± 0.264 cm. The tallest seedlings were those of *E. macrostachyus* and the shortest were those of *C. roxburghiana* with a mean of 17.23 ± 0.628 and 5.25 ± 0.295 cm, respectively.

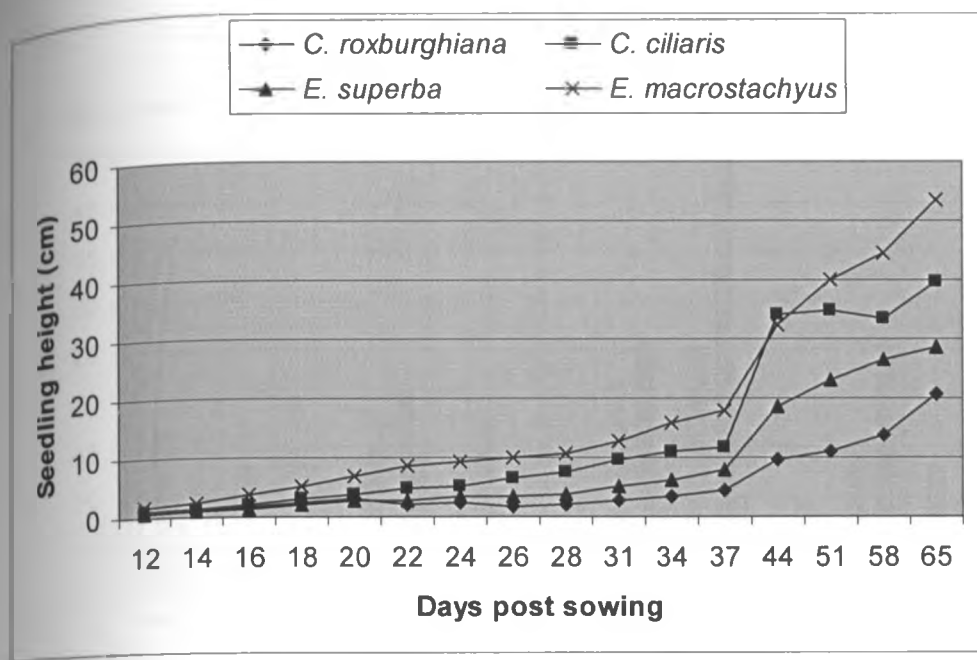


Figure 6.7. Growth curve as measured by seedling height (cm) averaged across three soil types and four watering regimes for four grasses potted in polythene bags during 2001 at KARI – Kiboko.

Seedling height values were not significantly ($p > 0.05$) different in the two FERRALSOL soils but were significantly ($p < 0.05$) higher than for histic GLEYSOL. The mean seedling heights were 14.17 ± 0.483 cm in rhodic FERRALSOL, 14.16 ± 0.496 cm in orthic FERRALSOL and 4.86 ± 0.302 cm in the histic GLEYSOL. Daily watering resulted in the shortest seedlings, particularly those of *C. roxburghiana* while *E. macrostachyus* had the tallest seedlings under all regimes of watering with the greater growth rate achieved with every fourth day regime. The combined effect of soil type and watering regime was observed most with *E. macrostachyus* and *E. superba*. The tallest seedlings (23.10 ± 2.396 cm) were for *E. macrostachyus* in the orthic FERRALSOL with every fourth day watering and the shortest (0.38 ± 0.261 cm) were for *E. superba* in the histic GLEYSOL with daily watering (Figure 6.8).

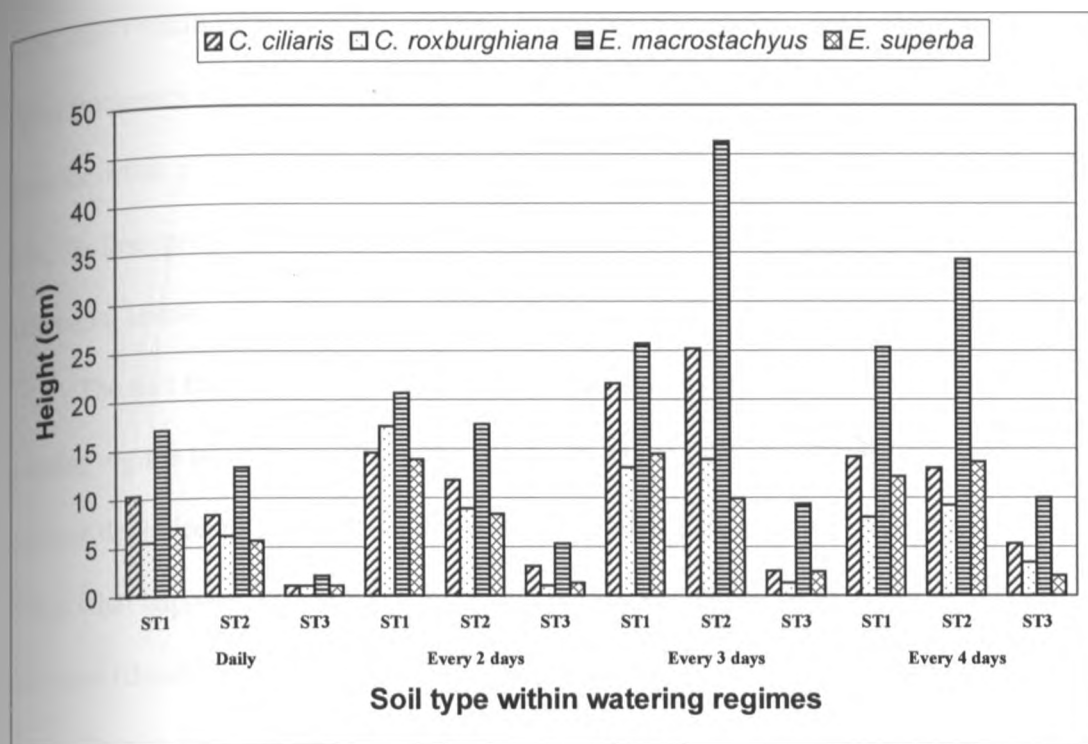


Figure 6.8. Mean seedling heights of four grasses potted in three soil types and subjected to four watering regimes in 2001 at KARI - Kiboko.

The ability to grow tall gives a seedling an advantage where they have to compete for light. The maximum heights attained by the grasses in this study are within normal range for the respective species. For example, the tallest plants were those of *E. macrostachyus* which is capable of reaching 90 cm in sandy loam soil where it is most commonly found naturally in Kenya (Bogdan and Pratt, 1967; Skerman and Riveros, 1990). However, the interaction between soil type and watering resulted in build up of soil moisture levels, and possibly other factors such as salts that affected plant growth (Dent and Raiswell, 1982). Salts tend to accumulate in the soil until concentrations are too high for satisfactory plant growth because cell division and elongation decrease as osmotic potential of substrate increases (Kramer, 1969; Dent and Raiswell, 1982). Most

of the salts remain when water is removed by evapotranspiration. Consequently, at higher frequency watering, plant heights were greatest in rhodic FERRALSOL and vice versa for orthic FERRALSOL. Therefore, it is apparent that even within closely related soils, the finer properties that differentiate soil units such as higher iron content and differential leaching of nutrients may influence plant performance.

The fact that, on average, better performance was observed at every 3 day watering regime implies that waiting up to the 4th day to water seedlings leads to soil moisture depletion to a point whereby most of the plants are affected physiologically. This is what happens when plants go beyond their wilting point before soil moisture is recharged (Bauder and Carlson, 1983).

Despite being the shortest, plants in histic GLEYSOL soils attained higher rates of height increase with less frequent watering. This is a reflection of the GLEYSOL's water holding capacity, tending to log-up easily and becoming mucky (Fitzpatrick, 1986; FAO, 2001). GLEYSOLS are also associated with lack of aeration, poor rooting conditions for most crops and poor conditions for soil fauna (FAO, 2001). Together, these rather unfavourable growth conditions may explain why generally the plants in this soil performed dismally compared with those grown in either of the FERRALSOLS.

6.3.3.2. **Tillering**

The first tiller was observed 28 days post sowing. The tillering rate differed significantly ($p < 0.001$) between the four grass species. The first species to tiller was *C. ciliaris* that was growing in the orthic FERRALSOL under every other day watering regime. Thereafter, *E. macrostachyus* and *C. ciliaris* seemed to level off, while the other two continued tillering albeit at a slower rate. However, at the final count *E.*

macrostachyus had the highest number of tillers and *C. roxburghiana* the lowest.

Although the rate of tillering remained different between the species almost through out the period of observation, in the last two weeks of observation there was no difference between *C. roxburghiana* and *E. superba* (Figure 6.9).

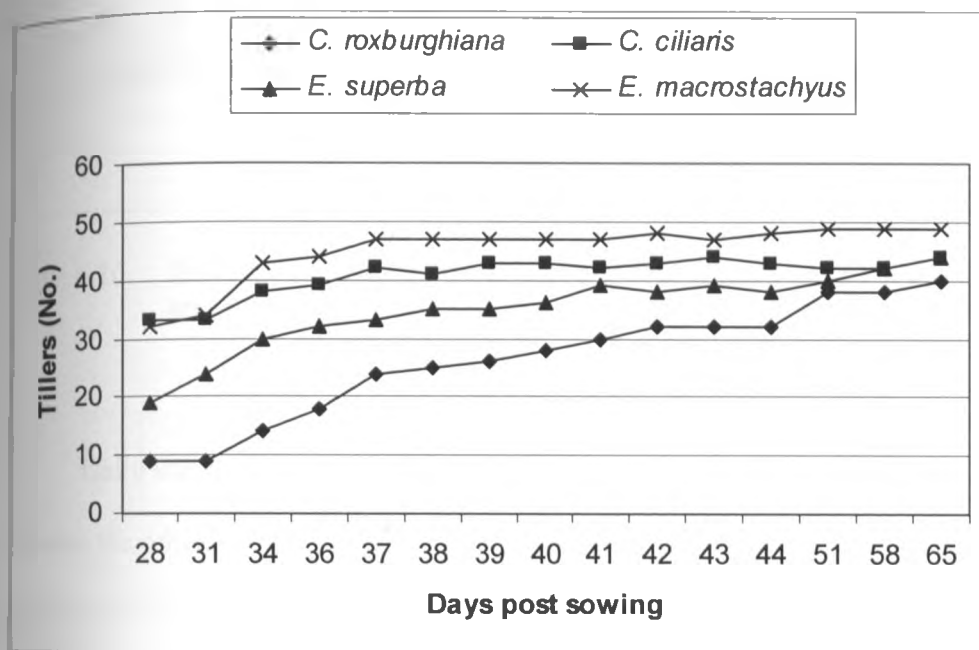


Figure 6.9. Relative mean tillering trends of four grasses potted in three soil types and subjected to four watering regimes in 2001 at KARI - Kiboko.

Soil type and watering regimes significantly ($p < 0.001$) affected plant tillering pattern. Tiller production in GLEYSOL had a late start but was followed by a fast rate of increase almost throughout the observation period whereas the process appeared to stop after Day 37 in the other soils (Fig. 6.10). Initially, the difference in tillering between watering regimes was minimal but it increased such that by day 36 significant ($p < 0.001$) differences emerged.

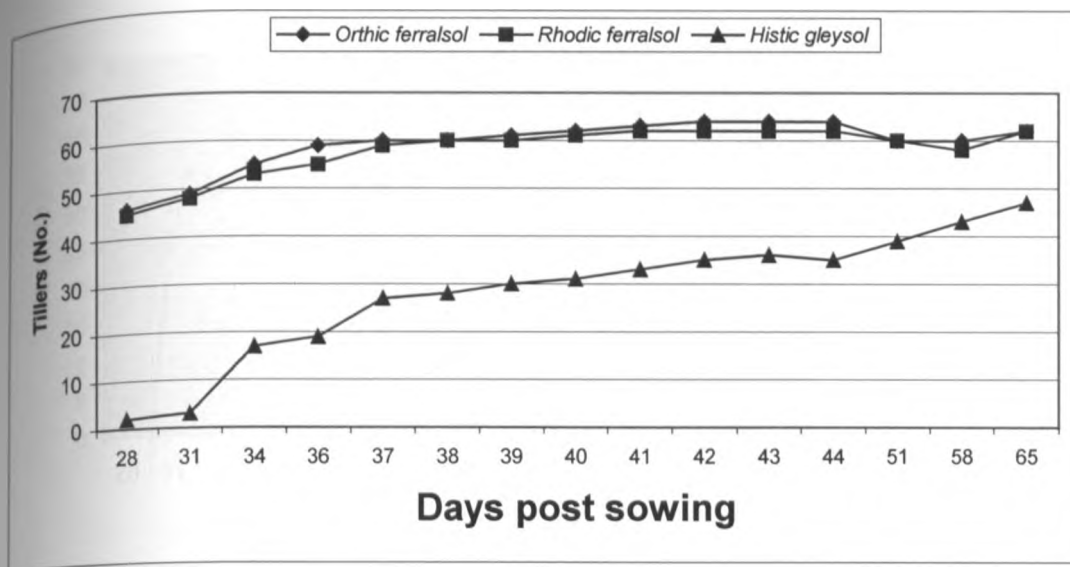


Figure 6.10. Effect of soil type on the tillering of four grasses potted in three soil types and subjected to four watering regimes in 2001 at KARI - Kiboko.

Daily watering had the least number of tillers while there was no clear difference between the other three regimes (Fig.6.11). In the last stages of observation, the highest number of tillers was observed in the “every three-day” watering regime. Regardless of watering regime, plants in histic GLEYSOL had the least number of tillers (Fig. 6.12). There was no tillering in the histic GLEYSOL with daily watering until day 37. The highest initial tillering was observed in plants in orthic FERRALSOL watered daily (Fig.6.11). Subsequently, plants in orthic FERRALSOL watered every four days attained and maintained the highest peak.

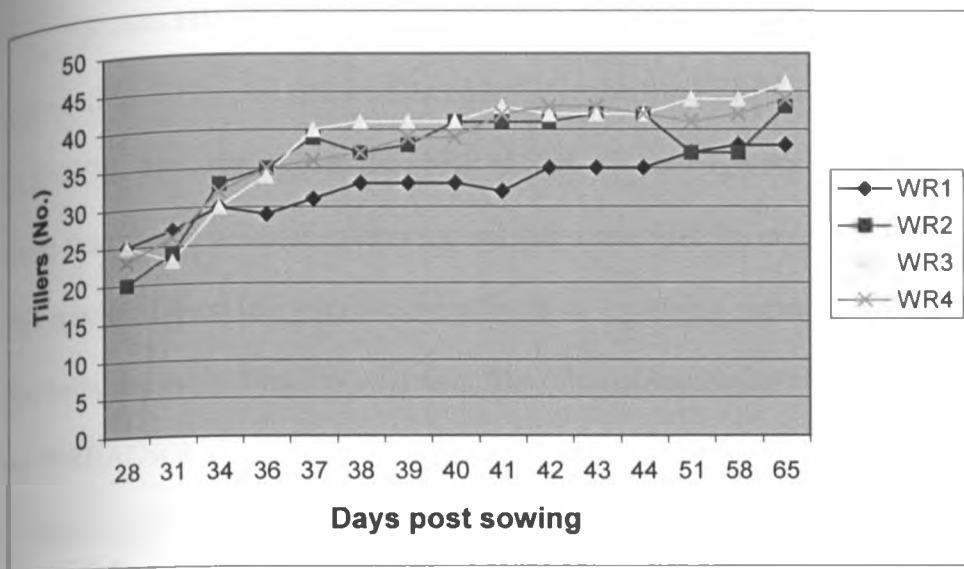


Figure 6.11. Effect of watering regimes on the tillering of four grasses potted in three soils types in 2001 at KARI - Kiboko. (WR1=daily, WR2=every 2 days, WR3=every 3 days and WR4=every 4 days).

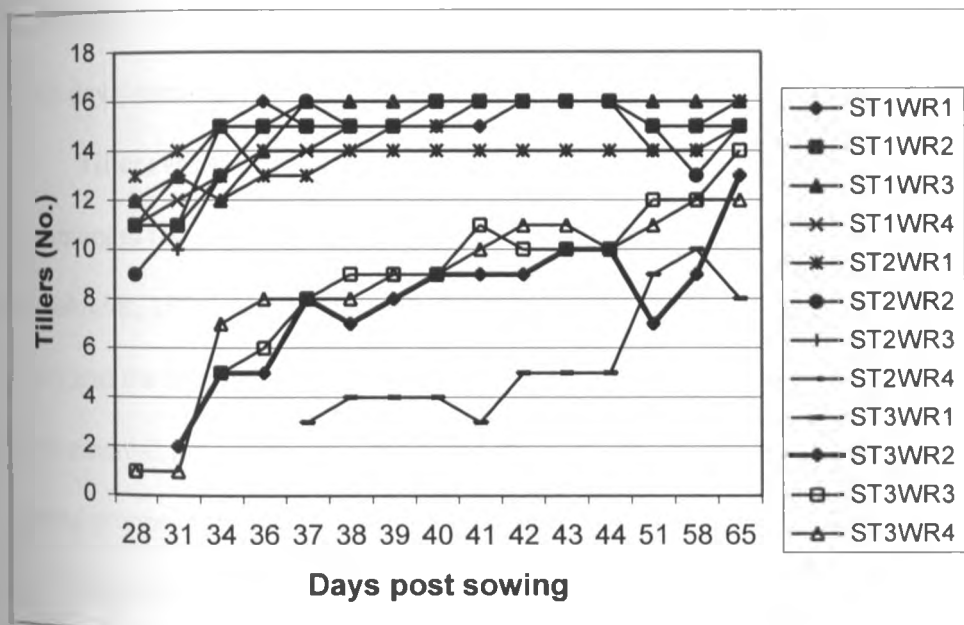


Figure 6.12 Effect of the interaction between soil type and watering regime on the tillering of four potted grasses in 2001 at KARI - Kiboko. (ST1WR1=orthic FERRALSOL watered daily, ST1WR2= orthic FERRALSOL watered every 2 days, ST1WR3= orthic FERRALSOL watered every 3 days, ST1WR4=orthic FERRALSOL watered every 4 days, ST2WR1=rhodic FERRALSOL watered daily, ST2WR2= rhodic FERRALSOL watered every 2 days, ST2WR3= rhodic FERRALSOL watered every 3 days, ST2WR4= rhodic FERRALSOL watered every 4 days, ST3WR1= histic GLEYSOL watered daily, ST3WR2= histic GLEYSOL watered every 2 days, ST3WR3= histic GLEYSOL watered every 3 days, ST3WR4= histic GLEYSOL watered every 4 days).

Grasses tillered differently under the various conditions of soil type and watering regimes (Fig. 6.12). All species tillered better in the two FERRALSOLS than GLEYSOL. However, within the FERRALSOL, *C. roxburghiana* tillered less in the orthic than rhodic with daily watering and vice versa with the every other day watering. This species tillered less with the every fourth day watering regardless of soil type, the best being the every third day watering. The other grasses behaved virtually the same in the FERRALSOL regardless of watering regime. However, differences were apparent in the histic GLEYSOL where *C. ciliaris* increased tillering with reduced frequency of watering while *E. superba* did not respond to a reduced frequency of watering after a peak at the every other day regime. On its part, *E. macrostachyus* tillered to a peak on the histic GLEYSOL at the every three day watering with less tillering under the every fourth day watering.

Tillers are formed from auxiliary buds of ontogenetically older parental phytomers at the nodes where leaves emerged (Hyder, 1972; Briske, 1986; Briske and Heitschmidt, 1991; Manske, 1998). They appear by the time the grass seedling has 4-5 leaves and the rate increases up to 4-8 weeks after sowing depending on crowding and environmental limitations (Skerman and Riveros, 1990). In this study therefore, the tillering process was within the range of time period referred to.

Reduction of the number of tillers associated with watering regimes was probably due to water stress. Bade *et al.* (1985) observed that water stress reduced the number of tillers in *Cynodon dactylon* and *Panicum coloratum* established under controlled conditions in a growth chamber in the USA.

Generally, a tiller possesses an emerging leaf, immature leaf, mature leaf and senescing leaf (Chapman *et al.*, 1984; Briske, 1991). Following a juvenile period of development, tillers are also capable of producing additional tillers from their own auxiliary buds (Mueller and Richards, 1986; Briske, 1991). Tillering of a plant is advantageous in several ways. It increases flowering points and subsequent seed production and increases canopy cover thereby protecting the ground thus reducing soil moisture loss through evaporation (Hacker, 1999). Tillers also increase the amount of foliage and hence provide more feed to animals. They increase a plant's chances of survival after its apical meristem is 'accidentally' lost through herbivory or fire before maturity (Skerman and Riveros, 1990). Thus, tillering is a good sign of perenniality / persistence, lack of which was a problem cited by the community members about some of the species they had tried to establish unsuccessfully.

6.3.3.3. *Tiller length and leafiness*

Mean tiller length was 9.34 cm for all grasses. Tiller length was significantly ($p < 0.05$) affected by soil type, watering regime ($p < 0.05$), number of days post sowing (age of seedlings) ($p < 0.0001$) and grass species ($p < 0.05$) (Table 6.7). The interaction between number of days post sowing and species also had significant effects on tiller development. Tiller length increased with seedling age. Seedlings growing in the two FERRALSOL soils produced tillers of similar length that were greater than those of plants growing in GLEYSOL. Tillers grew longer with less frequent watering, particularly in FERRALSOLS than in the GLEYSOLS. The longest tillers (9.85cm) were produced by *E. macrostachyus* while the shortest (6.56cm) were by *C. roxburghiana*. Total number of leaves produced by the grass tillers varied significantly

($p < 0.001$) by day, soil, and species and number of tillers. The mean was 8.63 for all grasses.

Table 6.7. Effects of soil type, watering regime seedling age and species on mean tiller length and leafiness of potted grasses in 2001 at KARI – Kiboko.

Independent variable	Mean tiller height (cm)		Mean number of leaves per tiller	
	N	Mean	N	
Soil type:				
Orthic FERRALSOL	64	9.69b	64	9.34b
Rhodic FERRALSOL	64	9.62b	64	9.01b
Histic GLEYSOL	64	7.95a	64	6.23a
Watering regime:				
Daily	48	8.77a	48	8.52a
Every 2 days	48	8.40a	48	8.33a
Every 3 days	48	9.69ab	48	8.80a
Every 4 days	48	10.44b	48	8.87a
Number of days post sowing:				
28	144	2.42a	144	6.12a
31	144	4.08ab	144	9.58c
34	144	4.96b	144	9.58c
37	144	5.28b	144	9.00c
44	144	10.86c	144	10.73d
51	144	11.97c	144	7.88b
58	144	13.82d	144	8.16b
65	144	15.08d	144	7.81b
Grass species:				
<i>Cenchrus ciliaris</i>	48	10.65c	48	9.17c
<i>Chloris roxburghiana</i>	48	6.56a	48	6.56a
<i>Enteropogon macrostachyus</i>	48	9.85 b	48	9.95d
<i>Eragrostis superba</i>	48	8.81ab	48	7.52b
Mean		9.34		8.63

Watering regime had no significant ($p > 0.05$) effect on the tiller leafiness, measured as the number of leaves per tiller. Plants in the FERRALSOLS produced similar number of leaves that were leafier than the plants in the histic GLEYSOL. Each of the four grass species was unique in leafiness, the leafiest being *E. macrostachyus* and

the least *C. roxburghiana*. Leafiness was highly significantly ($p < 0.0001$) dependent on total tillering.

Leaves develop from nodes formed below the meristematic apices and normally continue progressively as tillers develop. The main controlling factors are the species type (Humphreys and Riveros, 1990), and this agrees very well with the finding of this study. However, to what extent leaf formation will occur for a particular species appears to depend on its environment, in this case with soil type and much less with watering regimes. Further, it was observed here that leafiness depended also on the rate of tillering. Leaf demography, because of the associated leaf area, influences both photosynthetic capacity of plant and the amount of biomass available for consumption by herbivores. Essentially, leaf and tiller demography together determines the rate of biomass turnover, i.e. production versus senescence, within a plant canopy (Esau, 1953; Briske, 1991). In general, pasture persistence is dependent on the ability of the plants to maintain a high tiller density and the ability of the individual to maintain live leaves (the photosynthetic organ) and a major feed component (Skerman and Riveros, 1990; Briske, 1991; Boonman, 1993; Hirata and Pakiding, 2001).

From clipping studies, Woie (1986) observed that the large number of tillers produced by some grasses allowed them to attain a maximum growth rate at an earlier age and recover soon after defoliation. In those studies, *C. ciliaris* ranked highly in this respect which agrees with the results of this study. Emerging from this study also is *E. macrostachyus* which appears to have a high tillering and leaf production ability.

However, its behaviour under different regimes of utilization calls for further investigation.

Benefits from vegetative growth (tillering and leaf production) could be regarded as conferring plants with potential immortality. There is ecological benefit from continued site occupation and tiller replacement based upon the original parental resources to support younger tillers when this is compared to seedlings establishment from endosperm nutrient reserves, especially in less unfavourable growth conditions such as soils of low fertility and moisture. Growth and survival of stressed leaves and tillers generally have been shown to rely heavily on resources mobilized from associated less stressed tillers within the plant (Gifford and Marshall, 1973; Ong and Marshall, 1979; Briske, 1991). In addition, the leafy structure of plants, though suited for photosynthesis, is also conducive for a high water loss via transpiration (Pratt and Gwynne, 1977).

6.3.3.4. Senescence

Senescence varied significantly ($p < 0.01$) between species, by soil type and watering regime. Histic GLEYSOL supported plants in green state longest as measured by the number of dry leaves at two stages (Fig. 6.13). On average, the plants thrived better under the daily watering especially in the histic GLEYSOL.

The effect of the two FERRALSOLS on senescence was similar regardless of watering regime. The large difference between the FERRALSOLS at the first stage under every three-day watering could have been due to mineral content variation and salts build up. There was much more phosphorous and iron (Table 6.1) in orthic FERRALSOL than in the rhodic FERRALSOL which together with high levels of sulphates and chlorides in the irrigation water (Table 6.3) resulted in unfavourable plant growth conditions (Gonzalez-Bernaldez et al., 1968; Kramer, 1969). Supplying enough water to leach out the salt prevents plant damage which explains why there was less leaf

mortality under every four day watering since the volume applied was larger than under the three day watering regime (Kramer, 1969).

Among the grasses, *C. ciliaris* had significantly ($p<0.001$) more dead leaves than the other three, the least being *C. roxburghiana*. This trend was consistently so regardless of watering regime (Fig. 6.14). Two grasses, *E. macrostachyus* and *E. superba* produced the same number of dead leaves except under every four day watering where the latter produced a significantly ($p<0.05$) higher number.

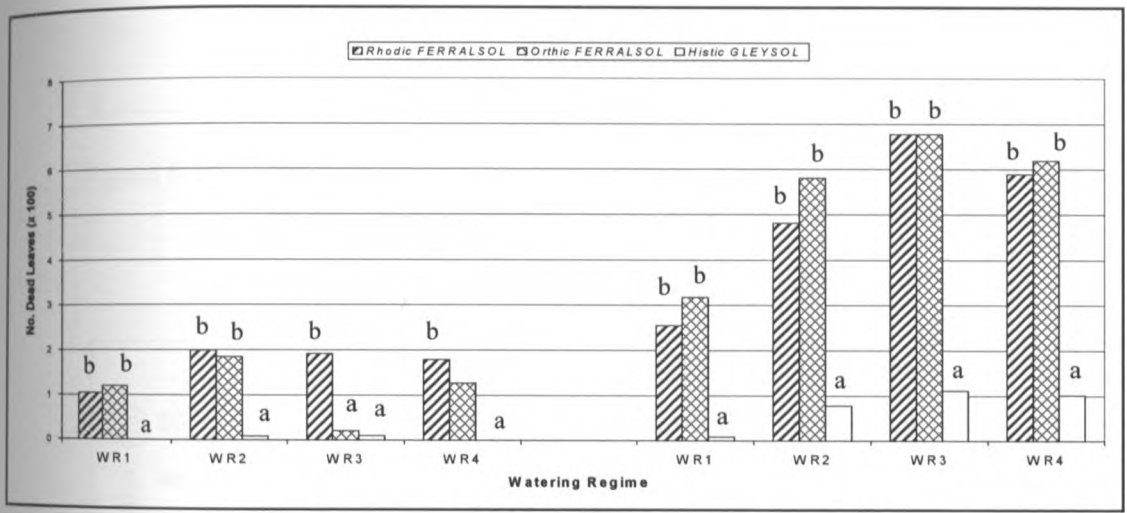


Figure 6.13. Total number of senescent leaves at two stages, left = 53 days and right = 70 days of seedling development post sowing of four species potted in three soil types and subjected to four watering regimes in 2001 at KARI – Kiboko.

The effect of soil type on the production of dead leaves by the four grasses is illustrated in Figure 6.15. There was a significant ($p<0.01$) difference between the two FERRALSOLS on one hand and the GLEYSOL on the other in their effects on dead leaf production for all grasses except *C. ciliaris* which showed no difference. Both *C.*

roxburghiana and *E. macrostachyus* grown in the FERRALSOLS produced more dead leaves than those in the histic GLEYSOL while, *E. superba* showed the opposite behaviour.

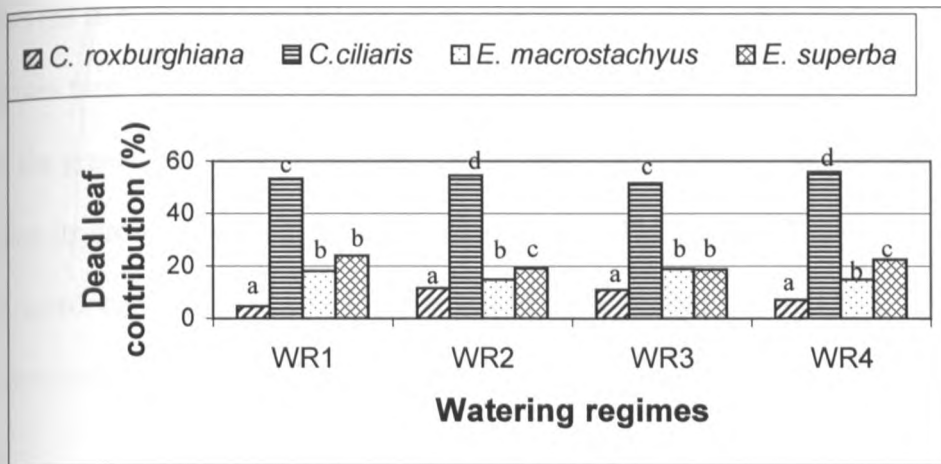


Figure 6.14. Relative contributions (%) to total number of dead leaves by four potted grasses (averaged across three soil types subjected to four watering regimes) at KARI Kiboko in 2001. Bars within clusters with similar letters are not significantly ($p > 0.05$) different.

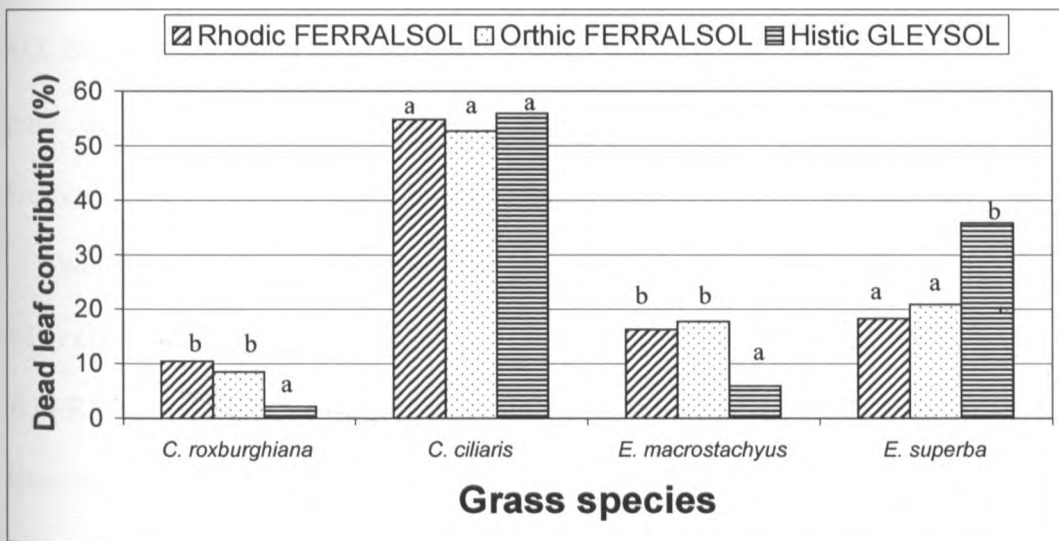


Figure 6.15. Relative contributions (%) to total number of dead leaves averaged across four watering regimes of four grasses potted in three soil types at KARI Kiboko in 2001. Bars within clusters with similar letters are not significantly ($p > 0.05$) different.

Browning of otherwise green leaves is a sign of necrosis that could be triggered by a number of things including mineral deficiency, infection, extreme weather conditions (as in frost and drought) or just old age (Roberts *et al.*, 1993; Hacker, 1999). When leaves turn brown, they lose photosynthetic capacity due to reduced chlorophyll. As such, the greater the proportion of dry leaves there is on a plant the less chance it has of attaining its growth and production potential (Hacker, 1999). Dead leaves may have high dry matter content but usually they are low in crude protein (Mnene *et al.*, 1996). This lowers pasture quality and it is disadvantageous, therefore, for a sward to senesce rapidly.

The grasses were observed to stay green longer under low quantity but high frequency of watering and especially in the histic GLEYSOL, because this is hydromorphic with the potential to retain high moisture levels longer (Scherer *et al.*, 1996; FAO, 2001). Addition of large volumes of water leads to water logging; subsequently, only those plant species that can withstand such conditions will be able to thrive. Further, histic GLEYSOL had a higher carbon content than the FERRALSOLS (Table 6.1), which means that it had a better nitrogen:carbon ratio that is considered a good fertility characteristic (FAO, 2001).

In FERRALSOL soils, plants had more senescent leaves possibly due to moisture stress. Even under daily watering water stress could occur since only small amounts of water were applied and considering that plants in the FERRALSOL soils were taller with more number of tillers and leaves, this probably placed a greater moisture demand through evapo-transpiration, commensurate with higher biomass. In addition, most

FERRALSOLS are clayey and have a strong water retention capacity at permanent wilting point, thus making them poorly equipped to supply plants with moisture during periods of drought (FAO, 2001).

Further, the plants were in pots that were restrictive to root spread (Plate 6.2) thus curtailing the possibility of roots reaching moisture that might drain out of the pots.

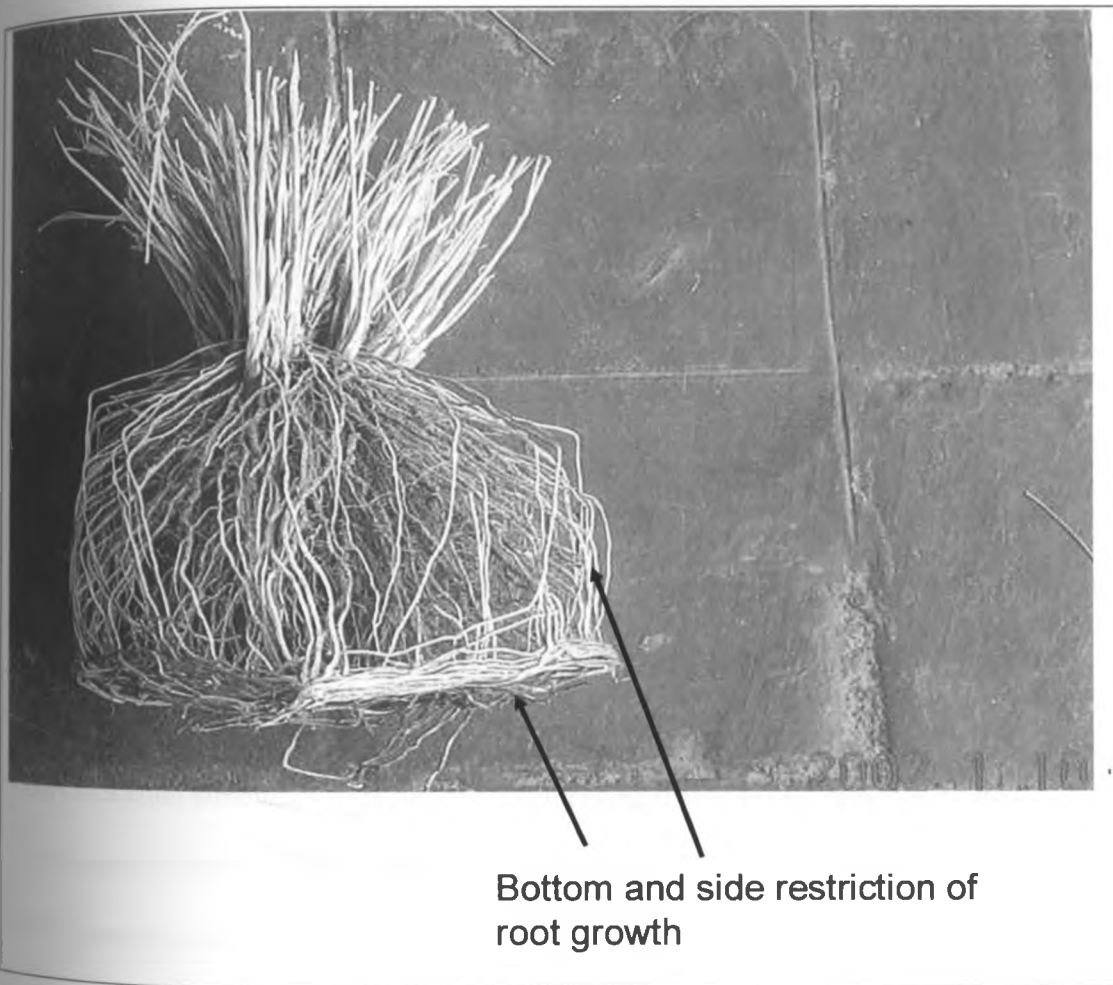


Plate 6.2. Illustration of rooting restriction of potted grasses; *C. ciliaris* at six months post sowing in a soil substrate packed in plastic tubing measuring 50 cm long by 30 cm diameter and filled to 40 cm height.

From field trials in Baringo, Ekaya and Kinyamario (2001) observed that when soil moisture availability is high as a result of good rainfall little biomass death occurs in the subsequent months resulting in low litter production. Leaf death rate is related to the number of live leaves and by implication to the amount of substrate available which then agrees with observation of Pakiding and Hirata (2001) on bahia grass (*Paspalum notatum*). Again, there is a possibility that potting resulted in limited substrate and that probably fewer plants per pot would have been more appropriate. Most grasses have ramified roots that occupy a large volume of soil. The best example is *C. ciliaris* that can penetrate over 6-m depth in only 18 months after planting (Dagg and McQueen, 1967; Pratt and Gwynne, 1977). This grass contributed 54% of all dead leaves in this study. Another possibility for this kind of results is that *C. ciliaris* has a carry-over of dead material resulting in a higher cumulative count subsequently (Mnene – personal observation) whereas the other grasses shed dead leaves quickly.

These results are in conformity with the general belief that leaf initiation and senescence maintains a relatively constant leaf number per tiller throughout much of their mutual developmental life (Esau, 1953; Anslow, 1966; Chapman *et al.*, 1984; Briske, 1991). These results are also in agreement with Briske (1991) who noted that the environmental conditions experienced by emerging leaves might programme their subsequent development to a larger extent than the conditions during growth or maturity. In temperate environments, leaves initiated under favourable growing conditions have shorter longevities than those initiated in less favourable environmental conditions (Chapman *et al.*, 1983; 1984). For example, leaves of perennial ryegrass exhibited mean longevities of 60-70 days when initiated in spring compared to 70-105 days when

initiated in fall. This experiment was set in July, usually a dormant period in the year for most plants including the grasses in this study. There are no such examples to be cited for the tropical conditions and these results may serve to point at the need for similar studies.

Short leaf longevities imply that grazing must be timed to optimize the harvest of live leaves, a delay of which leads to loss of pasture quality and ultimately quantity through litter formation and decomposition (Briske, 1991; Stuth, 1991; Ekaya and Kinyamario, 2001). Therefore, GLEYSOLS, which are generally considered to be of poor drainage quality (FAO, 2001), are better suited to support plants in green state longer. Herbage comprising a large proportion of dead material component results in herbivore diets of low nutritive quality (Mnene *et al.*, 1996) because as the leaves age and die much of assimilates is mobilized to support other tissues of the plant (Briske, 1991). Therefore, patches of the range that may have GLEYSOLS grown with these grasses would provide herbivores with a higher plane of nutrition late into the dry season. This is particularly true considering that GLEYSOL dominated areas are usually waterlogged during the wet season and only become accessible in the dry season (FAO, 2001).

6.3.3.5. Flowering onset and intensity

The mean daily number of flowers per pot was 4.67 ± 0.203 , which was significantly ($p < 0.05$) affected by the number of days post sowing, watering regime and soil type. Flowerings begun on day 35 post sowing with *E. superba* but took over ten days to really pick up (Fig. 6.16).

Although *E. macrostachyus* had rapid flowering initially, by Day 65 the total number of flowers was the same as that for the other grasses. Generally, after the initial

time lag, flowering was very rapid and continued to the end of the 70 days of observation. There was, however, no significant ($p > 0.05$) difference in flowering between the grasses.

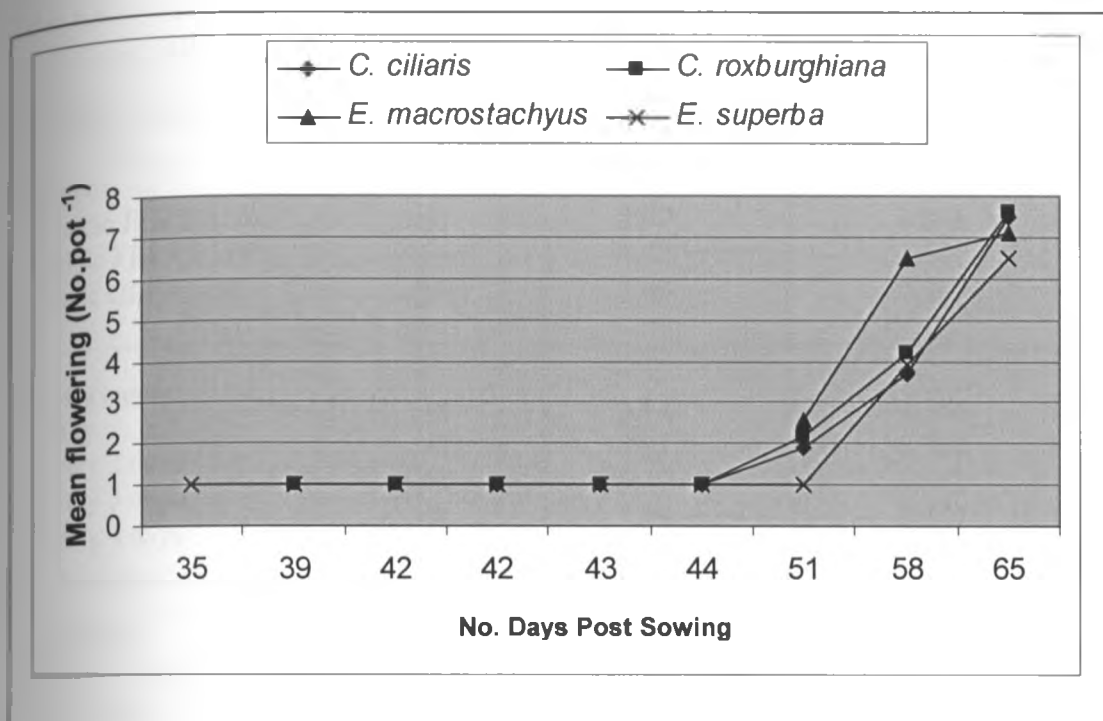


Figure 6.16. Mean daily flowering trend of four grasses averaged across three soil types and four watering regimes at KARI – Kiboko in 2001.

Although *E. macrostachyus* had rapid flowering initially, by Day 65 the total number of flowers was the same as the other grasses. Generally, after the initial time lag, flowering was very rapid and continued to the end of the 70 days of observation. There was, however, no significant ($p > 0.05$) difference in flowering among the grasses.

Flowering also did not differ significantly ($p > 0.05$) between plants in the FERRALSOL soils but was higher than those in the GLEYSOL. Similarly, flowering was not significantly ($p > 0.05$) different between plants under daily and every other day

watering regimes but these differed from those plants under the three and four day watering (Table 6.8).

Table 6.8. Effect of soil type, watering regime, seedling age and species on flowering of four potted grasses in 2001 at KARI – Kiboko.

Independent variable	N	Mean	Std. Error of Mean
Soil type:			
Rhodic FERRALSOL	64	4.99	0.346
Orthic FERRALSOL	64	4.82	0.301
Histic GLEYSOL	64	3.49	0.385
Watering regime:			
Daily	48	3.94	0.366
Every 2 days	48	3.91	0.322
Every 3 days	48	5.19	0.442
Every 4 days	48	5.28	0.407
Grass species:			
<i>Chloris roxburghiana</i>	48	4.80	0.486
<i>Cenchrus ciliaris</i>	48	4.90	0.384
<i>Enteropogon macrostachyus</i>	48	4.01	0.345
<i>Eragrostis superba</i>	48	5.04	0.432

Therefore, overall the number of flowers was similar among grass species. Most grasses produce seeds as a means of perpetuating themselves while others do so vegetatively (Esau, 1960; Bogdan, 1977; Boonman, 1993; Hacker, 1999). However, what is stored in the seed (photosynthates) is actually no longer available for the parent plant's current vegetative growth and survival. It is desirable to have a plant species that would yield sufficient seed for use in future propagation, but for a species that has longer persistence once established this may be unnecessary and actually disadvantageous (Hacker, 1999).

The rapid maturity of the grass seedlings is an inherent ability to avoid drought. In range reseeding, early maturity is a desirable trait since successful establishment of the sown plants requires completion of the growth cycle before the onset of drought. In this respect, *E. superba* and *C. roxburghiana* displayed this ability better than *C. ciliaris* and *E. macrostachyus*. In fact the results for *C. roxburghiana* are at variance with observations made from trials in Marsabit (Keya 1998) to the effect that this grass requires at least two seasons to complete its growth cycle. The explanation lies in the fact that:

- a) The Marsabit trial used seeds harvested at Kiboko
- b) The trials were conducted under two different environmental conditions;
 - i. The soils at the Ngurunit experimental site in Marsabit are eutric and calcic Cambisol / Luvisol while those used this study are rhodic and orthic FERRALSOLS and histic GLEYSOL
 - ii. The watering regimes were different.

Poor grass establishments from previous reseeding efforts forms the gist of undertaking the current study. Therefore, the above example may serve to demonstrate the validity of the hypothesis that reseeding an area with germplasm introduced from elsewhere leads to low performance, which is the subject of further investigation in this study in Chapter 8.

Lack of variation in flowering rate among the species cannot be inferred whether this would lead to lack of difference in subsequent seed production. What is implicit is that the sooner a plant sets flowers the more certain for it to have some seed that season (Loch *et al.*, 1999), as would be expected from *E. superba*, known to be an 'excellent' seeder (Bogdan 1977). When growing conditions are favourable, plants tend to delay

flowering and continue to grow vegetatively thus producing more biomass (Skerman and Riveros, 1990; Briske, 1991; Loch *et al.*, 1999). Conversely, reproductive tiller development terminates the development of leaf primordia and is followed by tiller death as the existing phytomers senesce (Essau, 1960; Noble *et al.*, 1979), which is no doubt a drought coping mechanism (Keya, 1998).

6.3.4. Above ground standing crop estimation and partitioning

The mean standing crop and its partitioning among the measured components are compared in Table 6.9.

Table 6.9. Effect of soil type on standing crop (mean $\pm$ SE) (g pot⁻¹) and its partitioning (%) by four potted grasses subjected to four watering regimes in 2001 at KARI – Kiboko.

Above ground component	Soil type		
	Rhodic FERRALSOL (N=32)	Orthic FERRALSOL (N=32)	Histic FERRALSOL (N=32)
Fresh weight (g)	35.48 $\pm$ 1.801	33.94 $\pm$ 1.843	30.71 $\pm$ 2.985
Dry matter (g)	16.27 $\pm$ 1.347	16.55 $\pm$ 1.080	10.13 $\pm$ 1.350
Dry matter (%)	44.11 $\pm$ 2.570	48.14 $\pm$ 1.895	30.55 $\pm$ 3.266
Leaf (%)	64.20 $\pm$ 2.963	62.42 $\pm$ 2.962	65.45 $\pm$ 4.359
Stem (%)	20.92 $\pm$ 2.237	23.37 $\pm$ 3.982	23.24 $\pm$ 3.982
Panicle (%)	14.87 $\pm$ 1.790	14.22 $\pm$ 1.790	11.31 $\pm$ 1.780

The mean dry weight was 14.50 $\pm$ 0.778 g per pot equivalent to 204.23 $\pm$ 10.958 g m⁻² with a mean dry matter (%DM) of 41.47 $\pm$ 1.659. Most of the standing crop was in the leaf component (63.94 $\pm$ 1.950%), while stems comprised 22.49 $\pm$ 1.693% and panicles 13.57 $\pm$ 1.035%. Of these components, soil type significantly (p<0.05) affected

only total standing crop. While, watering regime significantly ($p < 0.05$) affected total dry matter, %leaf and %stem but did not significantly ($p > 0.05$) affect %DM (Table 6.10).

Table 6.10. Effect of watering regime on standing crop (mean $\pm$ SE) (g pot⁻¹) and its partitioning (%) by four grasses potted in three soil types in 2001 at KARI – Kiboko.

Above ground component	Watering regime			
	Daily (N=24)	Every 2 days (N=24)	Every 3 days (N=24)	Every 4 days (N=24)
Fresh weight (g)	22.39 $\pm$ 1.856	27.95 $\pm$ 1.730	39.58 $\pm$ 1.994	43.48 $\pm$ 1.818
Dry matter (g)	9.26 $\pm$ 1.162	11.96 $\pm$ 1.151	18.03 $\pm$ 1.723	18.50 $\pm$ 1.170
Dry matter (%)	39.12 $\pm$ 4.001	41.41 $\pm$ 2.644	43.22 $\pm$ 3.941	41.96 $\pm$ 2.411
Leaf (%)	53.54 $\pm$ 4.529	68.99 $\pm$ 3.928	66.26 $\pm$ 3.218	66.87 $\pm$ 3.309
Stem (%)	33.16 $\pm$ 4.594	20.51 $\pm$ 3.293	17.02 $\pm$ 1.876	19.78 $\pm$ 2.532
Panicle (%)	13.29 $\pm$ 2.249	10.50 $\pm$ 1.532	16.73 $\pm$ 2.308	13.35 $\pm$ 1.928

Species varied in all standing crop components (Table 6.11), *C. ciliaris* and *E. macrostachyus* had the highest fresh weight and percent dry matter but the former had significantly ($p < 0.05$) higher %stem. The least total standing crop was produced by *C. roxbughiana*, which was, however, the leafiest species on a percent dry matter basis. The leaf components of the other three grasses were similar. The partitioning of dry matter to the panicles was highest in *E. superba* and lowest in *C. roxbughiana* with about 20 and 7 percent, respectively. There were no significant ($p > 0.05$) effects from interactions between soil types and watering regimes on biomass production.

Some important pointers of the subsequent season’s performance in terms of dry matter production can be seen from these data. Biomass estimates at the stage it was done (approximately 70 days post emergence) was rather premature in the sense that

ordinarily, a crop is not to be grazed in the first season of establishment. Total dry matter production was highest in *C. ciliaris* and *E. macrostachyus*, two species that had also shown early and higher growth rate and tillering. The latter grass particularly had a head start in almost all stages; it also had the highest seed germination both in the laboratory and in the pots. However, whereas *E. macrostachyus* was the leafiest in terms of number of leaves, *C. roxburghiana* turned out to be the leafiest in terms of percent dry matter partitioning. This, therefore, calls for caution in the use of the term leafiness whenever these grasses are described.

Table 6.11. Comparative species on standing crop (mean $\pm$ SE) (g pot⁻¹) and its partitioning (%) by four grasses potted in three soil types and subjected to four watering regimes in 2001 at KARI – Kiboko.

Above ground component	Grass species			
	<i>C. roxburghiana</i> (N=24)	<i>C. ciliaris</i> (N=24)	<i>E. superba</i> (24)	<i>E. macrostachyus</i> (24)
Fresh weight (g)	26.82 $\pm$ 3.396	40.22 $\pm$ 2.000	31.88 $\pm$ 2.124	34.78 $\pm$ 1.846
Dry matter (g)	8.85 $\pm$ 1.523	20.16 $\pm$ 1.399	12.70 $\pm$ 1.176	16.14 $\pm$ 1.145
Dry matter (%)	27.74 $\pm$ 3.832	50.35 $\pm$ 2.701	39.80 $\pm$ 2.555	46.29 $\pm$ 2.429
Leaf (%)	82.30 $\pm$ 3.451	53.63 $\pm$ 2.833	58.41 $\pm$ 3.919	64.07 $\pm$ 2.616
Stem (%)	10.55 $\pm$ 2.296	33.50 $\pm$ 2.775	22.40 $\pm$ 4.012	21.94 $\pm$ 2.238
Panicle (%)	7.14 $\pm$ 2.109	12.87 $\pm$ 1.798	19.20 $\pm$ 2.064	14.00 $\pm$ 1.607

Farmers tend to judge a species by its standing biomass, here referred to as fresh weight failing to recognize the fact that nutrients are actually contained in the dry matter component. What may appear as a lot of forage in a stand therefore may really be water as demonstrated by both *C. roxburghiana* and *E. superba* whose dry matter content was only a third of the fresh weight. These two were also the leafiest on dry matter basis.

Therefore, when subjected to grazers, such as cattle, they will not only fail to satisfy the animals' appetite but also through selection of the leaf component that is mostly preferred (Stuth, 1991; Mnene *et al.*, 1996) they are likely to be grazed out before the more stemmy species. This would be the case particularly were the plants to be grazed in the first season of establishment, regardless of soil type and moisture level. On the other hand, *C. ciliaris* and *E. macrostachyus* have a greater chance of surviving this threat because they, in addition to a relatively higher stemness, have high tillering and leaf production ability which starts early in the development of the seedlings. Plants survive grazing through grazing resistance and this ability varies greatly among species, which they achieve through intrinsic tolerance and avoidance mechanisms. In avoidance, plants escape herbivory because they are unpalatable or inaccessible while in tolerance, the plants have mechanisms that facilitate growth following defoliation (Briske, 1986; 1991).

The mean dry matter standing crop of $204.23 \pm 10.958 \text{ g m}^{-2}$ was within the range of those reported in natural stands in tropical rangelands. Similar values in different plant communities have been reported. For example Kinyamario and Imbamba (1992) in the Nairobi National Park recorded $73\text{--}338 \text{ gm}^{-2}$). Also, Sisay and Baars (2002) in the mid Rift Valley in Ethiopia recorded 85.81 and 263.36 g m^{-2} in communally and seasonally grazed areas, respectively dominated by *C. ciliaris* among other grasses. Given that the plants in this study were in their first season of growth, it is likely that higher production is tenable at a later stage.

6.3.5. Conclusion

Soil and climatic conditions are integrated and expressed in plant growth while soil fertility is useful in predicting crop productivity potential. In this study, it would be

safe to accept the hypothesis that soil types and soils moisture contents are important factors influencing grass seed germination and subsequent plant development. Specific results lead to this conclusion as stated below.

The three soil types interacted with four watering regimes to influence both grass seed germination and seedling growth. The orthic and rhodic FERRALSOL soils were generally better than the histic GLEYSOL in supporting the growth of all the four grass species. GLEYSOL, however, retained plants in green state longer, particularly under low amounts but high frequency of watering, possibly due to the soil's better nitrogen : carbon ratio compared with the FERRALSOL soils. Potting may have had a restriction to plant growth by limiting root growth and this requires further investigation.

The term leafiness, often used in describing and rating pasture quality, ought to be defined clearly whenever it is used. Based on data from this study, a leafy grass in terms of number of leaves (e.g. *E. macrostachyus*) is not necessarily the leafiest in terms of dry matter partitioning (e.g. *C. roxburghiana*). Nutritionally, higher dry matter is preferable since that may have a direct linkage to higher amounts of nutrients.

On the basis of seedling emergence, height, tillering and dry matter production within the realm of soil types and moisture interactions in this study the four grasses could be ranked thus:

FERRALSOLS generally: -

$C. ciliaris \geq E. macrostachyus > E. superba > C. roxburghiana.$

GLEYSOL, with high frequency watering: -

$E. macrostachyus \geq C. ciliaris > C. roxburghiana > E. superba.$

GLEYSOL, with low frequency watering -

C. ciliaris > *E. macrostachyus* > *E. superba* > *C. roxburghiana*

For some of the grass species, like *E. macrostachyus*, potting results were a reflection of their performance during laboratory germination tests in terms of rapid germination and emergence. However, for others it was different; this difference may manifest itself even more under field conditions where soil moisture recharge from rainfall is less predictable than with irrigation and farm conditions such as slope, history of use, tillage and grazing management are more variable. These will form some of the justifications for the study in the next chapter.

CHAPTER SEVEN

7.0. ON-FARM PITTING AND RE-SEEDING FOR NATURAL PASTURE IMPROVEMENT

7.1. INTRODUCTION

Predominantly low quality and quantity of natural pastures characterize semi-arid areas of Kenya, which is the major constraint to livestock production. The assessment reported previously (Chapter Four) pointed out clearly that most communities keep more livestock than their land holdings can sustain. Effects of grazing on vegetation and soil worldwide indicate that overstocking causes increased erosion and general loss of productivity (Milchunas and Laurenroth, 1993; Herlocker, 1999). Gradually, therefore, overstocking coupled with possibly a number of other factors such as drought, termite and bush encroachment contribute to gradual degradation of the natural pastures. This is in the form of decreased aboveground biomass, forage quality and species composition (Turner, 1993). Where there is adequate rainfall, grazing is a secondary factor affecting ecosystem processes whereas drought is a primary factor (Olson *et al.*, 1985; Biondini *et al.*, 1998).

Grazing and drought are major factors of degradation in the Kenyan semi-arid rangelands. Results in Chapter Four attests to this and the problem affects the eastern Africa region as a whole as reflected by impacts of drought reported by Ndikumana *et al.* (2002). Although pastoral communities have virtually no options available to manipulate drought occurrence, they have historically depended on moving livestock for sustainability. This is an indirect form of deferment or even rest rotation system similar

to the designs used in the USA AND South Africa to achieve high performance or high production grazing (Booyesen and Tainton, 1978; Heitschmidt and Taylor, 1991). The analogy here is more relevant where animals are moved before much damage to vegetation has occurred and are kept away well into the rainy season.

Unfortunately, movements are now curtailed by changing land tenure. Previously communally owned land holdings such as group ranches are rapidly undergoing individuation through sub-division (Lesorogol, 1991, 1998; Kimani and Pickard, 2002). Without concomitant reduction in herd sizes and access to other land, this places greater pressure on the smaller land parcels for a longer period with increased threat of heightened natural pasture degradation. Yet, what is readily realized is feed inadequacy and not the threat of pasture degradation in the long run. Further, since the loss of pasture integrity is not immediate, the problem may continue unchecked until it attains irreversible levels, especially when other exacerbating factors occur. Fortunately, a majority of the people in some of the districts recognizes the problem and the need for action (Mbogoh and Shaabani, 1999; Mnene *et al.*, 2000). The community survey results presented earlier (Chapter Four) also confirmed the same in the initial stages of this study.

Deferment has been reported to allow pasture time to rejuvenate itself (Heitschmidt and Taylor, 1991; Herlocker, 1999). Although deliberate, this is largely a passive attempt of restoration by removal of a specific disturbance, grazing in this case, thereby allowing ecological processes to bring about an independent recovery. Depending on the degree of degradation, however, this may well take a long time before realizing tangible improvement (SER, 2002). This approach presumes that there is

adequate soil seed bank for re-establishment of the depleted desirable forage species since it has been found that seeds are capable of staying viable in the soil for decades (Lloyd and Cavers 2002). In some instances, particularly where the soil surface is sealed through capping, runoff ensues leading to wastage of otherwise scarce moisture during the rains (Bogdan, 1977; Thurrow *et al.*, 1988a; Boonman, 1993).

However, in some situations degradation has advanced to a point that passive approaches alone may not yield desired results quickly. More active approaches are thus necessary (SER, 2002). Seedbed preparation is useful to encourage higher on site infiltration and possibly also allow for an easier seedling emergence (McIvor and Gardener, 1985) assuming availability of sufficient presence of viable seeds in the soils. Water harvesting involves altering the topography and surface of a site to direct limited rains to plants (Fidelibus and Bainbridge, 2004). Although communities in many dry areas of Africa, Australia, southwestern USA and Middle East practiced some form of water harvesting for centuries, the most developed example to date is in Israel- the Nabatean farms also referred to as Wadi Mashash (Fidelibus and Bainbridge, 1994). Here, micro-catchments are used which are especially contoured with slopes and berms designed to increase runoff from rain and concentrate it in a planting basin where it infiltrates and is effectively stored in the soil profile. The water is available to the plant but protected from evaporation. The basins are either constructed with equipment or by hand. The soil surface is often modified to reduce the threshold required to get runoff. Two approaches are used to achieve this, (1) defoliating the runoff area and (2) treating the runoff area with an impervious material e.g. low melting wax, sodium salts, synthetic

membranes, asphalt and concrete (Boers and Zondervan and Ben-Asher, 1986; Orev, 1988; Fidelibus and Bainbridge, 1994).

In Africa, some communities in Tanzania have used pitting as a form of seedbed preparation and micro-catchments to grow crops for many decades (Pike, 1938; Stenhouse, 1944; Sutton, 1969). Since its introduction to Kenya with some modification little adoption has occurred. Nonetheless, application of the technology has been promoted mostly for food crop production but little in pasture / range improvement (Mututho, 1989; Gichangi *et al.*, 1989; Simuyu *et al.*, 1992; Kitheka *et al.*, 1994). In this study, reseeding by way of re-introduction of native species with locally adapted forage species was done to increase the chances of an accelerated natural pasture improvement. Pitting, a form of seedbed preparation and micro-catchment of runoff were used to improve the possibility of success in pasture establishment.

7.1.1. Hypothesis

Soil seed bank of valuable but disappearing forage grasses does exist in denuded pasturelands and that external input are required to accelerate their re-establishment.

7.1.2. Objective

To test on-farm techniques of pasture improvement that involve pitting and reseeding with selected forage species and compare establishment with data from deferment and pitting applied separately with or without reseeding as options open to the spectra of social and economic status of different households.

7.2. MATERIALS AND METHODS

7.2.1 Site characterization

Two sites were selected and demarcated for the reseeded trials, one at Merueshi in Mashuru Division in Kajiado District and the other at Kavatini in Makindu Division in Makueni District. Both sites were among the 14 sites where on-farm-reseeding trials had been initiated in collaboration with extension service representatives (Mnene *et al.*, 2000). The two sites were also selected to represent two different production systems practiced by two different communities; Merueshi for pastoralism by the Maasai and Kavatini for agro-pastoralism by the Akamba. However, care was taken when demarcating the experimental blocks (each measuring 48x48 m) such that they all fall within similar soils, specifically FERRALSOL. This was the soil that had given more satisfactory performance of the grasses in the potted experiment (Chapter Six). Precaution for slope uniformity was also taken not to exceed 5% so as to make micro-catchments applicable (Fidelibus and Bainbridge, 1994).

The general site descriptions are given elsewhere (Chapter Three). In addition, the Kavatini site was situated within close range of the farmer's homestead and as such it had experienced continuous grazing by cattle, sheep and goats for over 20 years. The Merueshi site was a little removed from the homestead of one of the current landowner's sons and an abandoned kraal with a grazing history of over 50 years. It was evident from existing stumps and general sparseness that large trees at the two sites had been reduced as a result of cutting materials for fencing and charcoal burning. Numerous active termite mounds were present at both sites, which was testimony to possible termite foraging activity. During the study, several wild herbivorous species were encountered

at Merueshi including buffalo, wildebeest, eland, zebra, giraffe, kongoni and both Thomson and Grant's gazelles. However, at Kavatini all these species were absent and only on rare occasions were dik dik sited.

Three transects were laid at each site along which sampling was done to obtain the baseline data using standard range characterization approaches (ARC, 1962; SRM, 1983). Slope (%) was estimated using the dumpy level and staff method and was found to be 0.78% (range 0.00 - 2.11) at Kavatini and 2.27 % (range 1.31-3.20) at Merueshi. The woody component ground canopy cover (%) was estimated using the line intercept method and plant density (No. Ha^{-1}) was derived from 1-m belt transects. Herbaceous vegetation standing crop in terms of dry matter (kg DM Ha^{-1}) was sampled by the double sampling technique while ground cover (%) was by the quadrant estimation method. These approaches had been used previously in similar sites in and around Kiboko (Mnene, 1985; Mnene *et al.*, 1996; Mnene *et al.*, 2000).

7.2.2. Experimental design

A complete randomized block design was used; the main considerations were that Kavatini and Merueshi have a different history of land use and vegetation types as evidenced by the data from site characterization below. Two replicate blocks measuring 48 x 48 m each were demarcated at both sites. In each block, 4 plots each 20 x 20 m were marked with 2-m separation space between them. The four plots in each block were then randomly assigned 4 treatments, viz.:

1. Reseeding	2. Pitting
3. Pitting and reseeded.	4. Deferment

Three 20 m permanent transects were randomly located and marked at equi-distant in each treatment plot. Allowing 2 m at each end of each transect, 48 quadrants were marked measuring 1 m x 0.5 m for sampling herbaceous vegetation. Fencing was done to keep off grazers, both wild and domestic with an allowance of 3 m around the perimeter as recommended by Roberts *et al.* (1993) and Ekaya and Kinyamario (2001). At Merueshi where experimental land was not a limitation, an additional set up of two complete blocks was demarcated but not fenced so as to act as a true control. It was not possible to set up similar control blocks for the deferment at Kavatini due to limitation of land as realized in Chapter Four.

7.2.3. Pitting

Semi-circular pits were dug manually in rows along contours using hoes with soil scooped down slope and the arc tips pointed up slope. Each pit measured 1 m span width between the arc tips. Depth at the middle was 0.15 m but was made shallower towards both ends (Fig. 7.1). This resulted in a crescent whose ridge was higher at the centre than at the ends with the shape of a quarter moons, and is a modification of the interlocking Katumani pits (Kitheka *et al.*, 1994). Each pit crescent was firmed up on the up-slope side by ramming with the back of a shovel to minimize pit siltation. Spacing within and between rows was 0.5 m and 1 m, respectively. Each subsequent row of pits was staggered left and right alternately in order to harness runoff overflow from pits above in the one below. The whole pitting process was completed in October 1999, before the expected on-set of the rainy season later in the same month.

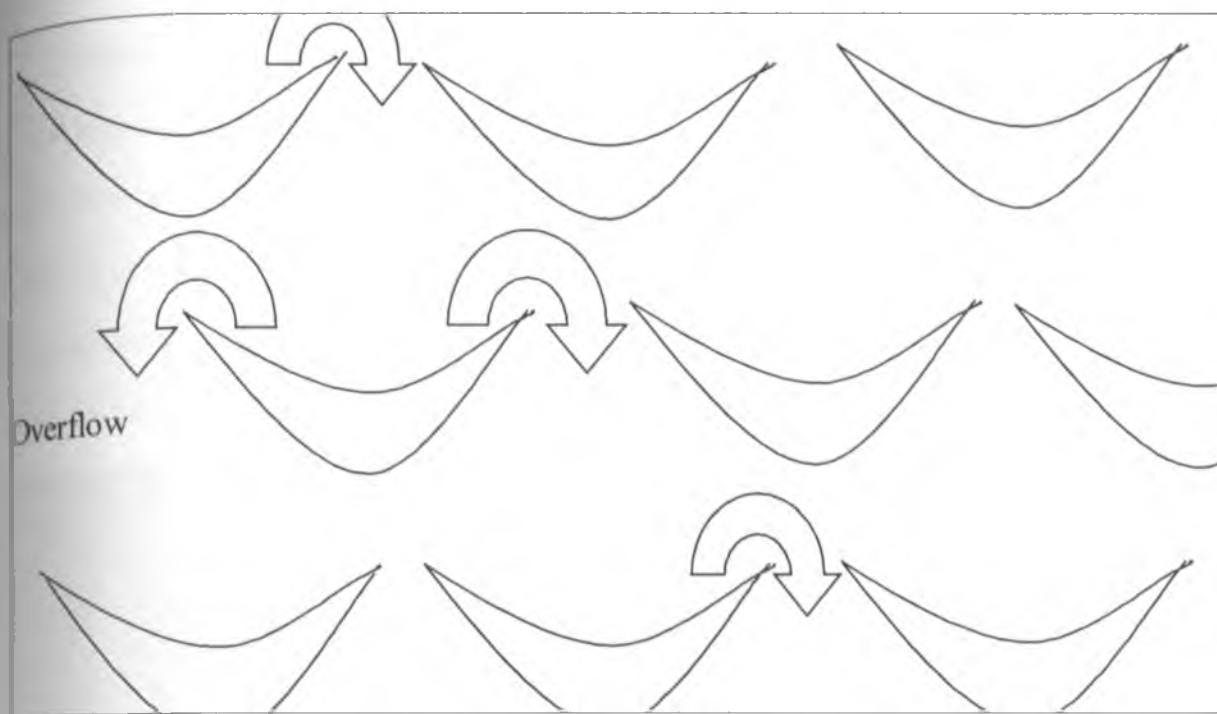


Figure 7.1. Schematic presentations of pits in a staggered row arrangement and block arrows shows movement of runoff overflow from one pit to the next down slope.

7.2.4. Seeds collection and sowing

Four grass species were selected earlier for this study on the basis of the community survey results on important perennial forage grasses that were depleted in natural pastures (Chapter Four). These are namely *Cenchrus ciliaris*, *Chloris roxburghiana*, *Enteropogon macrostachyus* and *Eragrostis superba*. Since seeds of these grasses are not readily available in the market, they had to be harvested from natural stands at the KARI – Kiboko centre. Harvesting was done at the end of the long and short rainy seasons of 1999 following the procedures detailed in Chapter Five. The seeds were put in polyethylene sacks and kept in a cool dry traditional grain store until needed for planting.

Sowing was done using two methods; one was inter-seeding by broadcasting by hand on bare patches in undisturbed plots, and the other was spreading seeds by hand along pit crescents as demonstrated in Plate No. 7.1. Although no specific measurements were taken to estimate runoff harvest (water plus sediments), pitting effectiveness as a micro-catchment, ocular observations indicated that pits were quite effective in harnessing the runoff as shown in Plate 7.2.



Plate 7.1. Demonstration of placement of seeds while sowing in a pitted field.



Plate 7.2. Water collecting in pits harnessed from runoff.

Sowing was done in mid-October 1999 before the onset of the short rains, which is considered more reliable than the long rainy season of March to May and as has been done by Kitheka *et al.* (1994) and Keya (1997). However, the rains were below normal that season at both sites and as such a repeat sowing was done in mid-October 2000.

7.2.5. Germination test for soil seed bank

Top 5 cm soil samples were collected using the soil corer 5-cm in diameter from each sub-plot for soil seed bank estimation by the germination method (Boutin and Harper, 1991). Samples were taken from each of two sites at the end of a growing season when the mature plants had shed seeds. The soil samples were spread on separate trays to air dry under shade. The soils were then crushed gently and sifted to eliminate other plant parts and stones. The sifted samples were sub-divided in two equal sub-samples by weight and each spread in petri dishes and watered regularly using distilled water.

Emerging seedlings were identified and counted every week for eight weeks. [It was assumed that since the normal rainy seasons last slightly over two months (D.K. Musembi – pers. com.), then any seed not germinating after this period will not do so, possibly until the following season.] Sixty-four trays were prepared thus: 2 sites x 4 treatments plots x 4 samples treatment¹ x 2 sub-samples. The emerging seedlings were counted and multiplied by a factor of 6.37 to derive the equivalent number in an m².

These seedling count values were then compared between sites.

7.2.6. Soil sampling and soil moisture estimation

Soil moisture was estimated by following the gravimetric method (ARC, 1962). Soil samples were collected by auguring at two depths, 0-15 and 15-30 cm. This was

done along the three permanent transects adjacent to the 4 quadrants for each of the four treatment plots in both replications in which herbaceous vegetation data were obtained. Sampling was repeated seasonally six times from the two sites at each experimental treatment plot over a period of 18 months between December 2001 and June 2002. Each soil sample put in a polythene bag and weighed immediately using a spring balance at the site. The samples were then transported to the KARI – Kiboko laboratory for oven drying at 100°C. Soil moisture (%) was then derived by expressing the loss in soil sample weight as a percent of the field weight.

7.2.7. Seedling counts and population estimation

Four quadrants out of the 48, each measuring 0.5 m², were selected at random for seedling counts in each treatment plot. All seedlings that could be identified by species for the four grasses used in re-seeding were counted. This was first done 2 months post sowing in December 1999 and six more times thereafter up to June 2002. Both long and short rainy season seedling cohorts were counted. The seedling counts were then doubled to obtain the population density (No. m⁻²).

7.2.8. Herbaceous standing crop

Herbaceous species dry matter (DM) standing crop was estimated using the double sampling technique (ARC, 1962; SRM, 1983). Visual herbage estimates (g) were done in four quadrants, after which, clipping was done at 5 cm above ground in two of the quadrants. Clipped material was put in labeled brown paper bags and transported to the research centre for oven drying at 100°C for 48 hours. Dry matter estimates were converted to g m⁻² then summarized into four components; the four treatment-grasses used in re-seeding, other perennial grasses, annual grasses and forbs.

7.2.9. Data analysis

GLM procedures were used to analyze for possible effects of treatments, dates of sampling, site and replication as well as their interactions on seedling population and standing crop dry matter estimates. SAS Version 8 for MS Windows was used.

7.3. RESULTS AND DISCUSSION

7.3.1. Woody species density

Totals mean density of woody species was similar between the two sites (Table 7.1). Major species were equally represented in the two sites except *Grewia similis* and *Triumfetta flavescens*, of which the former was more abundant in Merueshi and the latter in Kavatini. The most common shrub species were *Sericocomopsis hildebrandtii*, *G. similis*, *G. bicolor* and *G. villosa*; *Hibiscus aponeurus*, *Hoslundia opposita*, *Astripomoea hyocyamoides* and *Duosperma kilimandscharicum*. There were also scattered trees which were common to both sites, mainly *Acacia* and *Commiphora* species.

Table 7.1. Mean total density (N=3) of woody species (No. Ha⁻¹) at the two on-farm reseeded study sites in 1999.

SITE	TREATMENT	WOODY DENSITY	STD DEV.
Kavatini	Seeding	12, 900	7, 275
	Pitting	11, 835	8, 531
	Pitting & seeding	22, 500	3, 536
	Control	17, 000	11, 068
	Mean	16, 059	7, 602
Merueshi	Seeding	12, 375	2, 562
	Pitting	13, 625	4, 365
	Pitting & seeding	13, 000	2, 739
	Control	12, 645	3, 376
	Mean	12, 911	3, 260
Merueshi - unfenced	Seeding	13, 100	8, 292
	Pitting	11, 685	4, 341
	Pitting & seeding	13, 600	2, 381
	Control	12, 850	2, 381
	Mean	12, 809	4, 348

7.3.2. Woody canopy cover

Mean percent canopy cover was significantly ($p < 0.001$) different between the sites (Table 7.2). Merueshi had a higher cover with a mean of 69.16% compared to 30.48% for Kavatini. This was because unlike Kavatini, Merueshi does not have a history of both cultivation and charcoal burning.

The site at Kavatini had evidence of past cultivation and as such woody species re-establishment had not attained the level observed in adjacent areas that had not been disturbed. The neighbouring area seemed not only richer in floral diversity but also had greater woody canopy cover although herbaceous under-story was almost depleted. On the

other hand, much of the tree cutting at Merueshi had been done in the process of constructing houses and enclosures (kraals / bomas) for holding livestock at night.

Table 7.2. Mean canopy cover (%) of woody species (N=3) at the two on-farm reseeding study sites in 1999.

SITE	TREATMENT	WOODY CANOPY COVER	STD DEV.
Kavatini	Seeding	33.10	15.912
	Pitting	15.04	5.900
	Pitting & seeding	11.58	6.207
	Control	62.19	39.447
	Mean	30.48	16.867
Merueshi	Seeding	60.25	40.593
	Pitting	53.13	37.915
	Pitting & seeding	103.63	31.710
	Control	59.61	35.146
	Mean	69.16	36.341
Merueshi - unfenced	Seeding	38.26	26.777
	Pitting	41.53	12.481
	Pitting & seeding	41.95	12.427
	Control	118.70	22.627
	Mean	60.11	18.578

7.3.3. Soil seed bank estimation in the laboratory

From the baseline soil samples, seedlings of monocotyledonous plants were not significantly ($p > 0.05$) different between the two sites. However, those of dicots were significant ($p < 0.0001$) between the sites; Merueshi had a higher mean count of 12.33 than Kavatini with 7.34 seedlings per m^2 . Seedling counts varied significantly ($p < 0.0001$) from day to day. Out of the monocot counts, none were for the four

experimental grasses used in this study at Merueshi. However, approximately 10.41% of the monocot counts at Kavatini comprised these grasses, namely *C. roxburghiana* (6.20%) and *C. ciliaris* (4.21%). However, owing to high mortality rates of seedlings when they were too tiny for identification, data from subsequent soil sampling was discarded.

The soil seed bank, the store of seeds buried in the soil, is composed of seed stock of two possible origins; that produced by plants in the area plus that brought in from elsewhere by agents of seed dispersal. These agents include wind, runoff and animals (on their hair or wool and dung) (Pratt and Gwynne, 1977; Tolsma, 1989; Veenendaal, 1991; Keya, 1998). Depending on their state, seeds in the soil will germinate when appropriate conditions prevail; these are water and temperature. However, unfavourable drought conditions soon after germination may lead to 100% seedling mortality. In subsequent growing seasons, some more seeds germinate and the lot may face the same fate. Still seed reserves could encounter dangers such predation and diseases, eventually the whole seed bank are depleted (Harper, 1979; Chapin and Bliss, 1989). In short, both biotic and abiotic factors have a direct effect on the fates of individuals through their action on germination, growth pattern, reproduction and death.

7.3.2. Soil Moisture

Soil moisture estimates showed significant ($p < 0.05$) variation with time of sampling, depth, site and most interactions thereof (Table 7.3).

Factors that influenced soil moisture the most were date of sampling, site and depth – in that order. Treatment, replication and quadrant did not significantly ($p > 0.05$) affect soil moisture. However, with an R^2 of 0.47 for the model, it is suggestive that

there are other strong factors that would influence soil moisture at the two experimental sites such as soil type and rainfall amount, its distribution and evapo-transpiration (Black, 1963; Russell, 1988; Keya, 1998).

Table 7.3. Mean soil moisture (%) level at the two experimental sites shown by date and depth during 2000/02 study period, (N=32).

Date		Kavatini		Merueshi	
		0-15 cm	15-30 cm	0-15 cm	15-30 cm
Dec 2000	Mean	11.46	13.47	11.04	11.84
	Std Err	1.038	0.738	1.042	0.655
Feb 2001	Mean	10.84	11.16	7.34	10.47
	Std Err	1.190	0.904	0.783	0.679
May 2001	Mean	5.04	9.36	4.38	7.09
	Std Err	0.758	2.783	0.556	1.251
Jan 2002	Mean	7.46	6.96	11.10	7.54
	Std Err	0.753	0.706	2.269	0.867
May 2002	Mean	6.15	7.52	8.38	9.98
	Std Err	0.340	0.273	0.625	1.612
June 2002	Mean	6.88	6.43	6.04	7.42
	Std Err	1.389	0.270	1.208	0.530

The effect of date of sampling on soil moisture stems from some of the dates falling in the dry and others in the wet seasons. Dates here were therefore a reflection of seasonal rainfall patterns, which almost entirely forms the source of soil moisture recharge at the study sites as is true of other arid and semi-arid rangelands in Kenya (Keya, 1997; Ekaya *et al.*, 2001). Significant site effect was likely also as a result of difference in amounts of rainfall received at the two sites. It may also be due to probable difference in soil capacity for infiltration and moisture retention on site. Lower depths of

the soils had higher moisture content most of the time because the top part, being largely bare, was more exposed to the sun and heat and thus experience greater evaporation. The topsoil is also the zone within which most annual plants' roots are found thus placing a greater demand through transpiration leading to faster soil desiccation. The exception was in January 2002 when the topsoil was wetter at both sites and this could have been caused by a drier 2001 year, which had led to depletion of soil moisture to greater depths. The December / November 2001 rains may thus have not recharged the lower horizons sufficiently by the time of sampling. Such a situation adversely affects the survival of flora that is deep rooted and benefit those rooted shallow and hence encourage bush infestation (Polley *et al.*, 1995).

Lack of significant treatment effect (Appendix Table 7.1) implies that pitting, as a micro-catchment for water harvesting technique, did not meet the intended purpose. Probably this was due to relative flat land ($< 2.5\%$) on which the experiments were set up (Fidelibus and Bainbridge 2004); Kavatini was particularly flat but even Merueshi with 2.27% slope pits did not matter as far as soil moisture is concerned since treatment by site effect was insignificant. In addition, capping due to soil surface sealing was not evident in the two sites and as such infiltration impediment was probably not high. Nonetheless, the usefulness of pits in water harvesting was seen in Plate 7.2.

However, it is to be recognized that there are other benefits derived from pitting such as trapping or catching wind and water borne seeds and organic matter and provision of a more suitable environment for plant emergence and growth (Fidelibus and Bainbridge, 1994; 2004). Mbakaya (1986) reported that almost $2,000 \text{ kg ha}^{-1}$ of soil sediment is produced on bare ground with less than 5% slope at Bachuma, much of which

is the fertile top soil and could be curtailed using micro-cathments such as pits.

Therefore, further studies may be necessary on this subject.

7.3.4. Seedling population

Seedling counts were analyzed for variation between dates of sampling, sites and treatments. Generally, all four factors had highly significant ($p < 0.0001$) effects on total seedling populations (Appendix Table 7.2a). The overall total number of seedlings averaged 3.74 per 0.5m^2 . Mean seedling populations were highest under pitting and reseeding for all grasses (Figure 7.2). The second in abundance of seedlings was reseeding alone while the lowest seedling population was under the deferment without reseeding treatment.

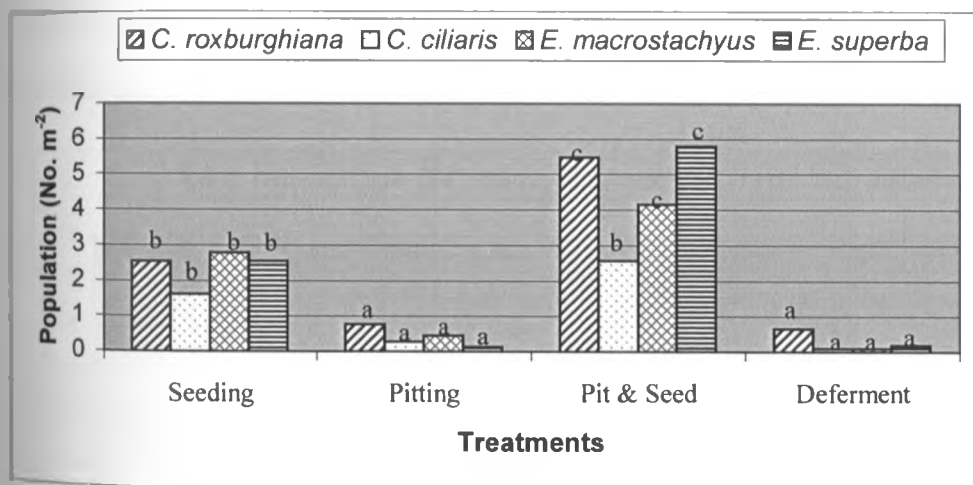


Figure 7.2. Treatment effect on the overall mean seedling populations (No. m^{-2}) of four grasses averaged across two sites (Kavatini and Merueshi) over the entire study period, 1999-2002 regardless of season. Bars between clusters with similar letter are not significantly ($p > 0.05$) different.

Individual grass species followed a similar pattern (Fig. 7.3; Appendix Table 7.2b-e). However, within treatments, species performed differently. For instance, in

reseeding alone *C. ciliaris* seedling population was the lowest, significantly lower than the other three grasses whose seedling populations were similar. Under pitting and reseeded, *C. ciliaris* still had the least seedling population followed by that of *E. macrostachyus* while the highest populations were those of *C. roxburghiana* and *E. superba* which were similar. Kavatini site had nearly three-fold the total population when compared with Merueshi. For all four species, re-seeding resulted in significantly ($p < 0.05$) higher seedling populations at Kavatini than at Merueshi.

At Kavatini all grasses, except *C. ciliaris*, had almost twice as many seedlings under pitting and reseeded than reseeded alone (Fig. 7.3). Also at Kavatini, pitting and reseeded had nearly 6-fold the seedling population of the four sown grasses compared to deferment alone. However, pitting had no significant ($p > 0.05$) effect on *C. ciliaris*. Treatment effects were less dramatic at Merueshi, where for instance pitting and reseeded did not significantly ($p > 0.05$) affect *E. macrostachyus* seedling population.

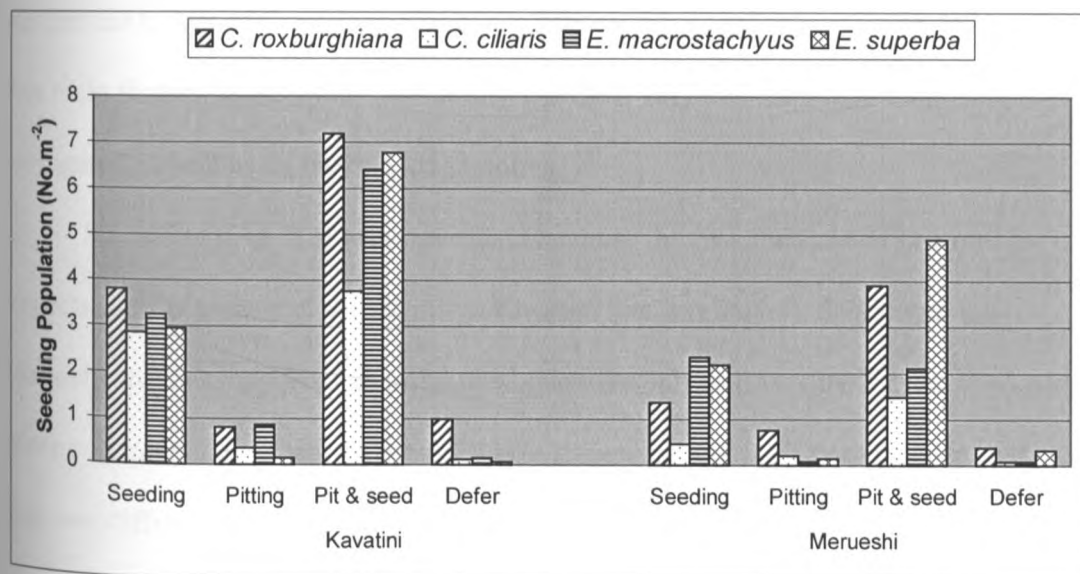


Figure 7.3. Site comparisons of overall mean populations (No. m⁻²) of four grasses in subjected to four treatments (averaged over the entire study period, regardless of season during 1999-2002).

The four grasses also differed in their response to the first, second and third level of the various factor interactions. On average both interactions between treatments and replication as well as treatment and site affected seedling population to a varying extent (Appendix Table 7.2b-e). Of the 15 factors used in the model, only date by replication by treatment interaction did not affect the populations in total. The least affected species was *E. macrostachyus* with more than half of the factors not effecting significant change in seedling population while the most affected was *E. superba* with 12 of the factors effecting a significant ($p < 0.05$) change.

Lack of significant effects on *E. macrostachyus* seedling populations by the various interactions was most likely a potential adaptability attribute. Unlike the other three grasses, *E. macrostachyus* was unaffected by replication (Appendix Table 7.2d). Therefore, this grass has the potential to establish in a wider area when sown in a farm, implying that it has a greater adaptation potential to microenvironments. This pattern was similar to that of *C. roxburghiana*. On other hand, *C. ciliaris* was affected by all four main factors; its seedling population depended very much on where and how it was propagated as well as on the date of sampling.

Site effect (Fig. 7.4) was significant because the two sites varied in a number of respects such as slope and soil fertility. Kavatini was a relatively flatter area than Merueshi and this may have an influenced rainwater infiltration, runoff generation and hence soil moisture. Data in Table 7.4 also shows that the fertility of soils from the two sites was different with that from Kavatini being richer in most elements. The apparent higher fertility of Kavatini soil may be a reflection of the site's shorter history of

settlement compared to Merueshi. Kavatini soil had twice as much organic carbon, which is essential in soil water holding capacity and biological activities (Young, 1997).

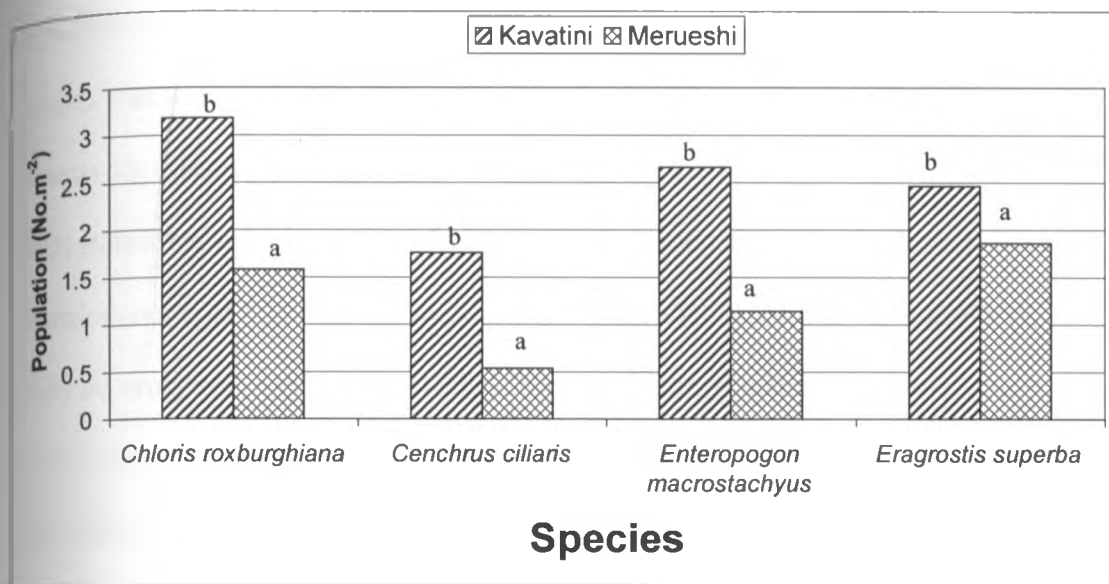


Figure 7.4. Species comparison of overall seedling populations (No.m⁻²) at the two on-farm experimental sites averaged across the four treatments (re-seeding, pitting, pitting plus reseeded and deferment) and over the entire study period 1999-2002.

Table 7.4. Mean ($\pm$ SE) levels of soil condition and nutrient overall comparison between sites used for on-farm re-seeding trials in Makueni and Kajiado districts (N=96).

Soil condition / Nutrient	Site	
	Kavatini	Merueshi
pH	6.86 $\pm$ 0.043	6.47 $\pm$ 0.042
Organic Carbon (%)	1.13 $\pm$ 0.052	0.67 $\pm$ 0.040
Phosphorus ppm (M)	160.22 $\pm$ 7.731	107.81 $\pm$ 4.450
Potassium me (%)	1.11 $\pm$ 0.033	1.10 $\pm$ 0.029
Calcium me (%)	6.34 $\pm$ 0.565	4.27 $\pm$ 0.526
Magnesium me (%)	4.22 $\pm$ 0.151	5.44 $\pm$ 0.881
Manganese me (%)	0.47 $\pm$ 0.022	0.40 $\pm$ 0.026
Copper ppm	4.61 $\pm$ 0.110	4.32 $\pm$ 0.113
Iron ppm	95.73 $\pm$ 2.851	87.69 $\pm$ 3.158
Zinc ppm	3.34 $\pm$ 0.206	2.22 $\pm$ 0.263
Sodium me (%)	0.60 $\pm$ 0.036	0.53 $\pm$ 0.032

Both soil moisture and microorganisms are essential for the initial root development of a plant (Black, 1967; Russell, 1988). Phosphorus and iron are two elements that were more abundant in Kavatini than in Merueshi soils. These two elements are essential in the growth and development of plants (Young, 1997). Tate (1995) stated that organic matter, of which organic carbon and nitrogen are constituents, is a major source of nutrients and any variation in its abundance may have profound effects on ecosystem well-being. Besides being a source of nutrients, organic matter holds water and other nutrients in available form, promotes soil aggregation and root development, and improves water infiltration and water-use efficiency (Allison, 1973). In addition, grazing history of an area influences the response of organic matter to grazing (Manley *et al.*, 1995; du Preez and Snyman, 2003). Therefore, given the soil fertility coupled with variation in amount and distribution of rainfall the effect of site becomes even more apparent. Marietta and Britton (1988) also observed in Texas that apart from year, site was the most important factor in establishment success of grasses.

Generally, all the four grasses at Kavatini had more seedlings with pitting plus seeding treatment than with seeding alone and this was in turn superior to pitting alone while deferment had the lowest. At Merueshi, the trends were similar except that *E. macrostachyus* responded differently in that seeding alone had the same seedling counts to seeding in pitted plots (Fig. 7.3). This could be as a result of relatively large awnless seeds of this grass, which are capable of establishing good contact with the soil (Pratt and Gwynne, 1977; Boonman, 1993). It has also been reported that grass seeds are highly

hygroscopic and as such they tend to find their way down through, say, litter thus reaching and burrowing into the soil (Sheldon, 1974; Peart, 1984).

The implication of this result is that under conditions similar to those at Merueshi, *E. macrostachyus* seedbed preparation may not be necessary. The same may apply for *C. ciliaris* under the Kavatini conditions. Low germination tendency by *C. ciliaris* was also observed in Marsabit where even with 77% FC soil moisture; germination was less than 4% (Keya, 1998).

Date effect was due to seasonal differences since some of the sampling dates were during the dry season while others were either at the beginning or end of a wet season (Fig. 7.5).

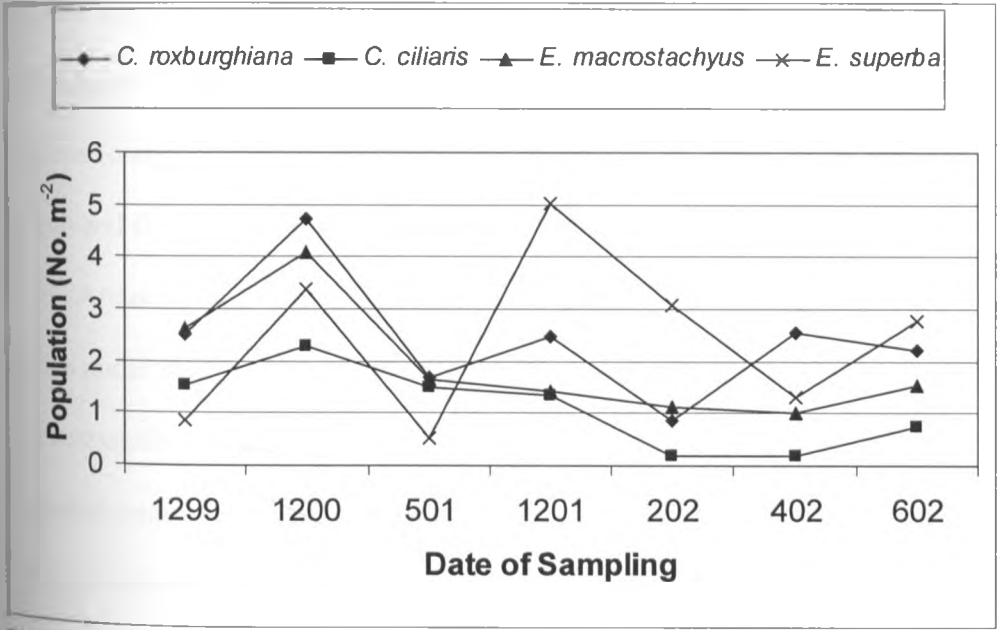


Figure 7.5. Seasonal species comparison of seedling populations (No. m⁻²) averaged across two on-farm experimental sites (Kavatini and Merueshi) and four treatments (re-seeding, pitting, pitting plus reseeded and deferment) during the study period December 1999 to June 2002.

Infant seedling mortality was apparent at the end of the dry season and this has been reported before in other studies (for example Woie, 1984), particularly for *C. roxburghiana* and *E. superba* which probably accounts for the greater population dynamics between dates. Further, rainy seasons differ in amount and distribution of rainfall, and this phenomenon was exhibited during this study (Chapter Four). Bearing in mind the significant variation in seedling populations effected by watering regimes (Chapter Six); similarly rainfall may have influenced the recruitment and mortality of new seedling cohorts in the field. Before an individual plant is said to have successfully established itself in a given site, it must go through not only germination but also growth to maturity, reproduction and seed dispersal (Harper, 1979; Chapin and Bliss, 1989; Veenendaal, 1991). Seedling survivorship is closely related to rainfall amount and soil type and plant species vary in their capacity to survive after germination. This is largely due to their variation in adapted morphology (especially root biomass) and water relations (osmotic potential and stomatal conductance) (Harper, 1979; Russell, 1988; Chapin and Bliss, 1989; Boutin and Harper, 1991).

Areas that were not re-seeded showed presence of seedlings of some of the species under study with passage of time. It is possible that natural seed dispersal agents were responsible for this. Thus, some seeds may have escaped from mature plants in the re-seeded areas probably blown over by wind or washed across by runoff. This would be true especially for small seeds like those of *C. roxburghiana*, which at 30 months into the study had a substantial establishment in the control treatment. This grass had performed relatively poorly at both the laboratory and potting stages but surprisingly it had high populations at both sites and in each treatment by the end of the study period (Fig. 7.3).

The grass's performance compared well with that of the other three grasses, especially under reseeding without pitting or pitting alone. At Kavatini in particular, *C. roxburghiana* had the highest seedling population under deferment without reseeding. Nonetheless, seedling population was quite low and it would take a long time to adequately re-vegetate these plots using this approach. In deed, natural re-vegetation after deferment of depleted range sites has been known to be a slow process requiring up to 20-40 years under favourable conditions (Stoddart *et al.*, 1975; Lusigi, 1981; 1984; Hacker, 1989; Keya, 1997).

The model used in the analysis of these data apparently did not account for much of sources of variation in seedling populations based on the low R^2 values observed. Other factors that would influence seedling population are seed quality (Carrenet *et al.*, 1987; Boonman, 1993), seed dormancy (Coyne and Bradford, 1985; Veneedaal *et al.*, 1991), seeding rate, rainfall and possibly presence of other vegetation. The R^2 tended to improve with size of seeds given that in the form they are planted (whole seed rather than naked caryopses); *C. roxburghiana* has the smallest size while *E. superba* has the largest. In Chapter Five and Chapter Six, it was demonstrated how the species varied in their rates of germination and establishment under controlled conditions. This has shown that seed size variations contributed to some of the differences observed in this field trial. Nonetheless, with *C. roxburghiana* as an example, the grasses' behaviour under one set of test conditions can not be used to generalize or predict their response to a different kind of performance test, particularly under field conditions. This is in agreement with similar observations in Australia (Loch and Ferguson, 1999).

7.3.4.1. *Effect of fencing*

Fencing very significantly ($p < 0.0001$) affected seedling population, with variations observed between the four grass species (Table 7.5). Generally, at the end of the study, there was many-fold the numbers of seedlings of most grasses within the fenced area than in the unfenced area.

Table 7.5. Mean ($\pm$ SE) per 0.5 m² of total seedling populations of four grasses sown at Merushi in Kajiado with or without fencing during year 2000-2002, N=32.

Sampling	Treatment	Fenced	Unfenced
1 (2 months post sowing)	Seeding	1.04 $\pm$ 0.683	2.03 $\pm$ 1.559
	Pitting	0.04 $\pm$ 0.000	0.04 $\pm$ 0.000
	Pitting & seeding	0.04 $\pm$ 0.000	4.28 $\pm$ 2.597
	Control	0.04 $\pm$ 0.000	0.04 $\pm$ 0.000
5. (8 months post sowing)	Seeding	4.40 $\pm$ 1.146	0.66 $\pm$ 0.374
	Pitting	0.29 $\pm$ 0.162	0.16 $\pm$ 0.124
	Pitting & seeding	5.91 $\pm$ 1.931	0.29 $\pm$ 0.162
	Control	0.04 $\pm$ 0.000	0.29 $\pm$ 0.249
8. (18 months post re-seeding)	Seeding	3.66 $\pm$ 1.904	0.41 $\pm$ 0.181
	Pitting	4.02 $\pm$ 1.221	0.29 $\pm$ 0.162
	Pitting & seeding	7.15 $\pm$ 2.635	1.90 $\pm$ 0.512
	Control	0.21 $\pm$ 0.166	0.16 $\pm$ 0.124

Initially, however, the unfenced plots had a high seedling population. This was probably due to a contribution of hoof effects by livestock and other animals prevalent in Merueshi that may have aided in seedbed improvement (Pratt and Gwynne, 1977; Herlocker, 1999). Subsequent counts dwindled and were negligible by the end of the study. The rapid decline in seedling population may be explained by a failure of the

seedlings to reach maturity due to premature grazing. Thus, no seeds were produced to replenish the soil seed stock, subsequently depleting it over time. Fencing in such studies, therefore, is a true treatment than a control, as has been mistaken before (Too, 1995).

Further, all available literature emphasizes the need to protect a reseeded area from herbivory and the related damage from trampling for a minimum of one growing season. This allows the plants to develop fully, and where applicable, until they produce and shed seeds before opening up the area for grazing. Even then, only light grazing is advised (Bogdan, 1977; Pratt and Gwynne, 1977; Veenendaal, 1991; Boonman, 1993; Herlocker, 1999; RELMA, 1999; Mnene *et al.*, 2000; Ludwig *et al.*, 2003). This is because seedling damage interrupts growth and impairs their chance of survival. It has also been shown that insects and their larvae could inflict serious damage to plants (Kinyamario, 1986; Keya, 1998).

7.3.5. Herbaceous standing crop

Dry matter production of all the four grass species were affected significantly ($p < 0.01$) by both site and treatment. In addition, *C. roxburghiana* and *E. macrostachyus* dry matter production was affected by replication, while date of sampling had no significant ($p > 0.05$) effect on any of the species except forbs and annual grasses. For all four species, the R^2 was low, ranging from 0.37 to 0.51.

Generally, Kavatini had more dry matter production than Merueshi (Table 7.6). The combined pitting and re-seeding treatment had the highest production while the least was in the deferment plots (Table 7.7). Most of the second and third level factor interactions significantly affected the total dry matter of the four grasses (Appendix Table

7.3a-e). Date, site and replication but not treatment affected the other associated herbage categories (perennial and annual grasses and forbs) (Appendix Table 7.3f-h).

Table 7.6. Mean ($\pm$ SE) dry matter (g m^{-2}) production of four grasses and other categories of plants at Kavatini Makueni and Merueshi in Kajiado across four treatments and four growing seasons between 2000 and 2002.

Species / category	Kavatini (N=192)	Merueshi (N=192)
<i>Cenchrus ciliaris</i>	12.63 $\pm$ 1.966	1.12 $\pm$ 0.416
<i>Chloris roxburghiana</i>	6.13 $\pm$ 1.813	2.66 $\pm$ 0.668
<i>Enteropogon macrostachyus</i>	6.29 $\pm$ 1.283	1.22 $\pm$ 0.446
<i>Eragrostis superba</i>	6.59 $\pm$ 1.464	0.80 $\pm$ 0.281
Total experimental grasses	19.21 $\pm$ 2.968	4.73 $\pm$ 0.893
Other perenual grasses	7.75 $\pm$ 1.043	5.66 $\pm$ 0.850
Annual grasses	29.97 $\pm$ 3.264	5.63 $\pm$ 1.054
Forbs	135.74 $\pm$ 11.767	64.90 $\pm$ 8.303
TOTAL	206.93 $\pm$ 14.072	79.14 $\pm$ 8.739

Factors that influence dry matter production are many. In this study, it was demonstrated that up to 50% of dry matter production variation could be explained by season (meaning rainfall), site and location within the site / farm, seedbed preparation or sowing method. In the earlier trials with pitting (Mututho, 1989; Gichangi *et al.*, 1989; Simuyu *et al.*, 1992; Kitheka *et al.*, 1994), accumulation of runoff water and sediments was reported which was also observed in this study (Plate 7.2.). However, greater seed germination and subsequent biomass was achieved in this study than what was reported by the earlier workers probably because of how seeds were sowed. Kitheka *et al.* (1994)

placed the seeds of *C. gayana* and *Stylosanthes guianensis* in the pits, which probably resulted in most of them been buried too deeply, thus failed to emerge on germination hence reducing the potential of increased dry matter production. Placing the seeds on the pit crescents / ridges may have minimized that risk in this study. Therefore, this is an area requiring a follow-up study to compare the two approaches of sowing seed in a pitted field.

Table 7.7. Mean ($\pm$ SE) dry matter (g m^{-2}) production of four grasses and other categories of plants under four treatments averaged across two sites (Makindu in Makueni and Merueshi in Kajiado) and four growing seasons between 2000 and 2002, N=48.

Species / category	Seeding	Pitting	Pitting & Seeding	Control
<i>Cenchrus ciliaris</i>	8.24 + 2.204	1.40 + 0.802	14.57 + 2.759	2.17 + 1.503
<i>Chloris roxburghiana</i>	11.68 + 2.50	0.24 + 0.172	5.28 + 2.588	0.24 + 0.109
<i>Enteropogon macrostachyus</i>	8.25 + 1.991	0.16 + 0.091	6.17 + 1.632	0.00 + 0.00
<i>Eragrostis superba</i>	5.90 + 1.695	0.58 + 0.440	7.42 + 2.196	0.25 + 0.204
Total four reseeded grasses	26.22 + 4.053	0.98 + 0.475	18.87 + 3.931	0.49 + 0.240
Other perenual grasses	7.41 + 1.397	7.07 + 1.371	5.26 + 1.218	7.09 + 1.375
Annual grasses	21.05 + 4.448	17.74 + 3.182	14.83 + 2.942	15.49 + 3.700
Forbs	108.11 + 15.539	87.70 + 11.593	87.60 + 11.694	109.41 + 20.732
TOTAL	170.06 + 19.406	114.92 + 13.798	145.07 + 15.703	134.74 + 22.761

Biomass accumulation depends on several factors but most importantly it requires that a plant has a high water use efficiency (in terms of extraction and use) and an efficient energy capture mechanism (especially many or large leaves that are

biochemically active) (Johnson, 1984; Arnon, 1992). In this study, dry matter production at Kavatini was higher than at Merueshi with variation between species. In particular, *C. ciliaris* was 53.13-85.39% more productive than all the other three grasses, whose biomass production was similar. Earlier, this grass had shown a high tiller and leaf production (Chapter Six), the latter of which are usually relatively larger than those of *E. macrostachyus*, the leafiest of the four grasses (Bogdan 1977; Boonman 1993). This, therefore, explains the higher biomass production by *C. ciliaris*. For example, at Kavatini *C. ciliaris* averaged $12.63 \pm 1.966 \text{ gm}^{-2}$ compared to $6.29 \pm 1.23 \text{ gm}^{-2}$ for *E. macrostachyus*. Also, in Chapter six it was demonstrated that potted plants depicted a similar trend with respect to biomass production with *C. ciliaris* producing 81.51-296.46% more biomass than the other grasses. In that experiment, as in this one, the ranking of the four grasses in terms biomass production was *C. ciliaris* > *C. roxburghiana* > *E. macrostachyus* > *E. superba*.

On the other hand, at Merueshi, *C. roxburghiana* was the superior species with $2.66 \pm 0.668 \text{ gm}^{-2}$. This is in agreement with Keya (1998) who reported that *C. roxburghiana* out-yielded *C. ciliaris* by more than 20%. In this case *C. roxburghiana* actually had twice as much yield as *C. ciliaris*. Possibly this particular species has not only a higher water use efficiency but also a lower nutrient requirement and a higher xeric adaptative capacity suggesting that it may serve as a pioneer in restoration of degraded arid areas after which those grasses with higher water and soil fertility requirements can follow. Work elsewhere has indicated that natural mixed grass stands shift their species composition when subjected to certain long-term fertilization regimes (Prof. K. Kirkman at the Ukulinga Research Station, Republic of South Africa). Kerridge

et al. (1992) reported low *C. ciliaris* persistence in soils with low phosphorus levels. Indeed, at Merueshi this grass was virtually missing and it may have disappeared due to diminishing fertility over time.

Disappearance of *C. ciliaris* in Merueshi may also be due to continuous overgrazing because Merueshi has a longer history of pastoral grazing than Kavatini which was settled more recently by agro-pastoralists. The grass is palatable (Boonman, 1993) and tends to regenerate quickly after the first rains (Mnene *et al.*, 1995). Therefore, animals are likely to select it thus stressing it further.

Further, in comparing species dry matter production under seeding alone with seeding on pits, it was observed that *C. roxburghiana* performed better with the former approach than in the latter while, the performance of *C. ciliaris* was the reverse. Performance of the other two species was unaffected in this respect. The unaffected species, *E. macrostachyus* and *E. superba*, could be having a wider adaptation to varying conditions. Therefore, though reseedling as a range management technique begun many decades ago with monocultures (Stoddart *et al.*, 1975; Valentine, 1979), these results re-emphasize not only the need to use native species (Jordan, 1957; Fredenslung and Cassady, 1969; Cook and Stubbendiek, 1980) but also plant mixtures. This is because all areas have varying conditions of soil, moisture and slope. In a mixture, each species may produce more abundantly on the site more nearly supplying its optimal needs (Stoddart *et al.*, 1975). The results also point out that site- and method-specific recommendations are necessary. In drier areas with low fertility such as Merueshi, using *C. roxburghiana* would be advantageous but without pitting while *C. ciliaris* would require some form of seedbed preparation and some form of water harvesting for a good

establishment. Stuth and Dahl (1972) reported that with intensive seedbed preparation and seeding methods reseeding success rates can be raised from an average of 30% which is considered normal in Texas to 65-100%.

The results also compare well with dry matter values obtained under natural herbaceous stands elsewhere; Coughenour *et al.* (1990) in Turkana District, Kinyamario and Macharia (1992) and Kinyamario and Imbamba (1992) both in the Nairobi National Park, Too (1995) in Kiboko and Ekaya *et al.* (2001) in Baringo district. The example in Baringo (Ekaya *et al.*, 2001) recorded 84.6-295.4 gm⁻². But perhaps more critical is the boost in perennial grass contribution to the total herbaceous standing crop realized in this study. There was approximately 356% more of the four re-seeded grasses than the other perennial grasses, in plots dominated by annual grasses and forbs. These other perennial grasses contributed less than 0.5% of the total standing crop compared to 6-10% by the four perennial grasses. Although Mututho (1989) and Kitheka *et al.* (1994) observed that pitting seemed to encourage a proliferation of forbs and annual grasses rather than the intended species, this does not appear to be the case in this study. In fact pitting had no significant effect on the relative abundance of other perennials, annual grasses and forbs.

Range degradation is closely tied to continuous over-utilization of a given area by livestock leading to loss of vegetation cover and loss of topsoil. More animals and longer period of use, therefore, would be integral factors influencing the chances of success in restoration efforts. That may explain why site had a significant effect on the seedling populations and subsequent dry matter production, especially given that the number of livestock is many-fold in Kajiado than in Makueni as reported in Chapter Four. Merueshi Division has continuously been a pastoral area, whereas communities from over-

populated parts of Machakos District have only recently settled Kavatini during the last 40 years.

Long term removal of palatable and thus more preferred forage species depletes them, paving way to a possible dominance by the less preferred (Archer and Smeins 1991). Cattle and to a lesser extent sheep are grazers and as such they tend to deplete the grass component. However, due to herbivore selection of forages, in conditions that more preferred forages have been depleted, animals would select the less palatable plant species leading to outright denudation. Earlier work in this environment had showed that when herbage availability is limited, cattle tend to become less selective and consume whatever forage is available (Mnene, 1985; Mnene and Kibet, 1995; Mnene *et al.*, 1996). Two livestock species predominated in Merueshi namely cattle and sheep (Chapter Four) while wild grazers such as Eland, Kongoni, Wildebeest and Zebra was noticeably higher than in Kavatini. When combined with other factors of range degradation, such as droughts and termite use, the potential for successful restoration decline and that may further explain why at Merueshi, dry matter production was much lower than in Kavatini, regardless of plant category or species.

In addition, while on a large scale rainfall and temperature regulate vegetation dynamics in semi-arid systems (MacMahon, 1980; Sala *et al.*, 1988), frequent small scale perturbations may affect a plant community structure and function (Collins, 1987). The results, therefore, tend to agree with the argument that the impact of grazing on ecosystems varies in relation to the evolutionary history of a site and level of grazing pressure (Stebbins, 1981; Milchunas *et al.*, 1988; Archer and Smeins, 1991). For some of the situations, as is the case in the test sites under study, the previously dominating

grasses are gone and it is necessary to re-seed them (Plath, 1954; Stoddart *et al.* 1975; Pratt and Gwynne, 1977; Boonman, 1993; Too, 1995).

Although it has been recommended that seedbed preparation is adequate to stimulate native re-vegetation (Houston and Adams, 1971; Kitheka *et al.*, 1994), this was not demonstrated in this study. Without re-seeding, there was no difference between pitting and the control treatments. However, a longer period may be necessary to observe significant change in both species composition and biomass production. This will imply an increase in the opportunity cost of deferment.

NB: While sampling in the plots it was observed that there was a greater presence of rodents, birds, grasshoppers, snakes and ticks within the well established patches of grass. Therefore, reseeding probably created a better habitat for diverse fauna, which may be part of a food chain. However, the presence of ticks and snakes pose social and economic challenge and may become negative impacts of this undertaking since they directly or indirectly harm livestock and herdsmen.

7.3.6. Conclusion

The field results in this study show that passive approach of rehabilitation, particularly deferred grazing will not alone restore the previously dominating grass species in the short term. Therefore, the hypothesis tested was accepted. It is also possible to propagate in the field all the four selected grass species, namely *C. ciliaris*, *C. roxburghiana*, *E. macrostachyus* and *E. superba* from whole seeds. However, initial successful establishment largely depends on rainfall amount and distribution and therefore, repeated sowing may be required.

Further, since establishment was better at Kavatini than at Merueshi, site is an important factor to consider in reseeding and results achieved from reseeding one area may not necessarily be repeated in a different area with equal success. This is because sites differ in a number of respects, notably soil fertility, rainfall and history of grazing. In addition, farmer's personal commitment is critical to ensure that the new seedling establishment is not disturbed pre-maturely as the case in Merueshi unless fencing is effectively used.

Pitting aided in greater establishment of most of the grasses and subsequent DM production meaning that a form of seedbed preparation and micro-catchment is desirable in reseeding most grasses. However, some grasses and *C. roxburghiana* in particular did not benefit from pitting. A high seedling establishment initially may not necessarily lead to a higher DM production by some of the species, for example *E. macrostachyus*.

Re-seeded grasses attained maturity, produced seeds and new seedling cohorts realized in subsequent wet seasons, indicating that the restoration of degraded sites was sustainable. Therefore, it is possible to improve degraded natural pastures by pitting and reseeding with selected grasses, especially where deferment is possible during the establishment phase.

However, a number of questions were raised and remain unanswered thus calling for in depth studies. These include:

1. How to sow a pitted field in order to achieve the best establishment.
2. Effects of specific soil nutrients on germination, establishment and persistence of selected grasses are necessary.

3. Persistence of the established grass under varying regimes of utilization also requires investigation.
4. Since germplasm used in reseeding is often, as was the case in this study, obtained from other areas, there may be lack of adaptation by seeds used to local environmental conditions. The last concern is addressed in the next chapter.

CHAPTER EIGHT

8.0. GENOTYPING OF CHLORIS ROXBURGHIANA

8.1. INTRODUCTION

Chloris roxburghiana Shult. (Horsetail grass), a member of the Chloridoid group of grass tribes, is one of the most important rangeland grasses in tropical East Africa and southern India (Bogdan, 1977; Pratt and Gwynne, 1977; Boonman, 1993). This species is perennial, and occurs naturally from sea level to 1,500-m elevation, in open or bushed grassland. The herbage is of good grazing value containing up to 16% crude protein (Bogdan, 1977). The grass has also been observed to be highly palatable both to cattle (Mnene and Kibet, 1995; Mnene *et al.*, 1996), sheep and goats (Kamau, 1986) and to a number of wild herbivores (Ng'ethe and Box, 1976). It is a prolific seeder; each panicle contains about 1,000 seeds and harvesting is easy. The caryopses are small; 6.5 to 13 million seeds per kg (Bogdan 1977). In a survey among pastoral and agro-pastoral communities in southern Kenya (Mbogoh and Shaabani, 1999; Mnene *et al.*, 2000), *C. roxburghiana* was highly rated as a valuable forage species.

In Kenya, effects of drought, termites, cultivation, indiscriminate burning and overgrazing have resulted in diminished or total loss of population of some important forage species, especially grasses (Mbogoh and Shaabani, 1999; Mnene *et al.*, 2000). Deferred grazing is one way of rejuvenating degraded pastures (as reported in Chapter Seven) but significant improvement results take a long time to realize. Further, resilience of rangelands is not understood well yet (Mworia *et al.*, 1997). In the mid years of the twentieth century, re-seeding as a means of rehabilitating degraded rangelands was attempted with some

encouraging success by Jordan (1957) and Bogdan and Pratt (1967). At the close of the 20th century further attempts were made with trials in the pastoral and agro-pastoral settings of West Pokot, Makueni, Kajiado and Taita-Taveta districts to improve poor natural pastures (RELMA, 1999; Mnene *et al.*, 2000) with similar outcomes. A number of forage species, particularly grasses like *Cenchrus ciliaris*, *Chloris roxburghiana*, *Eragrostis macrostachyus* and *E. superba* were used because they were previously the dominant ones in these rangelands. This was the same rationale given in Chapter Seven.

Unfortunately in all these trials seed availability has been a major constraint since seed multiplication methodologies for most typical range grasses like *C. roxburghiana* has not been given much attention. Hence, seed materials for these re-seeding trials had to be collected from wild stands within protected farms / ranches such as KARI– Kiboko. Most of the Kiboko farm lies within the ecological zone V whereas the re-seeding trial sites are spread from zone IV to VI with variation within and between zones in terms of soil type, rainfall and modal plant communities (Pratt and Gwynne, 1977). At most of these re-seeding test sites, most of the mixtures of four grasses used performed dismally in terms of germination and seedling survival. This happens despite using higher seed rates than that recommended (Bogdan, 1977; Pratt and Gwynne, 1977; Boonman, 1993; Too, 1995).

The communities advanced various reasons for the low establishment success rate in the past but the main ones were unreliable rainfall and hence low soil moisture, premature grazing (Keya, 1997), damage by termites (Mbogoh and Shaabani, 1999; Mnene *et al.*, 2000) and use of seed that were not harvested, processed or stored properly (Chin and Wong, 1993; HSU, 1994). Chapters Five to Seven have attempted to address the various components of soils and soil moisture as well as seed quality as factors contributing to low

grass establishment success. One other possibility could be genetic differences between ecotypes occurring as a result of adaptation to unique environmental factors of specific sites (Nevo, 1988). Therefore, understanding of the level, structure and origin of genetic variation within and among populations of the forage species used in the re-seeding programme is essential for optimum management strategies for sustainable seed collection, utilization and conservation.

Molecular genetic markers can provide a relatively unbiased method of quantifying genetic diversity in plants (Williams *et al.*, 1990). Random amplified polymorphic DNA (RAPD) analysis is especially useful for unstudied taxa because prior DNA sequence information is not required. These markers have been used to fingerprint genotypes in phylogenetic studies of population diversity in different plant species (Gunter *et al.*, 1996; Graham *et al.*, 1997; Paran *et al.*, 1998; Lowe *et al.*, 2000; Agufa, 2002). This technique is sensitive, quick to perform and can be applied to a large number of samples. As a pilot run, *C. roxburghiana* was selected for this study. This is because it is one of those acclaimed to have a wide ecological adaptation (Pratt and Gwynne, 1977; Boonman, 1993) and yet it often fails to establish well. RAPDs was applied to assess the level of genetic variation within and between populations, of four spatially separated *C. roxburghiana* grass populations found in the southern Kenya rangelands. This was aimed at providing an important input to devising judicious selection criteria to source seed material. It is anticipated that the observed genetic variation could lend explanation to why seeds collected from one site do not establish well in other re-seeding sites and hence a more judicious selection scheme to source for seed material in future may be obtained. Genetic studies on indigenous African rangeland grasses are

limited and analysis of *C. roxburghiana*, therefore, provides an important contribution to this subject as well as data of more general relevance.

8.2. MATERIALS AND METHODS

8.2.1. Study site description

Four sites were selected for collection of plant samples in this study; Kiboko and Kavatini in Makueni District, Merueshi in Kajiado District and Kimala in Taita-Taveta District (Figure 3.1). All four sites are situated within ecological zone V (Pratt and Gwynne, 1977). No sampling was done in ecozone IV because (1) it was assumed that *C. roxburghiana* population variations would be more obvious between than within zones and (2) there were no reseeding trials sites in this zone at that time. However, within ecozone V where sampling was done there were variations with respect to soils (Table 8.1), modal plant communities (Pratt and Gwynne, 1977) and history of land use (Mbogoh and Shaabani, 1999). Except for Kiboko, the sites are representatives of areas where earlier on-farm research trials on re-seeding had been initiated (Mnene *et al.*, 2000). Commercial dealers in Kenya do not stock seeds of typical rangeland grasses. As such Kiboko serves as a major source of germplasm for rangeland re-seeding initiatives countrywide. The grass seed from Kiboko is harvested seasonally from a mosaic of natural vegetation types (predominant heavy bush and wooded grassland).

The other three sites were described in Chapter Three and are situated as follows:

Merueshi to the west, Kavatini to the north and Kimala to the south of Kiboko, respectively.

The soils found at the four sites were analyzed at the National Agricultural Laboratories in Kabete and the results are shown in Table 8.1. For the properties analyzed, soil samples

from Kimala had lowest fertility which is in agreement with Jaetzold and Schmidt (1982) who classified the soil in that area in the low fertility group. Kavatini soil was rich in phosphorus and together with Merueshi also rich in iron. Organic carbon was generally low at all the sites which is characteristic of Ferralsols (FAO, 2001).

Table 8.1 Soil types and their fertility status at the four sites in southern Kenya where *Chloris roxburghiana* was found growing naturally in January 2001.

Variable	Kimala	Kavatini	Merueshi	Kiboko
Soil type	Red sandy Clay	Brown sandy Clay	Red sandy Clay	Red sandy Clay
Calcium	3.6	8.2	7.8	5.8
Copper	0.54	4.09	4.53	3.24
Iron	15.58	97.78	78.1	24.29
Potassium	0.36	1	1	0.76
Magnesium	0.65	3.9	4.55	2.6
Manganese	0.15	0.28	0.28	0.2
Sodium	0.24	0.75	0.7	0.42
Phosphorus	20	165	130	30
Zinc	1.13	2.46	1.62	1.18
Organic carbon	0.22	0.91	0.52	0.27
pH	5.7	6.7	6.5	6.2

Through the Geographical Information System (GIS), the distances between these sites based on Rhumb lines (straight lines between the points of measurement) were estimated at the International Livestock Research Institute (ILRI). The respective distances between the experimental sites are shown in Table 8.2.

Table 8.2 Estimated distances between *Chloris roxburghiana* sampling sites derived using Rhumb lines from GPS coordinates taken at centroid points.

From	To	Distance (km)
Kiboko	Kavatini	14.67
Kiboko	Merueshi	19.53
Kiboko	Kimala	130.62
Kavatini	Kimala	142.37
Merueshi	Kimala	126.04

The agro-pastoral Akamba who inhabit Kavatini area are sedentary and keep fewer animals than their pastoral Maasai neighbours in Merueshi. Hence, they do not need to take the animals far from their individual land holdings except during severe feed shortages mostly caused by drought. The Nairobi-Mombasa rail- and road highways separate Kiboko from Kavatini.

Taveta site was used as a communal grazing area for many decades. Recently, most of the land has been subdivided into a settlement scheme (Jipe Multipurpose— converted from private company growing sisal as a mono-crop with a large portion of fallow land to small-holder mixed farming) and a few people are already converting the area into arable land.

8.2.2. Plant sampling

Plant samples were collected during the growing season in early January 2001 from four natural populations of *C. roxburghiana*. Twenty-five individual plants were randomly sampled from each of the four sites, confining the selection within a homogeneous area measuring approximately 50 m². Five young growing entire leaves were picked from each of the 25 plants. The fresh leaves were promptly stored separately as plant 01 to 25 in labeled

plastic bags on dry ice in a cool box. These were transported to the International Livestock Research Institute (ILRI) laboratory in Nairobi within 48 hours and stored at -80 °C for later DNA extraction.

8.2.3. DNA extraction

An adaptation of Lassner *et al.* (1989) method called CTAB (hexadecyltrimethyl ammonium bromide) extraction technique as described by Doyle and Doyle (1990) was used to obtain the genomic DNA from the leaf samples. The grass leaves were taken from the freezer in their bags and covered well with dry ice then taken to the working bench in the laboratory. A set of pestle and mortar that was previously cleaned and steam dried then wrapped in aluminium foil to keep them disinfected was used. Two leaves were placed in a porcelain mortar and quick-frozen by adding 1-2 ml of liquid nitrogen. The leaves were then ground to a fine powder using a porcelain pestle, all the while placing the mortar on dry ice in a pail / tray. A new set of pestle and mortar was used to grind each leaf sample. The leaf powder was divided into two portions and placed in two 2-ml eppendorf tubes labeled A and B, filling up to the 0.5 ml mark. Other details on the tubes' label were sites (KIB, KAV, MER, and KIM being abbreviations for Kiboko, Kavatini, Merueshi and Kimala, respectively); and sample number 1-25 representing the individual plant accessions. The tubes were kept in dry ice until all those samples needed for the day's run were ground.

Then, to the eppendorf tubes 1 ml of CTAB extraction buffer was added followed immediately by 0.4ml chloroform. The buffer comprised of 140 mM Sorbitol, 220 mM Tris HCl pH 8.0, 22 mM EDTA pH 8, 800 mM NaCl, 0.8% CTAB and 1% Sarkosyl. The chloroform was made up of 1:24 Isoamyl alcohol / Chloroform. The alcohol was to reduce

foaming during DNA extraction while the chloroform removed proteins (denaturing) from the preparations of nucleic acids.

After shaking gently, the eppendorf tubes were placed in a plastic rack and incubated by placing in a water bath that was shaken at 5 cycles per minute for 10 minutes at 55 °C. They were then removed from the water bath, wiped dry using paper tissues and transferred into a microfuge while ensuring that all the tubes faced the same way (either up or down).

Spinning was done at 14,000 rpm for 10 minutes. The resultant supernatants were transferred into fresh well-labeled eppendorf tubes using a clean pipette tip per sample each time to avoid cross contamination. Then 1.2 ml of isopropanol was added, mixing gently for a few seconds and left to stand at room temperature for 1 hour. The stationary period allowed nucleic acids to precipitate. Thereafter, centrifuging was again done in a microfuge at 14,000 rpm for 10 minutes.

Each tube was checked gently and carefully on removal from the centrifuge to ensure there was a pellet formed at the bottom. Decanting of the supernatant was carefully done ensuring that the pellet was not lost. Each pellet was washed two times with 1 ml of 70% ethanol while shaking to ensure it is dislodged from the walls of the tube. Firmly stuck pellets were dislodged by disturbing the ethanol around them using a pipette and tip—squeezing and releasing a few times. The tubes were then centrifuged at 14,000 rpm for 10 minutes. To drain the ethanol, after aspiration with a pipette and tip, the tubes were placed up side down on clean tissue paper, taking care not to let the pellet slide out. After the second washing, the pellets were each dissolved in 50 μ l sterilized, triple de-ionized distilled water. RNase was also added at 1 μ l per tube. The solutions were incubated without

shaking in a water bath at 37 °C for 1 hour. This concluded the end of DNA extraction process. The solutions were kept as DNA stocks stored in a deep freezer set at -80°C.

8.2.4. DNA Concentration Determination

The DNA concentration was determined using a spectrophotometer. This was also followed by gel electrophoresis to check those samples that had bad or no DNA at all. The polymerase chain reaction (PCR), as a precaution, was carried out on duplicate samples.

8.2.4.1. Spectrophotometry

From the stock solutions of DNA, 5 μ l were drawn using a pipette into fresh well labeled 1.0 ml-eppendorf tubes and 995 μ l of distilled reagent water added. The DNA solution was drawn from the side of the tubes taking care not to touch the sediments at the bottom. The new mixture was shaken well by tapping and turning the tube up side down 3-5 times.

The spectrophotometer (Gene Amp PCR System 9700) was switched on and given time to calibrate itself. When ready, the machine set-up was then adjusted where necessary, especially for date (month and day), path length (used 10mm) units (used μ g/ml), and base type (DNA) and dilution (used 200 because of 5 μ l DNA to 995 μ l water). The machine was programmed to run thermo-cycles at different temperatures for 4 hours and 25 minutes. The cycle steps were:

- i. Initial de-naturation at 94 °C for 3 min,
- ii. 45 Cycles of 30 sec at 94 °C for de-naturation,
- iii. Cyclic annealing at 36 °C for 45 sec,
- iv. Cyclic elongation at 72 °C for 2 min (ramp rate between temperature change rate of 0.4 °C/s between 36 °C and 72 °C),
- v. Repeat cycling by going to step 2, 44 more times

- vi. Final extension at 72°C for 4 minutes

Following amplification, samples were stored at 4°C.

8.2.4.2. *Electrophoresis*

This was a 3-step procedure that covered making of the agarose gel, loading the gel and the dark room process for the purpose of checking the DNA integrity.

Step 1 Making the agarose gel

To make the gel, a clean mold (tray) was used; the open ends of which were closed using a tape to hold the gel. The tray was then placed on a flat and level bench (ascertained with a spirit level) and an appropriate size comb was selected and placed in place. The choice of the comb size depended on the number of samples to be run in the gel so that the desired number of wells was obtained. Similarly, an appropriate electrophoresis tank size was selected to match the tray and gel size.

Finally, a buffer solution (1X TBE) was made thus:

A 10X TBE solution comprised of 108 g Tris Base, 55 g Borate and 8.3 g EDTA was placed in a 1000 ml beaker and 900ml distilled reagent water added and stirred. Then the solution was topped to 1 litre using more distilled reagent water. Thereafter, 200ml of this solution were placed in a 2.5 l conical flask and topped to 2 litres with distilled reagent water making it a 1X TBE solution. Then, Ethidium bromide was added at the rate of 80ul per litre of 1X TBE, while stirring. The resultant solution was then ready to be used in making the gel and also filling the electrophoresis tank.

For testing purpose, a 1% agarose gel was used. Approximately 1.5 g of agarose was weighed and placed into a 200 ml conical flask. Then 150 ml 1X TBE was added and heated in a microwave oven to boiling point. The flask was taken out and placed on

a bench and allowed to cool while shaking gently periodically to avoid fluxing and bubbles. At about 50 °C the gel was poured into the tray. This was done gently but continuously again in order to avoid bubbles. The gel was allowed to set for about 20-30 minutes.

Step 2. Loading the gel.

When the gel was set, the tapes were removed from the tray ends. Then, the tray containing the gel was placed into in the electrophoresis tank half filled with 1X TBE buffer solution. The comb was removed gently, first by pulling up one end and then the other leaving behind a line of wells (holes). If the gel was not fully covered by the 1X TBE buffer, some more solution was added.

A piece of parafilm to be used in mixing the DNA solution with a dye was placed flat on the bench next to the tank. Bromophenol blue that colours the DNA solution and makes it sink into the gel wells more easily was used. The mixing rate was 1 μ l of dye for every 4 μ l DNA or proportions thereof as per amount of DNA in the spectrophotometer data. The dye was placed on the parafilm in a neat row using one pipette tip as per number of samples to be analyzed. But, using different tips every time, 4 μ l of DNA solutions were drawn into each of the dye spots. Gently, the tip and pipette were used to mix with the dye; this was readily achieved by releasing and drawing a few times (4-5) into the dye spot. Then, drawing fully all the dye and DNA mix, this was slowly directed into the second well, squeezed in and the tip withdrawn from the buffer before releasing the pipette plunger. This avoided bubbles that would have resulted in sample gushing out of the well. The procedure was repeated for all the samples.

Important tips:

1. When loading the gel it was found useful to place a piece of black sheet of paper below the electrophoresis tank to increase visibility of the wells.
2. Also, the pipette tip did not have to be inserted into the well. Because the dye is heavy, releasing at the top (mouth of the well) was sufficient and the DNA - dye mixture would just sink into the well on its own.
3. It was important to mark the order of samples in wells as loaded by, nipping one corner of the gel to be able to keep track later on.

The tank's electrical cables were then connected to the power unit (Pharmacia EC PS3000/150) and voltage adjusted to 100, ensuring proper +/- terminals connection relative to the wells in the gel. DNA may flow to the opposite direction into the buffer if cables are not properly connected. Some bubbling in the buffer was a sign of current flow. Electrophoresis was allowed to run for one hour.

Step 3 The darkroom process.

After electrophoresis, power was switched off and the gel with the tray was taken out of the buffer solution. And after allowing excess buffer to drip off, the gel alone was taken into the photography darkroom and placed on the camera stage. The stage was leveled to avoid the possibility of the gel sliding off. Normal lights were switched off and ultra-violet (UV) one put on. This was to check if electrophoresis had worked, in which case shiny bars denoted presence of DNA as fingerprinted by Ethidium bromide, which is fluorescent. Polaroid type film (Polaroid OPXW8331A; Polaroid Corp.) was then used to photograph the gel under UV light using a stage-mounted camera (Polaroid MT4 Plus). After pulling out the white film stub, the film exposure was also pulled out. About 30 seconds were allowed for the film to develop while shaking in the normal light.

8.2.5. The polymerase chain reaction (PCR) amplification

The PCR was undertaken according to Dawson *et al.* (1995). First the DNA stock solution was diluted to 5 ng/ μ l. For instance,

Let OD = 660 ng/ μ l for the sample. To make 5ng/ μ l,

Consider $C_1V_1 = C_2V_2$; i.e., $660 \times V_1 = 5 \text{ ng}/\mu\text{l} \times V_2$.

Where, OD is the optical density of a DNA stock solution

C_1 and C_2 are the stock and diluted solutions' concentrations, respectively.

Assuming that a diluted solution volume, $V_2 = 200 \mu\text{l}$

Then, the concentrated solution to use, $V_1 = (5 \times 200)/660 = 1.5$.

Thereafter, 1000 μ l-eppendorf tubes were labeled according to the number of primers used. 4 μ l diluted stock DNA solution was put in the eppendorf tube followed by the reagents below, strictly in the order and quantities shown:

1.	Distilled H ₂ O:	14.3 μ l
2.	10X buffer:	2.5 μ l
3.	MgCl ₂ :	2 μ l
4.	dNTPs:	1 μ l
5.	Primer:	1 μ l
6.	Taq DNA polymerase:	0.2 μ l,
-

This made a total of 25 μ l mixed solution in an eppendorf tube.

NB: Except for the Taq DNA polymerase, care was taken not to let the pipette tip touch the liquid already in the tube. As for the Taq polymerase, the tip was inserted deep into the preceding contents before releasing.

However, the above procedure was cumbersome. Therefore, to hasten the process, a master mix was made, enough for 100 samples at a time, comprising the following:

1. Sterile reagent water	1, 430 μ l
2. 10X TBE buffer solution	250 μ l
3. MgCl ₂	200 μ l
4. dNTP	100 μ l
5. Primer	100 μ l
6. Taq DNA polymerase	20 μ l
Total	2, 100 μ l

Then, 21 μ l of the master mix was added to 4 μ l of the 5 ng/ μ l DNA solution per sample.

The primers were available in stocks of varied concentrations. So, they had to be standardized as per dilution necessary to make a required volume, say 200 μ l having 5 Pmol/ μ l concentration recommended for PCR.

For example, for a primer stock solution with 6.0 Pmol/ μ l,

$$\text{Let } C_1V_1 = C_2V_2$$

$$\text{i.e. } 6 \times V_1 = 5 \times 200 \text{ and therefore, } V_1 = (5 \times 200)/6 = 166.7 \mu\text{l.}$$

So, 166.7 μ l of the primer stock solution would be drawn and put in an eppendorf tube and topped up to 200ul with 33.3 μ l of distilled reagent water. The respective concentrations and dilution done for the nine primers used in this study are as shown in the Appendix Table 8.2.

Mineral oil was added, a drop into each tube to reduce evaporation. The tubes were closed tightly using a plastic PCR plate cover and a roller. Then, after shaking gently they were placed in the PCR machine. Necessary set-up adjustments were done before analyzing the samples as before.

For the electrophoresis, a 2% agarose gel was made. A comb that gave enough wells to accommodate both the samples and PCR marker was used. The polymerized DNA and loading dye were mixed at 10:3 μ l ratio. Into the first well and one after the last sample well, a ladder (PCR marker) was put. Ready-Load 100 base pair (bp) DNA ladder from Life Technologies was used. It consisted of 15 blunt ended fragments between 100 and 1500 bp in multiples of 100 bp and an additional fragment at 2972 bp. The 600 bp band was approximately 2 to 3 times brighter than the other ladder bands to provide internal orientation. The electrophoresis was run and pictures taken as described earlier.

Initially, 17 RAPD primers were screened on a test panel of 4 individuals per population. Nine primers that revealed clear polymorphisms were selected for analysis of all 96 individuals.

Gel photographs were visually inspected and scored for presence (1) or absence (0) of the bands. Independently, two people scored both major and weak bands as well as estimating the length. It was assumed that:

(a) Each band was a locus with alternative alleles

(b) Alleles from different loci do not co-migrate during electrophoresis. Estimates of similarity were based on Nei and Li's (1979) definition of similarity.

8.2.6. **Data analysis**

The genetic diversity of each population (H_e), according to Nei's (1978) unbiased measure, was estimated assuming Hardy-Weinberg using POPGENE 1.2 (Yeh and Boyle, 1997). Cluster analysis based on genetic distances according to the equations of Nei (1973), using a unweighted pair-group method with arithmetic averaging (UPGMA; Sneath and

Sokal, 1973) was also undertaken with POPGENE. An analysis of molecular variance (AMOVA; Excoffier *et al.*, 1992) based on Euclidean distances between individual phenotypes was undertaken with ARLEQUIN 2.000 software package (Schneider *et al.*, 2000). During AMOVA, genetic variation was partitioned within and among populations and significance values assigned to variance components based on 5,000 random permutations of individual phenotypes assuming no genetic structure.

8.3. RESULTS AND DISCUSSION

8.3.1. Characteristics of RAPD markers

The nine primers produced a total of 148 scorable bands among the four populations. Others were too weak or ambiguous to be included. Examples of polymorphism in RAPD banding patterns among individuals of *C. roxburghiana* are shown in Figure 8.1. After excluding monomorphic bands, 131 polymorphic markers were left for further analysis.

The polymorphic markers' molecular sizes ranged from 300 to 2070 bp (Table 8.3). Amplification with individual primers ranged between 6 and 28 bands per sample. However, mostly between 12 and 21 bands were observed with only two primers detecting more or less bands. The number of polymorphic products ranged from 58 for Kiboko to 101 for Kimala equivalent to 44.27 to 77.10 percent, respectively. None of the primers amplified population specific markers.

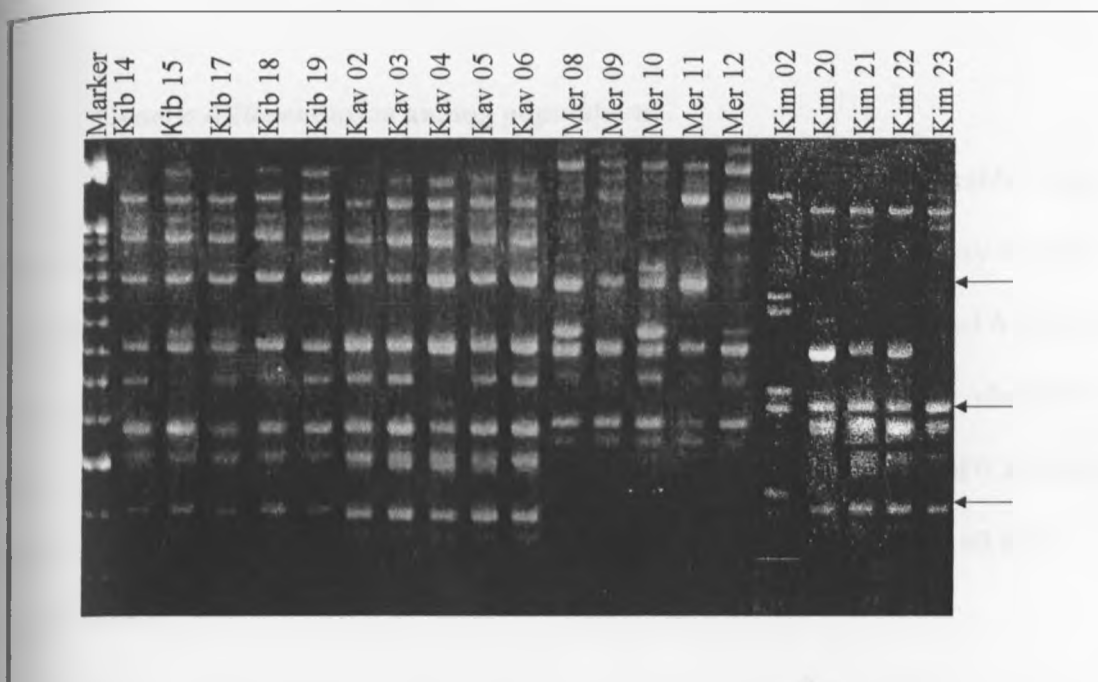


Figure 8.1 Bands amplified from *Chloris roxburghiana* individuals from four populations found at Kiboko (Kib), Kavatini (Kav), Merueshi (Mer) and Kimala (Kim); some polymorphic bands are indicated by arrows.

Table 8.3. List of the primers used in the RAPDs analysis of *Chloris roxburghiana* grass, their sequence, number of bands and size range.

Primer ^a ID. No.	Polynucleotide Sequence (5'-3')	No. of polymorphic bands	Size range of scorable bands (bp)
IL 4998	CGCAGTGTC A	6	610-970
IL 4996	TTCCAGCGCA	8	300-1460
IL 1558	GTCATGGTCG	12	430-1700
IL 1481	CCCGGTCGCA	12	300-1400
IL 4997	GCTAGGGCGG	12	430-1250
IL 4999	GCGGTCGGCG	16	460-1420
IL 5006	AAGCGAGCCG	14	300-1280
IL 1207	GCACCAGGGC	20	480-2070
IL 1212	GCGGCCGTAA	28	400-2070

^aPrimers were synthesized at the ILRI laboratories, Nairobi Kenya

8.3.2. Genetic differentiation among populations

Genetic diversity within *C. roxburghiana* populations varied considerably. The

loci that were polymorphic and estimate of Nei's (1973) unbiased genetic diversity for each population are presented in Table 8.4. The percentage of polymorphic loci ranged from 44 in Kiboko to 77 in Kimala. The *He* parameter, a good measure of genetic diversity, showed that the Kimala population had the greatest level of variability with a *He* value of 0.206 while Kiboko had the least with a *He* value of 0.142. The mean genetic diversity over all four populations was 0.175.

Table 8.4. Number of polymorphic loci, percentage polymorphic and mean of unbiased genetic diversity (*He*) of four *Chloris roxburghiana* populations in southern Kenya.

Population	No. Polymorphic Loci	Percent of polymorphic Loci	Gene diversity (<i>He</i> $\pm$ SD)
Kiboko	58	44.27	0.134 $\pm$ 0.1755
Kavatini	65	49.62	0.161 $\pm$ 0.1945
Merueshi	96	73.28	0.199 $\pm$ 0.1794
Kimala	101	77.10	0.206 $\pm$ 0.1769
Mean	80	61.07	0.175 $\pm$ 0.1816

Cluster analysis of individual phenotypes showed high differentiation among *C.*

roxburghiana populations, with all individuals assigned to their specific population, even for geographically proximate populations (Figure 8.2). The UPGMA cluster analysis of population product frequency data based on Nei's (1978) genetic distance indicated that Kiboko material was more similar to Kavatini, while Kimala material was similar to

Merueshi (Figure 8.3). The high differentiation among populations further was illustrated by a larger genetic distance, D (Table 8.5) between Kiboko and Kimala ($D=0.1333$) compared to that between Kimala and Merueshi ($D=0.0300$), despite the distance between them being almost the same (Table 8.2). AMOVA indicated significant ($p<0.001$) genetic variation among and within populations (Table 8.6). The variation partitioned among individuals within populations was 72%.

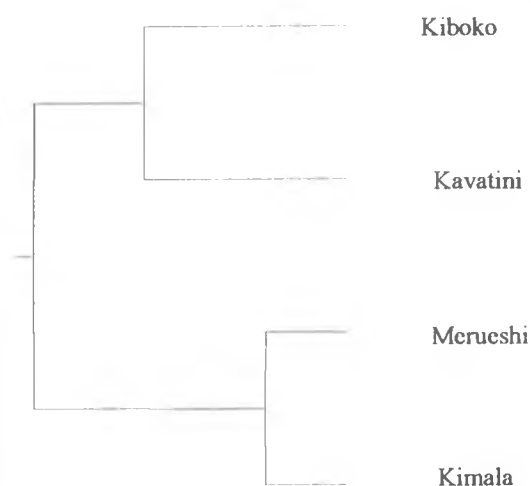


Figure 8.2. UPGMA tree for the four *Chloris roxburghiana* populations analysis showing close relationships between Kiboko and Kavatini and Merueshi and Kimala but each as separate groups.

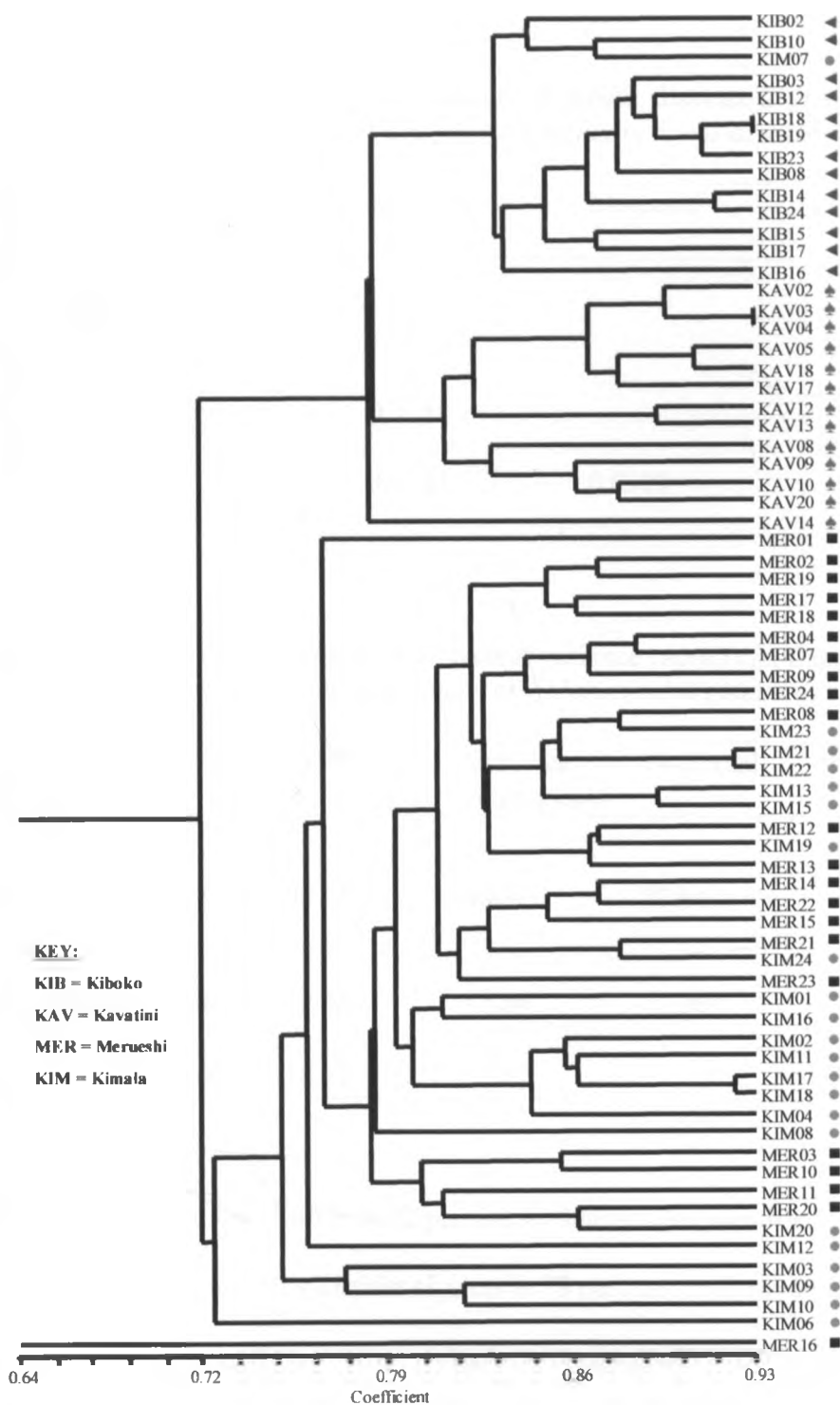


Figure 8.3. RAPD analysis of four populations of *Chloris roxburghiana* from southern Kenya rangelands; dendrogram based on coefficient of similarity.

Table 8.5. Estimate value of Nei's unbiased measure of genetic distance (*D*) based on Nei (1978) for four populations of *Chloris roxburghiana* found in southern Kenya rangelands.

Population	Kiboko	Kavatini	Merueshi	Kimala
Kiboko				
Kavatini	0.0764			
Merueshi	0.1594	0.1258		
Kimala	0.1333	0.1343	0.0300	

Table 8.6. Results of the analysis of molecular variance (AMOVA; Excoffier *et al.* 1992) between four populations of *Chloris roxburghiana* in southern Kenya.

Source of Variation	d.f.	MSD	Variance components	% of total	P-value
Among populations	3	95.28	4.83	27.64	<0.0001
Within populations	66	12.64	12.64	72.36	<0.0001
Total	69	16.23	17.47		

In Figure 8.2 two main clusters at 72 percent similarity were identified. Cluster 1 consisted of two smaller genetically distinct clusters at 78 percent similarity index; all individuals from Kiboko and one individual (KIM 07) from Kimala formed one cluster (KIB) while all Kavatini individuals alone formed the other cluster (KAV). Cluster 2 consisted of individuals from Merueshi and Kimala except for two individuals (MER 16 and KIM 06), that stood out separate from all the rest. MER 16 and KIM 06 were probably out crosses.

Therefore, distinct variation was seen between the four populations of *C.*

roxburghiana. However, Merueshi and Kimala populations are genetically more similar while being genetically more distinct from Kiboko and Kavatini that are more similar.

AMOVA analysis strongly indicated an out breeding behaviour of *C. roxburghiana* since most variation (72%) was within populations (Hamrick, 1989). The analysis, however, did not reveal any relationship between genetic and actual geographical distances among the populations. Rather, a significant variation (28%) among the populations suggests that gene flow between the sites may be limited. Further, these results suggest that genetic drift and/or natural selection may have caused the high divergence observed between individuals of different sites. Although Kimala is 126 km away south of Merueshi populations, *C. roxburghiana* plants found in these two areas are more closely related to each other than to those in Kiboko and Kavatini areas, which are hardly 15 km apart. This suggests that in the case of Kiboko and Kavatini, there are strong factors influencing genetic flow between the populations other than spatial distance.

The populations clustering due to reasons other than geographical isolation obtained in this study could be explained by difference in soil fertility of the study sites. Table 8.1 showed that there is variation in soil pH and organic carbon as well as both macro- and micro-elements found at the four sites. These results tend to agree with those by Dawson *et al.* (1993) on the study of *H. spontaneum* where it was observed that the distribution of diversity between pairs of populations appears to be associated more with ecological factors than with simple geographical proximity. Genetic diversity would therefore correlate significantly with a combination of climatic factors of rainfall, humidity and temperature (Nevo *et al.*, 1979; Nevo *et al.*, 1986). The *Hordeum* polymorphism was

also associated with soil type and topography (Nevo *et al.*, 1983). Further, Huff *et al.* (1998) found a strong correlation between soil fertility and genetic diversity of *S. scoparium* grass populations it was concluded that for a wide-ranging and highly variable species, local site differences in fertility and ecological history could promote genetic differentiation equal to or greater than geographical differentiation.

Geographical barriers, especially mountain ranges are known to have a strong influence on plant population diversity. Merueshi and Kimala are located along a well-defined corridor between Mt. Kilimanjaro to the southwest and the Kyulu hills range to the northeast (Figure 8.1). The mode of dispersal for *C. roxburghiana* is believed to be wind and herbivores. Wind dispersal is possible because the grass has seeds that are tiny and with long awns (Bogdan, 1977; Boonman, 1993). In addition, it is a highly palatable forage species (Mnene and Kibet, 1995; Mnene *et al.*, 1996) and movement of livestock and wildlife during periods of feed scarcity along this corridor might be a major factor contributing to significant gene flow between these two grazing sites.

Similarity of *C. roxburghiana* populations from Kimala and Merueshi might also be explained by the close proximity to game parks and the free wildlife movement within these areas due to the non-hunting nature of the communities in the two areas. As both the wild and domestic grazers move freely between the two areas, they also act as agents of seed dispersal within the ecosystem. The similarity in culture of the peoples of Merueshi and Kimala has promoted movement of livestock between the two over the years as bride price, barter trade and exchange of gifts (Mnene – personal experience). Nonetheless, Kimala is a long distance from Merueshi and this, together with some differences in soils, may have contributed to the variation observed between these populations.

Distinct clustering of Kiboko, Kavatini and Merueshi populations, despite their close proximity to each other is most likely due to restricted gene flow among these populations. Similarly, Graham *et al.* (1997) observed that the presence of many banding differences between populations of *Rubus idaeus* from neighbouring sites in Scotland was as a result of a high degree of genetic isolation. Also, studies in Thailand found that populations of *Afgekia sericea* varied genetically from province to province (Prathepha and Baimai, 1999). In those studies, the important isolating features were hedges, car parks and roads. Other barriers like creeks and steep hills were found to restrict gene flow between populations of rheophytes such as *A. gramineus* in Taiwan (Liao and Hsiao, 1998).

In this study, both Kiboko and Kavatini sites are closely situated within an area that in the past was commonly used as a hunting ground. Merueshi on the other hand is in Maasailand with a different pastoral historical background. Distinct clustering observed between Kiboko and Kavatini is probably because Kiboko retains a good number of wild herbivores that move in and out freely from the neighbouring Kyulu Game Reserve. However, virtually no wildlife ventures into Kavatini because of the traditional hunting practices of the local Akamba community targeting herbivores for their meat.

In addition, the Kyulu hills act as a barrier to herbivores that would otherwise move from the Tsavo National Park into the Kavatini area. Kiboko being a research facility has strict livestock movement in and out of the neighbouring areas. Coupled with the existence of a 100 year old railway line and a highway that run parallel to each other from Nairobi to Mombasa and separating Kiboko from Kavatini, the latter site is now devoid of wildlife, especially herbivores. Therefore, the *C. roxburghiana* population in Kavatini is quite isolated. The Maasai community in Merueshi has historical hostility with the Akamba

people from Machakos and Makueni. Hence, there has been minimal exchange and movement of livestock (and, hence, probably limited dispersal of *C. roxburghiana*) between Merueshi and Kavatini on one hand and between Merueshi and Kiboko on the other. Therefore, isolation of the populations of *C. roxburghiana* found at Kiboko, Kavatini and Merueshi sites together with soil difference may explain the results observed in this study.

8.3.3 Conclusions

Significant levels of genetic differentiation were observed within and between the four natural populations of *C. roxburghiana* in the southern Kenya rangelands. This may have possible implications for adaptation to variation in soil fertility, rainfall, limited livestock movement and wildlife movement between sites influenced by physical barriers imposed by hills, highways, railway track as well as the social and ecological history of the study area. However to link quantitative traits to adaptation, further studies should be undertaken to demonstrate such linkages.

The results suggest that seed from one site may not necessarily perform well when introduced to another site, even within short distances because they may represent distinct ecotypes. In the past, seeds were collected from natural stands and used elsewhere for both range rehabilitation and natural pasture improvement. Since RAPD analyses shows that the Kiboko *C. roxburghiana* population is not similar to those of other areas studied that may explain why its seeds have not established well in the past when introduced to different areas. Essentially then, *C. roxburghiana* seeds should be multiplied *in situ* or probably in selected habitats with very similar environments.

However, seeds from Kimala and Merueshi may have a greater chance of success in establishing elsewhere given their higher genetic diversity. But, to confirm this, seeds

from individuals from the four populations should be planted in a common garden at each of the four sites and evaluated for success in establishment. Currently, the wide genetic base in *C. roxburghiana* provides an opportunity for selection within the populations for traits desirable in natural pasture improvement and general rangeland rehabilitation. The Kimala site is part of a recent settlement scheme and the settlers are converting the area into arable land; therefore, urgent efforts are necessary to collect and conserve the local grasses. The same would apply to Merueshi where sub-division of the group ranches is presently on going.

CHAPTER NINE

9.0. GENERAL CONCLUSIONS AND RECOMMENDATIONS

The study was initiated to shed light on some of the many questions that the degradation of natural pastures poses. These included the following:

1. Are agro-pastoral and pastoral communities that derive livelihoods from natural pastures aware that land degradation is taking place and what the cause(s) are?
2. Do these communities have the capacity to deal with the problem with a view to arrest or even reverse the degradation trends for sustainable or even increased livestock production?
3. Is the communities' capacity being utilized to reverse land degradation and what are the possible constraints that impede success?
4. Do these constraints have solutions that could be tested and adapted to the local environments to achieve greater success in combating the degradation of natural pastures that threatens the livelihoods of these communities?

Arising from results of the literature review, a number of gaps were identified upon which studies were formulated and implemented. The results, backed by existing literature led to a number of conclusions on the basis of which some recommendations were made. These are presented below.

9.1. CONCLUSIONS

Degradation is recognized as a problem in almost the entire southern Kenya rangelands based on the perception of different communities and field verification. It is manifest in different forms but loss of important forage species, drastic increases in invasive

species and presence of extensive bare patches are some of the most telling signs.

Numerous reasons are given for this degradation, with continuous overgrazing and drought being the most important, although most certainly it is a combination of factors rather than any one of them alone.

The importance of considering a community's background when planning natural pasture improvement was emphasized in Chapter Four. From the survey carried out among communities in Makueni, Kajiado and Taita-Taveta, a number of salient features that are relevant in natural pasture improvement were identified. It was evident that the history of land use varied among communities, with Kajiado having sites that have been continuously grazed for longer periods and by larger herds than both Makueni and Taita-Taveta. These districts had both intra- and inter-community variation in opportunities to diversify sources of income and some were totally dependent on livestock for their livelihood. With large families and concomitant larger herds, some communities put greater pressure on forage resources thus depleting them to a greater extent than do others.

Research results of earlier studies showed that restoration is possible, but due to a number of reasons, adoption of the relevant technologies was low. In restoration, some of the options are deferred grazing to allow natural recovery, protecting bare patches with some form of cover, manure application to improve soil fertility and structure, water harvesting using a form of micro-catchment and reseedling. A large majority of communities are aware of at least one of these approaches, albeit to a varying degree.

Only a small minority of the communities are implementing any of the approaches to improve degraded natural pastures. Of these, most of them face a number of constraints and are discouraged mainly because of slow rates of recovery and general poor

plant establishment. Contributing to poor restoration success are the grazing history of an area, lack of appropriate seeds, drought, lack of control over land use, premature grazing, low adaptability of seeded species and low fertility of the soils.

Appropriate seeds should not only be those of forage species that are well adapted to a target area but also that are of high quality. These are often not in the market and one option is for communities to be encouraged to multiply their own seed stock on-farm. This implies that simple harvesting and storage techniques be identified and promoted. Results from experiments with harvesting methods, storage containers, time of storage and season of harvest showed that they are all critical considerations in achieving high quality seeds of range forage species (Chapter Five) just as much as they apply to commercial cultivars.

At the community level, a cold store is out of reach. So, a well-ventilated ordinary traditional grain store seems to serve well. The mean maximum and minimum temperature inside the store was lower than outside by one and two degrees Celsius, respectively. This enabled seeds to store well for 72 weeks (18 months) post-harvest without loss of viability and that is the upper limit of storage time reported for most pasture grass seeds to attain peak viability.

To test for seed quality through germination of caryopses, the coarseness of sandpaper used for extracting the caryopses had a significant effect. It was clear that different species require different grades of sandpaper due to variation in seed size and toughness of the seed coat. Fine sandpaper works well to scarify small seeds, whereas larger grit sandpaper works better for larger grass seed.

All four grasses used in this study have seeds of low but different germination potentials at harvest. The potential improves with storage to attain different peaks

depending on species, harvesting method, and type of storage container. Also, it should be noted that germination potential variation between species is normal. Results of this study clearly indicated that:

1. All four grasses have some degree of innate dormancy, and
2. Each species has its unique after-ripening period with *E. superba* having the longest dormancy period.

Poor establishment reported by farmers may also have been caused by soil condition; it was observed in this study that soil type had significant influences on seedling populations and subsequent growth and biomass production (Chapter Six). The soil effect varied less where soils were closely related as was the case between rhodic and orthic ferralsols compared to that of histic gleysol.

In addition, watering regime, even within a particular soil type, also had a significant effect on seedling development, populations and biomass production. Therefore, where a soil type is favourable, low or high soil moisture brought about by normal within season variation in rainfall distribution may result in poor or good establishment. Heavy storms could lead to water logging in gleysols while light ones will not recharge sandy soils sufficiently.

There is good likelihood that some forage species have significant genetic diversity between populations at different ecological sites. The RAPDs results of *C. roxburghiana* demonstrated this. Not only did the four populations of this grass differ significantly, within population diversity between individuals was also significant with Merueshi and Kimala populations being more diverse than those of Kiboko and Kavatini. Seeds collected from populations with a high genetic diversity between individuals should

have a greater chance of establishing well when seeded elsewhere because it is more likely that some of the individuals will be adapted to the new environmental conditions.

Generally, however, reintroduction of depleted forage grasses into degraded natural pastures was possible with variation exhibited among sites and species. Deferred grazing produced noticeable results, but only after a longer period. However, this was only possible because of the presence of a source of seed from neighbouring reseeded plots. The soil seed bank appeared to have been exhausted, particularly at Merueshi in the pastoral production area. Reseeding after pitting (as a micro-catchment and a form of seedbed preparation) resulted in greater and faster restoration than broadcasting seeds alone although some of the grasses did not display any benefit from the pitting treatment. Nonetheless, reseeding plots required protection from early grazing to allow time for seedlings to become established and mature. Pitting is a relatively laborious approach, which the agro-pastoral communities find easier to substitute with the ox-plough, especially where slopes are gentle. The opportunity to ox-plough is lacking within the pure pastoral communities who find it more convenient to reseed without any form of seedbed preparation but with deferment.

9.2. RECOMMENDATIONS

Arising from the aforementioned findings and conclusions, a number of recommendations are made as follows:

- i. There is need for a concerted effort to heighten awareness about natural pasture improvement through demonstrations, exchange visits and study tours - approaches found to have a significant impact with communities of diverse backgrounds in this study area.

- ii. Generally, it is important that grass seeds are harvested when fully mature or dry; after which they are further dried to lower moisture levels (8-12%) before storing.
- iii. Grass seeds may be harvested by stripping which is a more rapid technique compared to harvesting by cutting with stalks since the overall advantage of the latter technique in terms of germination is minimal except for *E. superba*.
- iv. Non-porous containers, such as aluminium or heavy gauge polyethylene types with tightly fitting lids, that minimize chances of high ambient relative humidity have beneficial effects on seeds, are more suitable than ordinary paper or cloth bags.
- v. Together with ensuring low moisture levels, cool temperature is a must for proper storage of seeds. They are best kept in cool conditions such as a traditional grain store where temperatures normally range from 25 to 30°C when the temperatures outside range from 26 to 33°C.
- vi. When extracting caryopses for germination tests, an appropriate grade of sandpaper for each grass species that depends on seed size should be used to avoid misleading results.
- vii. Grass seeds should not be planted immediately after harvesting as has been practiced by some farmers; instead they should be stored at least until the following rainy season.
- viii. Since each grass species tends to have unique dormancy characteristics, a general recommendation on how long to store seeds after harvesting is not possible from results of this study.
- ix. Grass seeds should be sown at sites with similar soils to that found where the seeds were harvested for a greater chance of successful plant establishment.

- x. Generally, using adapted species that match area specific conditions during reseedling is advisable. This may require further work to develop sufficient databases for mapping appropriate soil type, soil moisture regimes, and forage species recommendations for different districts.
- xi. In addition, and as an alternative, it would be more desirable to multiply seeds *in situ* in a community based seed production approach.
- xii. Since not all grasses displayed improvement in establishment as a result of pitting, this form of seedbed preparation is labour intensive and should be used with steep slopes where erosion is a greater problem.
- xiii. Fencing or some form of protection is absolutely necessary for reseedling to succeed.
- xiv. In deciding which field approaches to use or recommend to a community, the community background must be taken into account, even after taking appropriate precautions on seed quality, site selection and conditions for successful establishment.

9.3. SUGGESTED FUTURE RESEARCH

- a. Seed treatments to break dormancy for a uniform establishment so as to take advantage of scarce rainfall which should then encourage farmers to reseed damaged rangeland. Because seeds may remain in the soil for a number of wet seasons and only a few germinate each time, it is important that seed dormancy in the soil for different forage species be monitored under field conditions to determine how fast these soil seed banks are depleted.

- b. Further, there is need for transplant experiments to be able to identify species with a wider adaptation. In the meantime, there is still need to carry out similar genetic characterization of other important forage species selected by the communities for the purpose of pasture improvement and rehabilitation.
- c. Also, while it is critical that reseeding be done with mixtures of species, species that are most compatible to establish together is not well documented and the role of competition among range forage grasses should be better understood.
- d. Data should be collected to enable formulation of recommendations for effective use of micro-catchments, especially pitting, under a variety of soils and slopes.
- e. Although broad recommendations on sustainable management of pastures exist, it is important to:
 - i. Determine optimal defoliation frequencies and intensities for the range forage species.
 - ii. Assess the impact of termites on standing hay (what plant species do they target most and how much do they consume) and determine safe methods of dealing with what the pastoralist considers to be a menace.
- f. There is need to examine which grass species become habitat for different animals. This is critical given that in the current study; there have emerged claims that grass stands are habitats of birds, ticks, rats and snakes.
- g. Costs of various reclamation treatments should be determined.

10.0 REFERENCES

- ¹Agnew, A.D.Q. and J.E.C. Flux. 1969. Plant dispersal by hares (*Lepus capensis* L.) in Kenya. *Ecology*, 51:753-757.
- Agufa, C.A.C. 2002. Genetic variation in *Sclerocarya birrea* and *Uapaca kirkiana*—Indigeneous fruit trees of the Miombo woodlands. M.Sc. Thesis, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya.
- Ahmed, A.E.H. 1986. Some aspects of dry land afforestation in the Sudan with special reference to *Acacia tortilis* (Forsk.) Hayne, *A. senegal* Willd. and *Prosopis chilensis* (Molina) Stuntz. *For. Ecol. Manage.* 6: 209-221.
- Anslow, R.C. 1966. The rate of appearance of leaves on tillers of the Gramminae. *Heb. Abstr.* 36:149-155.
- Allison, F.E. 1973. Soil organic matter and its role in crop production. *Developments in Soil Science*. 3. Elsevier, Amsterdam.
- Al-Ani, T.A. and N.A. Ouda. 1969. Effect of moisture tension, temperature and light on germination of four exotic range grasses. *Ann. Arid Zone* 8(1): 45-51.
- Al-Kaisi, M. 2000. How to evaluate soil moisture in the field. Integrated Crop Management. Department of Entomology, Iowa State University, Ames, Iowa. <http://www.ipm.iastate.edu/ipm/icm/2000/4-24-2000/evalsoilmoist.html>
- Archer, S. and F. Smeins. 1991. Ecosystem - level process. *In*: Heitschmidt, R.K. and J.W. Stuth (eds.), *Grazing management: an ecological perspective*. Timber Press, Portland, Oregon.
- Arnheim, N. and H. Erlich. 1992. Polymerase chain reaction strategy. *Ann. Rev. Biochem.* 61:131-156.
- Arvier, A.C. 1983. Storage of seed in warm climates. Queensland Department of Primary Industries, Miscellaneous Publication. Brisbane, Australia.
- Ash, A.J., J.P. Corfield, and J.R. Brown. 1999. Patterns and processes in loss and recovery of perennial grasses in grazed woodlands of semi-arid tropical Australia. P. 229-230. *In*: D. Eldridge and D. Freudenberger (eds.), *People and Rangelands: Building the Future*. Proc. The VI International Rangeland Congress. Volumes 1 and 2. International Rangeland Congress, Inc., Aitkenvale, Australia.
- Baas, S. and J. Rouse. 1997. Poverty alleviation: The role of rural institutions and participation. P. 75-85. *In*: *FAO Sustainable Development Dimension, Land Reform*.
- Bade, D.H., B.E. Conrad, and E.C. Holt. 1985. Temperature and water stress effects on growth of tropical grasses. *J. Range Manage.* 38: 321-324.
- Baker, M.J. 1993. *Grasslands for Our World*. SIR Publishing, Wellington, New Zealand. 865p.
- Baland, J.M. and J.P. Platteau. 1996. *Halting degradation of natural resources: Is there a role for rural communities?* Oxford University Press, Oxford. UK. 423p.
- Barenburg, T.H. 1935. Veld improvement: Seed production - seed testing. *S. Afr. J. Sci.* 32: 257-267.

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- Beadle, C.L., M.M. Ludlow, and J.L. Honeysett. 1993. Water relations. P. 113-128. *In*: D.O. Hall, J.M.O. Scurlock, H.R. Bolhar-Nordenkamp, R.C. Leegood and S.P. Long (eds.). Photosynthesis and primary production in a changing environment – a field manual. UNEP / Chapman & Hall, London.
- Beckendam, J. and R. Grob. 1979. Handbook for seedling evaluation. ISTA, Zurich.
- Behnke, R. 1993. Natural resource management in Pastoral Africa. *In*: UNSO/UNDP, Proc. Of the First Technical Consultation of Donors/Specialized Agencies on Pastoral Development Issues, 13-14 Dec. 1993, Paris.
- Behnke, R. and I. Scoones. 1992. Rethinking range ecology: Implications for rangeland management in Africa. The World Bank; Environment Working paper No 53.
- 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.
- Black, C.A. 1963. Soil-Plant Relationships. Second edition. John Wiley & Sons, Inc., New York, NY, USA.
- Black, C.A. 1965. Bulk density. *In*: C.A. Black (ed.). Methods of Soil Analysis.
- Biondini, M.E., B.D. Patton, and P.E. Nyren. 1998. Grazing intensity and ecosystem processes in a northern mixed-grass prairie, USA. *Ecol. Appl.* 8(2):469-479.
- Bogdan A.V. and D.J. Pratt. 1967. Reseeding denuded pastoral land in Kenya. P. 1-46. *In*: Republic of Kenya, Ministry of Agriculture and Animal Husbandry, Nairobi, Govt. Printer.
- Bogdan, A.V. 1977. Tropical pasture and fodder plants (Grasses and Legumes). Longman Inc., New York.
- Boone, R.B. and N. Thompson. 2004. Lines around fragments: Effects of fencing on large herbivore. *Afr. J. Range and Forage Sci* 21(3): 147-158.
- Boonman, J.G. 1993. East Africa's Grasses and Fodder: Their ecology and husbandry. Kluwer Academic Publishers: Dordrecht, The Netherlands.
- Booyesen, P. de V. and N. M. Tainton. 1978. Grassland management: principles and practice in south Africa. P. 551-554. *In*: D.N. Hyder (ed.). Proc. 1st Intl. Range. Congr., Soc. Range Manage., CO., USA.
- Boutin, C. and J.L. Harper. 1991. A comparative study of the population dynamics of five species of *Veronica* in natural habitats. *J. Ecol.* 70, 199-221.
- Branson, F.A. 1985. Vegetation changes on western rangeland. Range Monogr. No. 2. Soc. Range Manage., Denver, CO. USA
- Bridge, B.J., J.J. Mott, and R.J. Hartigan. 1983. The formation of degraded areas in the savanna woodlands of northern Australia. *Austr. J. Soil Res.* 21:91-104.
- Briske, D.D. 1986. Plant response to defoliation: morphological considerations and allocation priorities. P. 425-427. *In*: P.J. Joss, P.W. Lynch and O.B. Williams (eds.). Rangelands: a resource under siege. Austr. Acad. Sci. Canberra, Australia.
- Briske, D.D. 1991. Developmental morphology and physiology of grasses. P. 85-108. *In*: R.K. Heitschmidt and J.W. Stuth (eds.). Grazing Management – an ecological perspective. Timber Press, Inc., Portland, OR, USA.
- Briske, D.D. and R.K. Heitschmidt. 1991. An ecological perspective. P.11-26. *In*: R.K. Heitschmidt and J.W. Stuth (eds.). Grazing Management – an ecological perspective. Timber Press, Inc., Portland, OR, USA.
- Bryant, J.A. 1985. Seed Physiology. Edward Arnold: London.

- Burtler, J.E. 1985. Germination of buffel grass (*Cenchrus ciliaris*). Seed Sci. & Technol., 13:583-591.
- Carren, C.J., Wilson, A.M. and Cuany, R.L. 1987. Caryopsis weight and planting depth of blue gramma. II. Emergence in marginal soil moisture. J. Range Manage. 40: 212-216.
- Cavaye, J. 1991. The buffel book: A guide to buffel grass pasture development in Queensland. QDPI Information Series Q190001, Brisbane, Australia.
- CCRS (Canada Centre for Remote Sensing). 2003. Fundamentals of remote sensing—soil moisture. <http://www.ccrs.nrcan.gc.ca/ccrs/learn/tutorials/fundam/chapter5/chapter5-14-e.html>
- Chapman, D.F., D.A. Clark, C.A. Land, and N. Dymock. 1983. Leaf and tiller growth of *Lolium perenne* and *Agrostis* spp. and leaf appearance rates of *Trifolium repens* in set-stocked and rotationally grazed hill pastures. N.Z. J Agri. Res. 26:159-168.
- Chapman, D.F., D.A. Clark, C.A. Land, and N. Dymock. 1984. Leaf and tiller or stolon death of *Lolium perenne*, *Agrostis* spp. and *Trifolium repens* in set-stocked and rotationally grazed hill pastures. N.Z. J Agri. Res. 27:303-312.
- Cheng'ole, J.M., L.N. Kimenye, and S.G. Mbogoh. 2000. Engendered analysis of the impact of improved fodder plants technology and other factors on small holder dairy productivity: A case study of Embu District, Kenya. Kenya Agricultural Research Institute, Nairobi, Kenya.
- Chin, H.F. and C.C. Wong. 1993. Importance of tropical pasture seed quality and factors affecting it in smallholder farming systems. P. 695-608. In: M.J. Baker (ed.). Grasslands for our world, SIR Publishing, Wellington, New Zealand.
- Chin, H.F. and J. Hanson. 1999. Seed storage. P. 303-315. In: D.S. Loch and J.E. Ferguson (eds.). Forage seed production. 2. Tropical and subtropical species. CAB International Publishing, Wallingford, Axon, UK.
- Cleaver, K.M. and G.A. Scheiber. 1994. Reversing the spiral: The population, agriculture and environment nexus in sub-Saharan Africa. World Bank, Washington D.C.
- Cohen, J.I., J.T. Williams, D.L. Plucknett, and H. Shands. 1991. *Ex situ* conservation of plant genetic resources: Global development and environmental concerns. Science, 253: 866-872.
- Collins, S.L. 1987. Interaction of disturbances in tall grass prairie: A field experiment. Ecology, 68:1243-1250.
- Cook, S.J. and G.R. Dolby. 1981. Establishment of buffel grass, green panic and siratro from seed broadcast into spear grass pasture in southern Queensland. Austr. J. Agri. Res. 32:749-759.
- Cook, C.W. and J. Stubbendiek. 1986. Range research: Basic problems and techniques. Soc. Range Manage., Denver, CO.
- Coughener, M.B., 2004. The Ellis paradigm – humans, herbivores and rangeland systems. Afr. J. Range and Forage Sci. 21(3): 191-200.
- Coughenour, M.B., D.L. Coppock, and J.L. Ellis. 1990. Herbaceous forage variability in an arid pastoral region of Kenya: Importance of topographic and rainfall gradients. J. Arid Environ. 19:147-159.
- Coupland, R.T. 1979. Grassland ecosystem of the world. Cambridge University Press, Cambridge, London.

- Coyne, P.I. and J.A. Bradford. 1985. Morphology and growth in seedlings of several C4 perennial grasses. *J. Range Manage.* 38: 504-512.
- Crow, J.F. and K. Aoki. 1984. Group selection for a polygenic behavioral trait: Estimating the degree of population subdivision. *Proc. The National Academy of Science, USA.* 81: 6073-6077.
- Crowder, L.V.C. and H.R. Chheda. 1982. *Tropical grassland husbandry.* Longman, London.
- Culiver, D.C. and A.J. Beattie. 1983. Effects of ant mounds on soil chemistry and vegetation patterns in a Colorado montane meadow. *Ecology*, 64:485-492.
- Curry, J. M. Waithaka, and E. Njue. 1999. Introduction to socio-economic concepts and tools of research for scientists in applied agricultural research. ARSP, KARI. Report on Training course held at KARI Marsabit on 14-28, April 1999.
- Dagg, M. and M. MacQueen. 1967. Rooting habits of East African grasses. *Rep. E. Afr. Agric. For. Res. Org.* 1966: 21-24.
- Dahlquist, G. (Undated). Seed Germination Tests. US Water Conservation Laboratory. <http://www.uswcl.ag.gov/exper/seedgerm.html>.
- Daubenmire, R. 1968. Ecology of fire in grasslands. *Adv. Ecol. Res.* 5:209-266.
- Dawson, I.K., K.J. Chalmers, R. Waugh, and W. Powell. 1999. Detection and analysis of genetic variation in *Hordeum spontaneum* populations from Israel using RAPD markers. *Mol. Ecol.* 2, 151-159.
- de Leeuw, P.N., S. Bekure, and B. Grandin. 1985. Some aspects of livestock productivity in Maasai group ranches in Kenya. P. 247-251. *In: J.C. Tothill and J.J. Mott (eds.). Ecology and Management of the World's Savannas.* Austr. Acad. Sci., Canberra. .
- Defoer, T., A. Budelman, C. Toulmin, and S.E. Carter. 2000. Building common knowledge. Participatory learning and action research (Part 1). *In: T. Defoer and A. Budelman (eds.). Managing soil fertility in the tropics. A Resource Guide for Participatory Learning and Action Research.* Royal Tropical Institute. Amsterdam, The Netherlands.
- Delouche, J.C., R.K. Mathews, G.M. Dougherty, and A.H. Boyd. 1973. Storage of seed in subtropical and tropical regions. *Seed Sci. and Technol.* 1: 671.
- Deshmukh, I.K. 1986b. Primary production of a rangeland in Nairobi National Park, Kenya. *J. Appl. Ecol.* 23:115-123.
- Detling, J.K. 1988. Grasslands and savannas: Regulations of energy flow and nutrient cycling by herbivores. P.131-148. *In: L.R. Pomeroy and J.J. Alberts (eds.). Concepts of ecosystem ecology,* Springer-Verlag, New York.
- Dewald, C.L. and V.A. Beisel. 1983. The Woodward flail-vac seed stripper: Recent progress in harvesting chaffy seed. P.1823-1824. *In: Proc. The XVII International Grassland Congress.*
- Dietz, T. 1987. Pastoralists in dire straits: survival strategies and external interventions in semi-arid region of Kenya-Uganda border, west Pokot, 1980-1986. ISBN 90 6983 0188.
- Dougill, A. and J. Cox. 1995. Land degradation and grazing in the Kalahari: New analysis and alternative perspectives. ODI, Rural Policy and Environment Group. Network Paper 38c. <http://www.odi.org.uk/pdn/papers/paper38c.html>.

- Doyle, J.J. and J.L. Doyle. 1990. Isolation of plant DNA from fresh tissue. *Focus* 12: 13-14.
- du Preez, C.C. and H.A. Snyman 2003. Soil organic matter changes following rangeland degradation in semi-arid South Africa. P. 476-478. *In*: N. Allsopp, A.R. Palmer, S.J. Milton, K.P. Kirkman, G.I.H. Kerley, C.R. Hurt, and C.J. Brown (eds.). *Proc. The VIIth Intl. Range. Congr.*, 26th July - 1st August 2003, Durban, South Africa.
- Edwards, D.C. 1935. A further note on Rhodes grass. *E. Afr. Agric. J.* 1: 233-235.
- Edwards, D.C. 1940. Pasture and fodder grasses of Kenya. *E. Afr. Agric. J.* 5: 248-254.
- Edwards, D.C. 1943. The Nzoia type of Rhodes grass (*Chloris gayana*) for temporary leys. *E. Afr. Agric. J.* 9: 62-68.
- Ekaya, W.N. and J.I. Kinyamario. 2001. Production and decomposition of plant litter in a semi-arid rangeland of Kenya. *Afr. J. Range and Forage Sci.* 18:125-129.
- Ekaya, W.N., J.I. Kinyamario, and C.N. Karue. 2001. Abiotic and herbaceous vegetational characteristics of an arid rangeland in Kenya. *Afr. J. Range and Forage Sci.* 8:117-124.
- Elberse, W. T. and H. Breman. 1989. Germination and establishment of Sahelian rangeland species. I. Seed properties. *Oecologia*, 80:477-484.
- Ellstrand, N.C. and D.R. Elam. 1993. Population genetic consequences of small population size: Implications for conservation. *Ann. Rev. Ecol. Systems* 24: 217-242.
- Ernst, W.H.O. and D.J. Tolsma. 1988. Dormancy and germination of semi-arid annual plant species, *Tragus berteronianus* and *Tribulus terrestris*. *Flora* 181:243-251.
- Esau, K. 1960. *Anatomy of seed plants*. John Wiley & Sons, NY, USA.
- Esau, K. 1953. *Plant Anatomy*. Second Edition. John Wiley & Sons, NY, USA.
- Esilaba, A.O., B.M. Ikombo, A.M. Kilewe, J.M. Miriti, N.E. Odongo, D.M. Mwangi, J.M. Kaiyare, J.S. Ademba, and E. Wanyama. 2002. Effect of grasses and legumes on soil chemical properties in central Kenya. *E. Afr. agric. For. J.* 68(2):101-110.
- Evans, J.O., S.P. Simpkin, and D.J. Atkins. 1995. Camel keeping in Kenya. *Range Management Handbook of Kenya, Volume III*, 8. Ministry of Agriculture, Livestock Development and Marketing (MALDM), Republic of Kenya, Nairobi, Kenya.
- FAO (Food and Agriculture Organization). 1998. World Reference Base for Soil Resources. Food and Agriculture Organization of the United Nations, Rome, Italy. <http://www.fao.org/docrep/W8594E>
- FAO (Food and Agriculture Organization). 2001. Lecture notes on the major soils of the world. P. Driessen (ed.). Publishing and Multimedia Services, Information Division, Rome, Italy. [Hhttp://www.fao.org/DOCREP/003/Y1899E/y1899e00.htm](http://www.fao.org/DOCREP/003/Y1899E/y1899e00.htm)
- FAO (Food and Agriculture Organization). 2002. Livestock Production Systems Toolbox. www.virtualcentre.org/en/dec/toolbox/FAO/
- Felsenstein, J. 1993. *PHYLIP (Phylogeny Inference Package), version 3.5c edition*. University of Washington: Seattle, Washington, USA.

- Fidelibus, M.W. and D.A. Bainbridge. 1994. Microcatchment water harvesting for desert re-vegetation. Restoration in the Colorado Desert: Management Notes. <http://www.serg.sdsu.edu/SERG/techniques/microcatch.html>.
- Fredenslung, A. and J. Cassady. 1969. Seeding grasses on denuded Kenya bushland. *Kenya Farmer*. 159: 7, 30.
- Fynn, R.W.S., T.G.O'Connor. 2000. Effect of stocking rate and rainfall on rangeland dynamics and cattle performance in a semi-arid savanna, South Africa. *J. Appl. Ecol.* 37(3): 491-507.
- Galaty, J.G. 1992. "The land is Yours": Social and economic factors in the privatization, sub-division and sale of Maasai ranches. *Nomadic Peoples*, 30:26-40.
- Galaty, J., A. Ornas, C. Lane, D. Ndagala, H. Salih, P. Salzman, E. Fratkin, R. ole Kuney, A. Gabre-mariam, and N. Bazaara. 1994. The pastoral crisis: national debates, tenure theory and practice, dispossession and resistance in Eastern Africa. Special Issue of *Nomadic Peoples*, 34:35-39.
- Galvin, K.A., P.K. Thorton, and J. Sunderland. 2003. Climate variability and impacts on East African livestock herders. Nutritional ecology of herbivores: Proceedings of the 6th International Symposium on the Nutrition of Herbivores. Amer. Soc. Anim. Sci. Savory, IL, USA
- Galvin, K.A., R.B. Boone, N.M. Smith, and S.J. Lynn. 2001. Impacts of climate variability on East Africa pastoralists: Linking social science and remote sensing. *Climate Res.* 19: 161-172.
- Gardner, E.J. and D.P. Snustad. 1984. *Principles of Genetics*. Seventh Edition. John Wiley & Sons, New York, NY, USA. 580p.
- GEO (Global Environment Outlook). 2000. Alternative policy study: West and Central Africa. UNEP, Nairobi, Kenya.
- Gichangi, E.M., R.K. Jones, D.M. Njarui, J.R. Simpson, J.M.N. Mututho, and S.M. Kithika. 1989. Pitting practices for rehabilitating eroded grazing land on smallholder farms in the semi-arid tropics of eastern Kenya – a progress report. Proc. The 6th International Soil Conservation Organization Conference, Addis Ababa, November 1989.
- Gifford, R.M. and C. Marshall. 1973. Photosynthesis and assimilate distribution in *Lolium multiflorum* Lam. Following differential tiller defoliation. *Aust. J. Biol. Sci.* 26:517-526.
- Gill, A.M. 1975. Fire and the Australian flora: A review. *Austr. For.* 38:4-25.
- Gitunu, A.M.M. 1994. Description and comparison of factors affecting production and management practices in two ecologically different agro-pastoral communities of Makueni district, Kenya. MSc. Thesis, University of British Columbia, Canada.
- Gitunu, A.M.M. 1999. Livestock production and food security in a changing socio-cultural environment due to involuntary relocation of agro-pastoralists into semi-arid areas of Makueni district, Kenya. Ph.D. Thesis, University of Wales, Bangor.
- Gitunu, A.M., W. Ngoyawu Mnene, E.N. Muthiani, J.M. Mwacharo, R. Ireri, B. Ogilo, and S.K. Karimi. 2004. p. 45-73. In: L. Crissman (ed.). Proc. Agricultural research and development for sustainable resource management and food security in Kenya. Agriculture / Livestock Research support Programme Phase II, End of programme conference, KARI, 11-12 Nov. 2003. Nairobi, Kenya.

- Global Livestock CRSP. 2002. Annual report. University of California, Davis, CA, USA.
- Government of Kenya. 2001. Poverty alleviation strategy paper, 2001-2004. Government Printer, Nairobi, Kenya.
- Government of Kenya. 2004. National policy for the sustainable development of the arid and semi-arid lands of Kenya. 3rd Draft. January 2004.
- Graham, J., G.R. Squire, B. Marshall, and R.E. Harrison. 1997. Spatially dependent genetic diversity within and between colonies of wild raspberry *Rubus idaeus* detected using RAPD markers. *Mol. Ecol.* 6: 1001-1008.
- Grandin, B.E., P. de Leeuw, and P. Lembuya. 1989. Drought, resource distribution and mobility in two Maasai group ranches in southeastern Kajiado district. p. 245-263. *In*: T.E. Downing, K.W. Gitu and C.M. Kamau (eds.). Coping with drought in Kenya. National and local strategies. Lynne Rienner Publishers, Boulder, CO, USA.
- Green, D.F. and E.A. Johnson. 1989. A model of wind dispersal of winged or plumed seeds. *Ecology*, 70:339-347.
- Griffiths, J.F. 1962. The climate of East Africa. *In*: E.W. Russell (ed.), The natural resources of East Africa, D.A. Hawkins Ltd in association with East Africa Literature Bureau, Nairobi, Kenya.
- Griffiths, R. 1993. Sustainable supplies of quality herbage seed for sub-Saharan Africa smallholders. p. 662-665. *In*: M.J. Baker (ed.). Grasslands for our World. Sir Publishing, Wellington, New Zealand.
- Groves, R.H., M.W. Hagon, and P.S. Ramakrishnan. 1982. Dormancy and germination of seed of eight populations of *Themeda australis*. *Austr. J. Bot.* 30:373-386.
- Guerin, L.J. and T.F. Guerin. 1994. Constraints to the adoption of innovations in agricultural research and environmental management: a review. *Austr. J. Exp. Agric.* 34: 549-571.
- Gunter, F.E., G.A. Tuskan, and S.D. Wulfschleger. 1996. Diversity among populations of switchgrass based on RAPD markers. *Crop Sci.* 36: 1017-1022.
- Hacker, J.B. 1984. Genetic variation in seed dormancy in *Digitaria milanjiana* in relation to rainfall at the collection site. *J. Appl. Ecol.* 21: 947-959.
- Hacker, J.B. 1989. The potential for buffel grass renewal from seed in 16 year-old Buffel Grass-Siratiro pastures in south-East Queensland. *J. Appl. Ecol.* 26:213-222.
- Hacker, J.B. and D. Ratcliff, D. 1989. Seed dormancy and factors controlling breakdown in buffel grass accessions from contrasting provenances. *J. Appl. Ecol.* 26: 201-212.
- Hagon, M.W. 1976. Germination and dormancy of *Themeda australis*, *Danthonia* spp., *Stipa bigeniculata* and *Bothriochloa macra*. *Austr. J. Bot.* 24: 319-327.
- Hamrick, J.L. 1989. Isoenzymes and the analysis of genetic structure in plant populations. p. 87-105. *In*: D.E. Soltis and P.S. Soltis (eds.). Isoenzymes in Plant Biology. Dioscorides Press, Portland, OR, USA..
- Hanson, J. 1994. Seed production by smallholder farmers. Proc. ILCA/ICARDA Research Planning Workshop held at ILCA, Addis Ababa, Ethiopia, 13-15 June 1994. ILCA (International Livestock research Institute), AA, Ethiopia.
- Hare, M.D. 1985. Tropical pasture seed production for village farmers in South-East Asia. Grasslands Division, DSIR, Palmerston North, New Zealand.
- Harper, J.L. Population Biology of Plants. Academic Press, London, UK.

- Hartl, D.L. 1980. *Principles of population genetics*. Sinauer Associates, Sunderland, Massachusetts, USA.
- Harty, R.L., J.M. Hopkinson, and B.H. English. 1983. Germination, dormancy and longevity in stored seed of *Panicum maximum*. *Seed Sci. and Technol.* 11:341.
- Heady, H. 1986. Opportunities for rangeland development. p. 9-16. *In*: R.M. Hansen, B.M. Woie and R.D. Child (eds.). *Proc. Range Development and Research in Kenya conference*, Agricultural Resource centre, Egerton College, Njoro, Kenya, April 1-5, 1986..
- Heitschmidt, R.K. and C.A. Taylor, Jr. 1991. Livestock production. p.161-177. *In*: R.K. Heitschmidt and J.W. Stuth (eds.). *Grazing Management – an ecological perspective*. Timber Press, Inc., Portland, Oregon, USA.
- Herlocker, D. 1999. Rangeland resources in eastern Africa: their ecology and development. German Technical Cooperation, Nairobi, Kenya.
- Hiernaux, P. 1993. The crisis of Sahelian pastoralism: Ecologic or economic? International Livestock centre for Africa, Addis Ababa, Ethiopia.
- Hill, M.J. and D.S. Loch. 1993. Achieving potential herbage seed yields in tropical regions. p. 652-658. *In*: M.J. Baker (ed.), *Grasslands for our World*. Sir Publishing, Wellington, News Zealand.
- Hinchcliffe, F., J. Thompson, and J. Pretty. 1996. Sustainable agriculture and food security in East and Southern Africa: An emperical analysis of current initiatives and a review of literature. IIED (international Institute for Environment and Development), London, UK.
- Hobbs, T.N. and K. Galvin. 2003. Rangeland dynamic systems – fragmentation of rangelands: ecological and economic implications. A tribute to Jim Ellis. *Afr. J. Range & Forage Sci.* 20(2): 113.
- Holochek, J.L., R.D. Pieper and C.H. Herbel. 1989. *Range management; principles and practice*. Prentice hall, Englewood Cliffs, NJ, USA.
- Homewood, K., E.F. Lambin, E. Coast, A. Kariuki, I. Kikula, J. Kivelia, M. Said, S. Serneels and M. Thompson. 2001. Long-term changes in Seregengeti-Mara wildebeest and land cover: pastoralism, population or policies? *In*: proceedings of the Nat. Acad. Sci. 98(22): 12544-12549.
- Hopkinson, J.M., B.H. English, and R.L. Harty. 1988. Effects of different drying patterns on quality of seed of some tropical pasture grasses. *Seed Sci. and Technol.* 16:361-369.
- Hopkinson, J.M. and P.T.P. Clifford. 1993. Mechanical harvesting and processing of temperate and tropical pasture seed. p. 1815-1822. *In*: *Proceedings of the XVII International Grassland Congress*..
- Houston, W.R. and R.E. Adams. 1971. Inter-seeding for range improvement in the northern Great Plains. *J. Range Manage.* 24:457-461.
- HSTA 2004. All about plants and seeds – Educational extensions for a plant unit. UHH Conference Centre 2001. http://conference.uhh.hawaii.edu/hsta/plants_seeds.htm
- HSU (Herbage Seed Unit). 1994. *Forage Seed Production*. ILCA Training Manual. ILCA (International Livestock Centre for Africa), Addis Ababa, Ethiopia.
- Huff, D.R., J.A. Quinn, B. Higgins, and A.J. Palazzo. 1998. Random amplified polymorphic DNA (RAPD) variation among native little blustem [*Schizachyrium*

- scoparium* (Michx.) Nash] populations from sites of high and low fertility in forest grassland biomes. *Mol. Ecol.* 7: 1591-1597.
- Humphreys, L.R. and F. Riveros. 1986. Tropical pasture seed production. 3rd Edition. FAO Plant Production and Protection. Paper 8. FAO (Food and Agriculture Organization of the United Nations), Rome, Italy.
- Huston, J.E. and W.E. Pinchak. 1991. Range animal nutrition. p. 27-63. *In*: R.K. Heitschmidt and J.W. Stuth (eds.). *Grazing Management – an ecological perspective*. Timber Press, Inc., Portland, Oregon, USA.
- Hyder, D.N. 1972. A general hypothesis of species diversity. *Am. Nat.* 113:81-101.
- Ibrahim, K.M. and C.H.S. Kabuye. 1988. An illustrated manual of Kenya grasses. FAO, Rome.
- ICARDA (International Centre for Agricultural Research in Dry Areas). 2000. Annual Report. Aleppo, Syria.
- IDS (Institute of Development Studies). 1995. Confronting famine in Africa. IDS policy briefing 3. IDS, University of Sussex, Brighton, Sussex, UK.
- IFAD (International Fund for Agricultural Development). 2004. Combating Range Degradation: The Experience of IFAD. <http://www.ifad.org/lrkm/theme/range.html>
- ISTA (International Seed Testing Association). 1999. Rules for Seed Testing, 1999. *Seed Sci. and Technol.* 27: Suppl., Rules.
- ISU 2000. Test Methods. Seed Testing Laboratory. Iowa State University, Ames, Iowa, USA. <http://www.seeds.iastate.edu/seedtest/index.html>
- Jacobs, A.H. 1983. An overview of population dynamics in Kenya's rangelands, 1969-1979. A report submitted to the Director of Research, Ministry of Agriculture and Livestock Development, Government of Kenya. Winrock International, Morrilton, Arkansas, USA.
- Jaetzold, R. and H. Schmidt. 1982. Farm management handbook of Kenya. Vol. II. Nairobi, Kenya.
- Johnson, M., A. Olivares, and G. Fernandez. 1990. Soil seed-bank of annual Mediterranean grassland. p. 276-278. *In*: CIRAD. Proc. The 4th International Rangeland Congress. Montpellier, Cedex, France.
- Jordan, S.M. 1957. Reclamation and pasture management in the semi-arid areas of Kitui District, Kenya. *E. Afr. agric. For. J.* 25: 18-22.
- Kachigan, S.K. 1986. Statistical analysis. An interdisciplinary introduction to univariate & multivariate methods. Radius Press, New York.
- Kadmon, R. and A. Schimida. 1990. Patterns of spatial variation in the reproductive success of a desert annual. *Oecologia*. 83:139-144.
- Kamara, A.B. 2001. Property rights, risks and livestock development in southern Ethiopia. *Socioeconomic Studies on Rural Development*. Vol. 123. Gottingen, Germany.
- Kamau, P.N. 1986. Effects of available forage on goat dietary selection and nutrition. p.103-108. *In*: R.M. Hansen, B.M. Woie and R.D. Child (eds.). *Range research and development in Kenya*, Winrock International Institute Agricultural Development. Morrilton, Ark. USA.
- Kemei, I.K. 1986. Vegetation-environmental relationships at the National Range Research Station, Kiboko, Kenya. p. 287-300. *In*: R.M. Hansen, B.M. Woie and

- R.D. Child (eds.). Range research and development in Kenya, Winrock International Institute Agricultural Development. Morrilton, Ark. USA
- Kerridge, P.C. R.W. McLean, and R.M. Jones. 1992. The impact of soil fertility and legume on the yield and performance of buffel grass. P. 410-413. *In*: Proc. The Australian Society of Agronomy conference. Armidale, Australia.
- Keya G.A 1997. Environmental triggers of germination and phenological events on an arid savanna region of northern Kenya. *J. Arid Environ.* 37:91-106.
- 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. Ph.D. Thesis, Trier University, Trier, Germany.
- Keya, G.A. and B Hornetz. 1998b. Studies on rangeland production potential and its limitations in the arid and semi-Arid lands of northern Kenya. *In*: Proc. Agricultural research and development for sustainable Resource Management and increased production. 6th KARI Scientific conference, 9-13th November 1998, Nairobi, Kenya.
- Keya, G.A. 1998c. Growth water relations and biomass production of the savanna grasses *Chloris roxburghiana* and *Cenchrus ciliaris* in Kenya. *J. Arid Environ.* 38:205-219.
- Kimani, K. and J. Pickard. 2002. Recent implications of group ranch subdivision and fragmentation in Kajiado District, Kenya. *Geogr. J.* 164: 202.
www.dti.rkk.h/library/toc/geogj/1998/geogj9802.html.
- Kinyamario, J.I. and F.M. Muthuri. 1986. Foraging preferences of the African Armyworm (*Spodoptera exempta* Walk.). p. 239-242. *In*: R.M. Hansen, B.M. Woie and R.D. Child (eds.). Range research and development in Kenya, Winrock International Institute Agricultural Development. Morrilton, Ark.USA.
- Kinyamario, J.I. and S.K. Imbamba. 1992. Savanna at Nairobi National Park, Nairobi. p. 25-68. *In*: S.P. Long, M.B. Jones and M.J. Roberts (eds.). Primary productivity of grass ecosystem of the tropics and sub-tropics. Chapman and Hall, London.
- Kitheka, S.K., J.R.M. Wambua, D.J. Nixon, J.K. Itabari, J.M. Waitiki, S.C. Simiyu, and J.N. Kihumba. 1994. The use of pitting for rehabilitation of eroded grazing lands in semi-arid eastern Kenya. p. 231-245. *In*: P.O. Fungoh, G.C.O. Mbadi and H. Ondatto (eds.). Proc. Focus on Agricultural Research for Intensifying Rural and Industrial Development, 4th KARI Scientific Conference, 25-28 October, 1994. Silver Springs Hotel, Nairobi, Kenya.
- Klinner, W.E., M.A. Neale, R.E. Arnold, A.A. Geikie, and R.N. Hobson. 1987. A new concept in combine harvester headers. *J. Agric. Engin. Res* 38: 37-45.
- Koning, R.E. 1994. Seeds and seed germination. Plant Physiology Information Website. http://koning.ecsu.ctstateu.edu/plants_human/seedgerm.html
- Kowithayakorn, L. and C. Phaikaew. 1993. Harvesting and processing techniques of tropical grass and legume seeds for smallfarmers. p. 1809-1813. *In*: Proc. of the XVII International Grassland Congress.
- Kristjanson, P., M. Radeny, D. Nkedianye, R. Kruska, R. Reid, H. Gichohi, F. Atieno, and R. Sanford. 2001. Valuing alternative land use options in Kitengela wildlife dispersal area of Kenya. Impact Assessment Series 8. International Livestock Research Institute (ILRI), Nairobi, Kenya.

- Lane, C. and J. Pretty. 1990. Displaced pastoralists and transferred wheat technology in Tanzania. IIED Gate Keeper Series 20. IIED (International Institute for Environment and Development), London, UK.
- Larcher, W. 1983. Physiological Plant Ecology. Springer-Verlag, Berlin.
- Lassner, M.W., P. Peterson, and J.I. Yoder. 1989. Simultaneous amplification of multiple DNA fragments by polymerase chain reaction in the analysis of transgenic plants and their progeny. *Plant Mol. Biol. Rep.* 7:116-128.
- Le Houerou, H.N. 1993. Grasslands of the Sahel. p. 171-196. *In*: R.T. Coupland (ed.). Natural grasslands: Eastern hemisphere and resume. Ecosystems of the World, 8B. Elsevier, Amsterdam.
- Leisinger, K.M., K. Schmitt, and ISNAR. 1995. Survival in the Sahel. International Service for National Agricultural Research (ISNAR). The Hague.
- Lemunyete, L. 2004. The advantages of partnership for milk and meat preservation participatory technology development project: Experiences of Ngurunit site team. p. 75-77. *In*: L. Crissman (ed.). Proc. Agricultural research and development for sustainable resource management and food security in Kenya. Agriculture / Livestock Research support Programme Phase II, End of programme conference, KARI, 11-12 Nov. 2003. Nairobi, Kenya.
- Lelo, F., J. Ayieko, P. Makenzi, N. Muhia, D. Njeremani, H. Muiruri, J. Omolo, and W. Ochola. 1995. PRA field handbook for participatory rural appraisal practitioners. The PRA Programme, Egerton University, Njoro, Kenya.
- Leriche, H. X. Le Roux, F. Desnoyers, D. benest, G. Simioni, and L. Abbadie. 2003. Grass response to clipping in an African savanna: testing the grazing optimization hypothesis. *Ecol. Appl.* 13(5):1346-1354.
- Leserogol, C.K. 1991. Pastoral production and transformation among the Samburu of northern Kenya. M.A. Thesis, UCLA, LA, Calif., USA.
- Leserogol, C.K. 1998. Life on the margins: Perspective on pastoralism and development in Kenya. A paper submitted to USAID/Kenya.
- Li, W. and D. Graur. 1991. Fundamentals of Molecular Evolution. Sinauer Associates Inc. Publishers, Sunderland, Massachusetts.
- Li, Y.C., T. Fahima, A. Beiles, A.B. Korol, and E. Nevo. 1999. Microclimatic stress and adaptive DNA differentiation in wild emmer wheat, *Triticum dicoccoides*. *Theor. and Appl. Gene.* 98: 873-883.
- Liao, L.C. and J.Y. Hsiao. 1998. Relationship between population genetic structure and riparian habitat as revealed by RAPD analysis of the rheophyte *Acorus gramineus* Soland. (Araceae) in Taiwan. *Mol. Ecol.* 7: 1275-1281.
- Liebenberg, L.C.C. 1942. Production of grass seed. *Farm. in S. Afr.* 17: 761-762.
- Lin, T.P., Y.P. Cheng, and S.G. Huang. 1997. Allozyme variation in four geographic areas of *Cinnamomum kanehirae*. *J. Hered.* 88: 433-438.
- Lind, E.M. and M.E.S. Morrison. 1974. East African vegetation. Longman, London.
- Lloyd, G.S. and P.B. Cavers. 2002. Dormancy, germination patterns and seedling vigour of fresh and aged seeds of different biotypes of proso millet, *Panicum miliaceum* L. *Seed Sci. and Technol.* 30: 641-649.
- Loch, D.S. 1991. Tropical herbage seed production – origins, progress and opportunities. *J. Appl. Seed Prod.* 9: (suppl.), 14-26.

- Loch, D.S. 1999. *Cenchrus ciliaris* in Australia. p. 351-3361. *In*: D.S. Loch and J.E. Ferguson. (eds.). Forage seed production. Volume 2: tropical and subtropical species. CAB International Publishing. Wallingford, Axon, UK.
- Loch, D.S. and F.H. de Souza. 1999. Seed harvesting and drying: Grasses. p. 191-212. *In*: D.S. Loch and J.E. Ferguson (eds.). Forage seed production. Volume 2: tropical and subtropical species. CAB International Publishing. Wallingford, Axon, UK.
- Loch, D.S. and J.E. Ferguson. 1999. Tropical and subtropical forage seed production: an overview. p. 1-40. *In*: D.S. Loch and J.E. Ferguson (eds.). Forage seed production. Volume 2: Tropical and subtropical species. CAB International Publishing. Wallingford, Axon, UK.,
- Long, S.P., M.B. Jones, and M.J. Roberts. 1992. Primary productivity of grass ecosystem of the tropics and sub-tropics. Chapman Hall, London.
- Lowe, A.J., A.C.M. Gilles, J. Wilson, and I.K. Dawson. 2002. Conservation genetics of bush mango from central/west Africa: Implications from random amplified polymorphic DNA analysis. *Mol. Ecol.* 9: 831-841.
- Ludwig, J., D. Tongway, D. Freudenberger, J. Noble, and K. Hodgkinson. 2003. Landscape ecology - function and management principles from Australian rangeland. CD-ROM, CSIRO Sustainable Ecosystem, ISBN 0958084556, Brisbane, Australia.
- Lusigi, W.J. 1981. Combating desertification and rehabilitation degraded production systems in northern Kenya. Integrated Project in Arid Lands (IPAL) Technical Report A-4, UNESCO. Nairobi, Kenya.
- Lusigi, W.J. 1984. The Integrated Project in Arid Lands (IPAL), Kenya. *In*: P.J. Joss, P.W. Lynch and O.B. Williams (eds.). Proc. 2nd International Rangelands Congress. Adelaide, Australia.
- Lusigi, W.J. 1986. Kenya arid lands research station. p. 277-285. *In*: R.M. Hansen, B.M. Woie and R.D. Child (eds.). Proc. Conference on Range Development and research in Kenya., April 1-5, 1986, Agricultural Resource Center, Egerton College, Njoro, Kenya.
- Lusigi, W.J., E.R. Nkurunziza, and S. Masheti. 1984. Forage preferences of livestock in the arid lands of northern Kenya. *J. Range Manage.* 37:542-548.
- Manley, J.T., G.E. Schuman, J.D. Reeder, and R.H. Hart. 1995. Rangeland soil carbon and nitrogen responses to grazing. *J. Soil and Water Conserv.* 50: 294-298.
- Manske, L.L. 1998. General description of grass growth development. Dickinson Research Centre, North Dakota State University, ND, USA.
<http://www.ag.ndsu.edu/dickinson/research/1998/range98a.htm>.
- Marietta, K.L. and C.M. Britton. 1988. Establishment of seven high yielding grasses on the Texas High Plains. *J. Range Manage.* 42(4): 289-294.
- Martin, C.C. 1975. The role of glumes and gibberelic acid in dormancy of *Themeda triandra* spikelets. *Physiol. Planta.* 33: 171-176.
- Mbakaya, D.S. 1986. Infiltration and soil loss as influenced by vegetation and cover types. p. 209-215. *In*: R.M. Hansen, B.M. Woie and R. D. Child (eds.). Proc. Conference on Range Development and Research in Kenya, April 1-5, 1986, Agricultural Resource Center, Egerton College, Njoro, Kenya.

- Mbogoh, S.G. and S.B. Shaabani. 1999. Socio-economic study on characterization of recommendation domains for pasture improvement in pastoral and agro-pastoral production systems in Kenya. Part II Consultancy Report. KARI/EU ARSP II. KARI, Nairobi, Kenya.
- McCarthy, N., A. Kamara, and M. Kirk. 2002. The effect of environmental variability on livestock and land-use management: The Borana plateau, southern Ethiopia. Socio-economics and policy research Working Papers No. 35. ILRI, Nairobi, Kenya.
- McCarthy, N., B. Swallow, P. Hazell, and M. Kirk. Property rights, risks and livestock development: summary of research results. ILRI/IFPRI/GIRD. Nairobi, Kenya.
- McIvor, J.C. and C.J. Gardener. 1981. Establishment of introduced grasses at different stages of pasture development: effects of seedbed. *Austr. J. Exp. Agric. and Anim. Husb.* 21: 417-423.
- McIvor, J.C. and C.J. Gardener. 1985. Germination of introduced pasture species in the semi-arid tropics. p.77-279. *In: J.C. Tothill and J.J. Mott, (eds.). Ecology and Management of the World's Savannas.* Austr. Acad. Sci., Canberra.
- McNaughton, S.J. 1979. Grazing as an optimization process: Grass-ungulate relationships in the Serengeti. *Amer. Nat.* 113: 691-703.
- McNeely, J., M. Gadgil, C. Leveque, C. Padoh, and K. Redford. 1995. Human influences on biodiversity. p. 711-821. *In: Global Biodiversity Assessment.* UNEP (United Nations Environment Programme). Nairobi, Kenya and Cambridge University Press, Cambridge, UK.
- McPeak, J.G. 2001. Analyzing and addressing localized degradation in the commons Land Econ.. www.york.ac.uk/depts/eeem/temp/degradation_of_commons.htm
- Michieka, D.O. and van der Pouw. 1977. Soils and vegetation of Kiboko Range Research Station. Report 53, Kenya Soil Survey, Ministry of Agriculture, Nairobi.
- Milchunas, D.G., O.E. Sala, and W.K. Lauenroth. 1988. A generalized model of the effects of grazing by large herbivores on grassland community structure. *Amer. Nat.* 132:87-106.
- Milchunas, D.G. and W.K. Lauenroth. 1993. Quantitative effects of grazing on vegetation and soils over a wide range of environments. *Ecol. Monogr.* 63(4):327-366.
- Miles, M.B. and A.M. Huberman. 1994. An expanded source book – Qualitative Data Analysis. 2nd Edition, SAGE Publications, London.
- Mnene, W.N. 1985. Influence of herbage/browse allowance on nutritive intake of cattle grazing a *Commiphora* savannah in Kenya. MSc. Thesis, Texas A&M University, College Station, TX, USA.
- Mnene, W. Ngoyawu. (Undated). Pitting and reseedling for small-scale natural pasture improvement in semi-arid areas. Brochure, KARI Publication Unit, Nairobi, Kenya.
- Mnene, W.N. and P.F.K. Kibet. 1995. Effects of plant community types on botanical composition and nutritive value of cattle diets. *E. Afr. agric. and For. J.* 60: 247-253.
- Mnene, W.N. and D.S. Mbakaya. 1997. Pastoralists' problems, coping strategies and opportunities: a report on participatory rural appraisal of the Masimba sub-location in Kajiado District, Kenya.

- Mnene, W.N., F.P. Wandera, and S.H. Lebbie. 1998. Arresting environmental degradation through accelerated on site soil sedimentation and re-vegetation using micro-catchment and re-seeding. In: Proc. Agricultural Research and Development for sustainable Resource Management and Increased Production. 6th KARI Scientific Conference, 9-13th November 1998. Nairobi, Kenya.
- Mnene, W.N., F.P. Wandera, and S.H. Lebbie. 2000. Arresting environmental degradation through accelerated on site soil sedimentation and re-vegetation using micro-catchment and re-seeding. In: Egyptian Society of Animal Production, Proc. The 3rd All Africa Conference on Animal Agriculture, Alexandria, Egypt.
- Mnene, W.N., J.W. Stuth, and R.K. Lyons. 1996. Effects of herbage and bush level on diet selection and nutrient intake of cattle in a *Commiphora* savanna. Trop. Grassl. 30: 378-388.
- Mnene, W.N., W.Ego, D.S. Mbakaya, and P.F.K. Kibet. 1997. Seasonality of range forage and the importance floral diversity for sustained productivity. p. 580-591. In: Proc. Focus on agricultural research for sustainable development in a changing economic environment. 4th KARI scientific conference, 14-16th October 1996, Nairobi, Kenya.
- Mott, J.J., G.M. McKeon, and C.J. Moore. 1976. Effects of seedbed conditions on the germination of four *Stylosanthes* species in the Northern Territory. Austr. J. Agric. Res. 27: 811-823.
- Mott, J.J. 1987. Patch grazing and degradation in native pastures of the tropical savannas in northern Australia. p. 153-16. In: F.P. Horn, J. Hodgson, J.J. Mott and R.W. Brougham (eds.). Grazing lands research at the plant-animal interface. Winrock International institute for Agricultural Development, Ark, USA.
- Mueller, R.J. and J.H. Richards. 1986. Morphological analysis of tillering in *Agropyron spicatum* and *Agropyron desertorum*. Ann. Bot. 58:911-921.
- Mukhebi, A.W., A.M. Gitunu, J. Kavoi, and J. Iroha. 1985b. Impact of the 1983/84 drought on cattle, sheep and goats in Kenya. Socio-economics Division, NRRC, Kiboko. Makindu, Kenya.
- Musembi, D.K. 1986. The seasonal climate of rangelands. p. 183-200. In: R.M. Hansen, B.M. Woie and R.D. Child (eds.). Range Research and Development in Kenya. Winrock Intl. Inst., Morrilton, Ark. USA.
- Muthiani, J. 1973. Akamba from within: Egalitarianism in social relations. Exposition Press, New York, NY, USA.
- Mututho, J.M. 1989. Some aspects of soil conservation on grazing lands. p. 315-322. D.B. Thomas (ed.). In: Soil and Water Conservation in Kenya. Proc. The 3rd National Workshop, September 1986, Nairobi, Kenya.
- Mwebesa, M.M.N. 1970. East African Observer's Handbook (Handbook of standard procedures for surface weather observing and recording of Climatological data). East African Meteorological Departmenet, Nairobi.
- Mworia, J.K., W.N. Mnene, D.K. Musembi, and R.S. Reid. 1997. Resilience of soil and vegetation subjected to different grazing intensities in a semi-arid rangeland of Kenya. Afr. J. Range and Forage Sci. 14: 26-31.
- NAS – NRC (National Academy of Sciences – National Research Council). 1962. Basic problems and techniques in range research. NAS-NRC Publication 890. Washington D.C.

- Ndikumana, J., J. Stuth, R. Kamidi, S. Ossiya, R. Marambii, and P. Hamlett. 2000. Coping mechanisms and their efficacy in disaster prone pastoral systems of the Greater Horn of Africa. Effects of the 1995-1997 drought and 1997-1998 El-Nino rains and the responses of pastoralists and livestock. ILRI Project Report. A-AARNET (ASARECA – Animal Agriculture Research Network), Nairobi, Kenya. GL-CRSP LEWS (Global Livestock Collaborative Research support Program Livestock Early Warning System), College Station, Texas, USA and ILRI (International Livestock Research Institute), Nairobi, Kenya.
- Nei, M. 1972. Genetic distance between populations. *Amer. Nat.* 106: 283-292.
- Nei, M. 1987. *Molecular Evolutionary Genetics*. Columbia University Press, New York, NY, USA.
- Nei, M. and W.H. Li. 1979. Mathematical model for studying genetic variation in terms of restriction endonucleases. *Nat. Acad. Sci.* 76: 5269-5273.
- Nevo, E. 1988. Genetic diversity in nature: patterns and theory. *Evol. Biol.* 23: 217-246.
- Nevo, E., D. Zohary, A.H.D. Brown, and M. Haber. 1979. Genetic diversity and environmental associations of wild barley, *Hordeum spontaneum*, in Israel. *Evolution*, 33: 815-833.
- Nevo, E., A. Beiles, N. Storch, H. Doll, and B. Anderson. 1983. Microgeographic edaphic differentiation in *Hordein* polymorphisms of wild barley. *Theor. and Appl. Gene.* 64: 123-132.
- Nevo, E., A. Beiles, and D. Zohary. 1986. Genetic resources of wild barley in the Near East: structure, evolution and application in breeding. *J. Linnean Soc. London–Bot.* 27: 355-380.
- Nelson, R. 1988. Dryland management: “The desertification problem”. The World Bank; Environment Department, Working paper No. 8. NY, USA.
- Ng’ethe, J.C. and T.W. Box. 1976. Botanical composition of Eland and goat diets on an acacia-grassland community in Kenya. *J. Range Manage.* 29: 290-293.
- Nill, D., U. Schwertmann, U. Sabel-Koschella, M. Bernhard, and J. Breuer. 1996. Soil erosion by water in Africa – Principles, predictions and protection. [Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), GmbH]. Rossdorf: TZ-Verl.-Ges.
- Njoka, T.J. 1984. Evaluation of seasonal and drought effects on range trend analysis in Kajiado District, Kenya. p. 195-206. *In*: W. Siderius (ed). *Proc. Workshop on Land Evaluation for Extensive Grazing*. International Land Reclamation and Improvement Publ. 36. Wageningen, The Netherlands.
- Noble, J.C., A.D. Bell, and J.L. Harper. 1979. The population biology of plants with clonal growth. I. The morphology and structural demography of *Carex arenaris*. *J. Ecol.* 67:983-1008.
- Nobel, P.S., I.N. Forseth, and S.P. Long. 1993. Canopy structure and light interception. p. 79-90. *In*: D.O. Hall, J.M.O. Scurlock, H.R. Bolhar-Nordenkamp, R.C. Leewood and S.P. Long (eds.). *Photosynthesis and Production in a Changing Environment – A Field and Laboratory Manual*, Chapman and Hall, London.
- Okubo, A. and S.A. Levin. 1989. A theoretical frame work for data analysis of wind dispersal of seeds and pollen. *Ecology*. 70:329-338.

- Okuro, J.O., F.M. Muriithi, H. Verkurjl, W. Mwangi, Hugo de Groote, and M. Gethi. . Factors affecting the adoption of maize production technologies in Embu District, Kenya. p. 45-55. *In*: E.A. Mukisira, F.H. Kiriro, J.W Wamuongo, L.W. Wamae, F.M. Muriithi and W. Wasike (eds). Proc. 7th Biennial Scientific KARI Conference, Collaborative and Participatory Research for Sustainable Improved Livelihoods, 13-17 November 2000, KARI HQ, Nairobi, Kenya.
- Olindo, P.M. 1971. Fire and conservation of the habitat in Kenya. Proc. Fire in Africa. Annual Tall Timbers Fire Ecol. Conf. Tallahassee, FA, USA. 11:243-257.
- Olson, K.C., R.S. White, and B.W. Sneider. 1985. Response of vegetation of the northern Great Plains to precipitation amount and grazing intensity. *J. of Range Manage.* 38:357-361.
- Olukoye, G.A., J.I. Kinyamario, J.W. Wakhungu, W.N. Wamicha, and J.I. Mwanje. 2003. Ecological and economic implications of land sub-division in Laikipia rangelands of Kenya. p. 610-612. *In*: N. Allsopp, A.R. Palmer, S.J. Milton, K.P. Kirkman, G.I.H. Kerley, C.R. Hurt, C.J. Brown (Eds.). Proc. The VIIth International Rangelands Congress, 26th July -1st August 2003. Durban, South Africa.
- Ong, C.K. and C. Marshall. 1979. The growth and survival of severely-shaded tillers in *Lolium perenne* L. *Ann. Bot.* 43:147-155.
- Otieno, S. 2001. Community drought coping strategies in Kajiado district. *In*: E. Ruto (ed.). Proc. Stakeholders' workshop on efficiency and constraints of marketing of livestock and livestock products EU/KARI ARSP II, KARI Kiboko.
- Ott, L. 1988. An introduction to statistical methods and data analysis. Third Edition. Merrell Dow Research Institute. PWS-Kent Publishing Company, Boston.
- Pakiding, W. and M. Hirata. 2001. Leaf appearance, death and detachmert in bahia grass (*Paspalum notatum*) pasture under cattle grazing. *Trop. Grassl.* 35:114-123.
- Paran, I., A. Aftergoot, and C. Shfriss. 1998. Variation in *Capsicum annuum* revealed by RAPD and AFLP markers. *Euphyt.* 99:167-173.
- Parsons, A.J., E.L. Leafe, B. Collett, P.D. Penning, and J. Lewis. 1983. The physiology of grass production under grazing. II. Photosynthesis, plant growth and animal intake of continuously grazed swards. *J. Appl. Ecol.* 20:127-139.
- Peacock, C.P., P.N. de Leeuw, and J.M. King. 1982. Herd movement in the Mbirikani area. Internal document, ILCA. Nairobi, Kenya.
- Perkins, J.S. and D.S.G. Thomas. 1993a. Environmental response and sensitivity to permanent cattle ranching, semi-arid central Botswana. p. 273-286. *In*: D.S.G. Thomas and R.J. Allison (eds.). Landscape sensitivity. J. and Sons, Chichester.
- Perry Jr., L.J. and L.E. Moser. 1975. Seedling growth of three switch grass strains. *J. Range Manage.* 28(5):391-393.
- Phaikaew, C., C. Manidool, and P. Devahuti. 1993. Ruzi grass (*Brachiaria ruziziensis*) seed production in north-east Thailand. p. 1766-1767. *In*: Proc. The XVII International Grassland Congress.
- Pike, A.H. 1938. Soil conservation among the Matengo tribe. *Tanganyika Notes and Records* 6:79-81.
- Plath, C.V. 1954. Reseed now? *J. Range Manage.* 7:215-217.

- Polley, H.W., H.B. Johnson, H.S. Mayeux Jr., and C.R. Tischler. 1995. Are some of the recent changes in grassland communities a response to rising CO₂ concentrations? TEKTRAN, United States Department of Agriculture, Agricultural Research Service.
<http://www.nal.usda.gov/ttic/tektran/data/000006/07/0000060763.html>.
- Prathepha, P. and V. Baimai, V. 1999. Genetic differentiation in Thai populations of the rare species *Afgekia sericea* Craib (Leguminosae) revealed by RAPD-PCR assays. *Genetica*. 105: 193-202.
- Pratt, D.J. 1963. Reseeding denuded land in Baringo District, Kenya. *E. Afr. Agric. For. J.* 29(1): 78-91
- Pratt, D.J. 1966. Control of *Disperma* in semi-desert dwarf shrub grassland. *J. Appl. Ecol.* 3:369-382.
- Pratt, D.J. and J. Knight. 1964. Reseeding denuded lands in Baringo District, Kenya. 3. Techniques for capped red loam soils. *E. Afr. agric. For. J.* 30(2): 117-125.
- Pratt, D.J. and M.D. Gwynne. 1977. *Range Management and Ecology in East Africa*. Hodder & Stroughton, London.
- Reid, R.S., P.K. Thornton, and R.L. Kruska. 2004. Loss and fragmentation of habitat for pastoral people and wildlife in east Africa: concepts and issues. *Afr. J. Range and Forage Sci.* 21(3): 171-181.
- RELMA (Regional Land Management Unit). 1999. We work together. Land rehabilitation and household dynamics in Chepareria Division, West Pokot District, Kenya. Technical report Series 22. Nairobi, Kenya.
- Richards, B.N. 1974. *Introduction to the soil ecosystem*. Longman, London.
- Roberts, M.J., S.P. Long, L.L. Tieszen, and C.L. Beadle. 1985. Measurement of plant biomass and net primary production. p. 1-19. *In*: J. Coombs, D.O. Hall, S.P. Long and J.M.O. Scurlock (eds.). *Techniques in bioproductivity and photosynthesis*, 2nd Edition. Pergamon Press, Oxford.
- Roberts, M.J., S.P. Long, L.L. Tieszen, and C.L. Beadle. 1993. Measurement of plant biomass and net primary production of herbaceous vegetation. p. 1-21. *In*: D.O. Hall, J.M.O. Scurlock, H.R. Bolhar-Nordenkamp, R.C. Leewood and S.P. Long (eds.). *Photosynthesis and Production in a Changing Environment – A field and laboratory manual*. Chapman and Hall, London.
- Roeleveld, A.C.W. 1996. The diagnostic phase in research on livestock systems. *In*: A.C.W. Roelveld and A. van den Broek (eds.). *Focusing livestock systems research*. Royal Tropical Institute, The Netherlands.
- Rundel, P.W. and W.M. Jarrell. 1989. Water in the environment. P. 29-56. *In*: R.W. Pearcy, J. Ehleringer, H.A. Mooney and P.W. Rundel (eds.). *Plant Physiology and Ecology – Field methods and instrumentation*, Chapman and Hall, London.
- Russel, R.S. 1988. *Plant Root Systems – Their function and interaction with the soil*. ELBS.
- Russel, E.W. 1988. *Soil Conditions and Plant Growth*. 10th Edition. A. Wild (ed.), Longman group (UK) Ltd, Essex.
- Sala, O.E., W.J. Parton, L.A. Joyce, and W.K. Lauenroth. 1988. Primary production of the central grassland regions of the United States. *Ecol.* 69:40-45.
- Sanchez, P.A. 1976. *Properties and management of soils in the Tropics*. John Wiley & sons, New York, NY, USA.

- Sandford, S. 1983. Management of pastoral development in the Third World. John Wiley & Sons / Overseas development Institute (ODI), London.
- SAS Institute. 1990. SAS/STAT users guide. Version 6.1. Statistical Analysis Systems Institute (ed.), Cary, North Carolina, USA.
- Scarpa, R., E.S.K. Ruto, P. Kristjanson, M. Radeny, A.G. Drucker, and E.O. Rege. 2003. Valuing indigenous cattle breeds in Kenya: an empirical comparison of stated and revealed preference value estimates. *Ecol. Econ.* 45: 409-426.
- Schneekloth, J., J. Bauder, I. Broner and R. Waskom. 2002. Measurement of soil moisture. Colorado State University Cooperative Extension. <http://www.ext.colostate.edu/drought/soilmoist.html>
- Scholes, R.J. 1990. The influence of soil fertility on the ecology of southern Africa dry savannas. *J. Biogeogr.* 17:415-419.
- Schwartz, H.J. and W. Schultka. 1995. A compedium of important forage plants in the semi-arid and arid rangelands of Kenya. Range Management Handbook of Kenya 3 (9). Min. Livestock Development and Marketing / GTZ, Nairobi.
- Scifres, C.J. 1980. Bush Management – Principles and practices for Texas and the Southwest. Texas A&M University Press, College Station, TX, USA.
- Scoones, I. 1995. Living with uncertainty. International Institute for Environment and Development, ITP Ltd., London, UK.
- Seed Labs. 2000. Procedures – Significance of vigour. 20/20 Seed labs Inc., <http://www.2020seedlabs.com/info.php?i=30>
- Sharpley, A.N. and J.R. Williams. 1990. EPIC – Erosion Productivity Impact Calculator: 1. Model documentation. U.S. Department of Agriculture Technical Bulletin No. 1768.
- Sidahmed, A.E. 1996. The rangelands of the arid/semi-arid areas: Challenges and hopes for 2000s. Proc. Symposium D: Range Management. The International Conference on Desert Development in the Arab Gulf Countries. 23-26 March 1996. KISR, Kuwait.
- Simiyu, S.C., E.M. Gichangi, J.R. Simpson, and R.K. Jones. 1992. Rehabilitation of degraded grazing lands using the Katumani pitting technique. *In: M.E. Probert (ed.). Proc. A Search for Strategies for Sustainable Dry land Cropping in Semi-arid Eastern Kenya.* Austr. Centre Inter. Agric. Res. 41: 83-87.
- Sinclair, A.R.E. 1979. Dynamics of the Serengeti ecosystem: Patterns and process. *In: A.R.E. Sinclair and M. Norton-Griffiths (eds.). Serengeti: Dynamics of an Ecosystem.* University of Chicago Press, Chicago.
- Singh, P. and A.N. Ghosh. 1993. Forage and animal management on common rangelands in arid and semi-arid rangelands. p. 38-42. *In: M.J. Baker (ed.). Grasslands for Our World.* SIR Publishing, Wellington, New Zealand.
- Skerman, P.J. and F. Riveros. 1990. Tropical Grasses. Food and Agriculture Organization of the United Nations, Rome.
- Skovlin, J.M. 1971. The influence of fire on important range grasses of East Africa. *In: Fire in Africa. Annual Tall Timbers Fire Ecology Conference, Tallahassee, Florida.* 11:201-217.
- Skovlin, J. 1984. Long-term trends from selected range sites throughout Kenya. p. 537-538. *In: Proc. II International Rangeland Congress 2.* Adelaide, Australia.

- Smith, J.G. 1898. Experiments in range improvements. US Dept. of Agr., Div. of Agrostology, Circ. 8.
- Sneath, P.H.A. and R.R. Sokal. 1973. Numerical Taxonomy. Freeman. San Francisco, USA.
- SNV / SARDEP (Netherlands Development Organization – Semi arid development programme). (Undated). Poverty, target groups and governance environment in Kajiado District, Kenya: A district analysis. Nairobi, Kenya.
- Society for Ecological Restoration Science and Policy Working Group. 2002. The SER Primer on Ecological Restoration. www.ser.org/.
- SRM (Society of Range Management). 1983. Guidelines and terminology for range inventories and monitoring. Soc. Range Manage., Denver, Colorado, USA.
- Sombriek, W.G., H.M.H. Braun, and B.J.A. van der Poun. 1982. Exploratory soil map and agroclimatic zone map of Kenya, 1980, scale 1:1,000,000. Exploratory Soil Survey Report No. E-1. Kenya Soil Survey, Nairobi.
- Stahl, M. 1993. Land degradation in East Africa. *Ambio*, 22(8):505-508.
- Stebbins, G.L. 1981. Co-evolution of grasses and herbivores. *Ann. Missouri Bot. Gard.* 68:75-86.
- Steinfeld, H., C. de Haan and W.H. Blackburn. 1996. Livestock and environment interactions. A summary of global issues and options. Draft paper presented at Environmentally sustainable Development Conference on Rural Well Being, September 2, 1995 in Washington DC. The World Bank, Washington DC., USA
- Stenhouse, A.S. 1944. Agriculture in the Motengo highlands. *E. Afr. agric. and For. J.* 11:22-24.
- Stoddart, L., A.D. Smith, and T.W. Box. 1975. Range Management. McGraw-Hill Book Company, New York.
- Stuth, J.W. 1991. Foraging behaviour. p. 65-83. *In*: R.K. Heitschmidt and J.W. Stuth (eds.). *Grazing Management – An Ecological Perspective*. Timber press, Inc., Portland, Oregon, USA.
- Stuth, J.W. and B.E. Dahl. 1972. Evaluation of rangeland seeding following mechanical brush control in texas. *J. Range Manage.* 27:146-149.
- Stuth, J.W. and P.N. Kamau. 1990. Influence of woody plant canopy cover on dietary selection by goats in an *Acacia senegal* savanna of East Africa. *Small Rumin. Res.* 3(3):221-225.
- Stuth, J.W., J.R. Conner, and R.K. Heitschmidt. 1991. The decision making environment and planning paradigm. p. 201-223. *In*: R.K. Heitschmidt and J.W. Stuth (eds.). *Grazing Management – an ecological perspective*. Timber press, Inc., Portland, Oregon, USA.
- Sutton, J.E.G. 1969. Ancient civilizations and modern agricultural systems in southern highlands of Tanzania. *Azania*, 4:1-3.
- Sweeny, E.C. and J.M. Hopkinson. 1995. Vegetative growth of nineteen tropical and sub-tropical pasture grasses and legumes in relation to temperature. *Trop. Grassl.* 9(3):209-217.
- Sys, C., E. Vanranst, and J. Debayeve. 1991. Principles in a land evaluation and crop calculation. p. 95-105. *In*: Part 1. Agricultural Publication No. 7 AGCD. Brussels.
- Tate, R.L. 1995. Soil Microbiology. John Wiley & Sons, New York, NY, USA.

- Tefera, B., G. Ayele, Y. Atnafe, M.A. Jabbar, and P. Dubale. 2002. Nature and causes of land degradation in the Oromiya region: A review. Socio-economic and Policy Working Paper 36. ILRI (International Livestock Research Institute), Nairobi, Kenya.
- Tessema, S. 1986. Chemical composition and in vitro dry matter digestibility of herbage. P. 85-92. *In*: R.M.Hansen, B.M. Woie and R.D. Child (eds.). Range Development and Research in Kenya. Winrock International Institute for Agricultural Development, Morrilton, Ark, USA.
- Thompson, M. and K. Homehood. 2002. Elites, entrepreneurs and exclusion in Maasailand. *Human Ecol.* 30(1):107-138.
- Thorton, P.K., R.K. Kruska, N. Henninger, P.M. Kristjanson, R.S. Reid, F. Atieno, A. Odero, and A. Ndegwa. 2002. Mapping poverty and livestock in the developing world. International Livestock Research Institute, Nairobi, Kenya.
- Thurrow, T.L. 1995. Understanding and facilitating rangeland management in the Trans Mara sub-district. GTZ / Trans Mara Development Programme. GTZ, Nairobi, Kenya.
- Timmerman, G.M. and J. A. McCallum. 1993. Application of random polymorphic DNA (RAPD) markers in plant biology. P.343-349. *In*: M.J. Baker (ed.). Grasslands for Our World. Sir Publishing, Wellington, New Zealand.
- Tolsma, D.J. 1989. On the ecology of savanna ecosystems in south-eastern Botswana. Ph.D. Thesis. Free University, Amsterdam.
- Too, D.K. 1995. Increasing primary production of Kenya Rangelands through bush control and grass seeding. Ph.D. Dissertation. Colorado State University. Fort Collins, USA.
- Too, D.K., F.E. Smeins, and R.D. Child. 1986. Effects of defoliation frequency and intensity on production of grassland communities. P. 253-262. *In*: R.M. Hansen, B.M. Woie and R.D. Child (eds.). Range Development and Research in Kenya. Winrock International Institute for Agricultural Development, Morrilton, AR, USA.
- Too, D.K., M.J. Trlica, E.T. Bartlett, D.M. Swift, and W.N. Mnene. 1997. Valuing increased herbaceous production following brush clearing, manure and grass seeding in Kenya. P. 755-763. *In*: P.O. Fungoh and G.C.O. Mbadi (eds.). Focus on agricultural research for sustainable development in a changing economic environment, Proc. 5th KARI Scientific Conference, 14-16th October, 1996. Nairobi, Kenya.
- Tothill, J.C. 1977. Seed germination studies with *Heteropogon contortus*. *Austr. J. Ecol.* 2:477-484.
- Trapnell, C.G. 1959. Ecological results of woodland burning experiments in northern Rhodesia. *J. Ecol.* 47:129-168.
- Troughton, A. 1957. The underground organs of herbage grasses. Commonwealth Bureau of Pasture and Field Cops. Bull. 44, Hurley, Berkshire.
- Tueller, P.T. 1973. Secondary succession, disclimax and range condition standards in desert shrub vegetation. P. 57-65. *In*: D.N. Hyder (ed.). Proc. Arid shrublands workshop. US / Australia Rangeland Panel. Tucson, Arizona.
- Turner, M. 1993. Overstocking the range – a critical analysis of the environmental science of Sahelian pastoralism. *Econ. Geogr.* 69:402-421.

- UNDP (United Nations Development Programme). 1994. Pastoral natural resource management and policy. Proc. The sub-regional workshop held on 6-10 December 1993. Arusha, Tanzania.
- UNDP (United Nations Development Programme). 2003. Human Development Reports. http://hdr.undp.org/reports/global/2003/indicator/cty_f_KEN.html.
- UNEP (United Nations Environment Programme). 1997. National degradation assessment and mapping in Kenya. Nairobi, Kenya.
- USAID (United States Agency for International Development). 1994. President Clinton Institute on the Horn of Africa: Building a foundation for food security and crisis prevention in the Greater Horn of Africa: A concept note for discussion. USAID, Washington D.C., USA.
- Unger, P.W. 1968. Soil organic matter and nitrogen changes during 24 years of dryland wheat tillage and cropping practices. *Soil Sci. Soc. Am. Proc.* 32:427-429.
- Valdivia, C., C. Jette, L. Markowitz, J. Cespedes, J.S. de Queiroz, C.M. Quiroga, and E. Dunn. 2001. Household economy and community dynamics at San Jose Llanga. p.117-166. *In*: D.L Coppock and C. Valdivia (eds.). *Sustaining agropastoralism on the Bolivian Altiplano: the case of San Jose Llanga*. USAID/Global Livestock Collaborative Research support Programme. Washington, D.C.
- Valentine, J.F. 1979. *Range Development and Improvements*. Brigham Young University Press, Provo, Utah, USA.
- Veenendaal, E.M. 1991. Adaptive strategies of grasses in a semi-arid savanna in Botswana. Ph.D. Thesis, Vrije Universiteit, Amsterdam.
- Veenendaal E.M., W.H.O. Ernest, and G.S. Modise. 1996. Effect of seasonal rainfall pattern on seedling emergence and establishment of grasses in a savannah in southeastern Botswana. *J. Arid Environ.* 32:305-317.
- Walker, B.H. 1993. Rangeland ecology: Understanding and managing change. *Ambio*, 22(2-3):80-87.
- Wandera, F.P. 1993. Patches in *Heteropogon contortus* dominated grassland in southeastern Queensland – their characteristics, probable causes, implications and potential for rehabilitation. Ph.D. Thesis, University of Queensland, Canberra, Australia.
- Wandera, F.P., J. Sitienei, W.N. Mnene, W. Wanyangu, P. Audi, and C.O. Ahuya. 1996. PRA report for Kajiado and Baringo district.
- Wang'ang'a. 2001. Effects of the last two major droughts in Kajiado on (capital base) livestock and livelihood. *In*: E. Ruto, (ed.). *Proceedings of Stakeholders' workshop on efficiency and constraints of marketing of livestock and livestock products EU/KARI ARSP II, KARI Kiboko*.
- Waters – Bayer, A. and W. Bayer. 1994. Planning with pastoralists: PRA and more: A review of methods focused on Africa. German Agency for Technical Cooperation (GTZ), Division 422 Working Paper. Eschborn, Germany.
- Welsh, J. and M. McClelland. 1990. Fingerprinting genomes using PCR with arbitrary primers. *Nucleic Acids Res.* 18: 7213-7218.
- Werner, H. 2002. Irrigation management – electrical resistance blocks to measure soil moisture. Cooperative Extension Service, South Dakota University, DA, USA. <http://agbiopubs.sdstate.edu/articles/FS899.pdf>

- White, F. 1983. The vegetation of Africa. UNESCO Natural Resources Research Series XX. Paris.
- Willms, W.D., J.F. Dormaar, and G.B. Schaalje. 1988. Stability of grazed patches on rough fescue grasslands. *J. Range Manage.* 41:503-508
- Williams, J.G.K., A.R. Kubelik, K.J. Livak, J.A. Rafalski, and S.V. Tingey. 1990. DNA polymorphism amplified by arbitrary primers is useful as genetic markers. *Nucleic Acids Res.* 18:6531-6535.
- Williams, J.R., P.T. Dyke, W.W. Fushs, V.W. Benson, O.W. Rice, and E.D. Taylor. 1990. EPIC – Erosion Productivity Impact Calculator: 2. User Manual. A.N. Sharpley and J.R. Williams (eds.). U.S. Department of Agriculture Technical Bulletin No. 1768.
- Woie, B.M. 1984. Influence of frequency and intensity of clipping on forage yield, crude protein content and digestibility of six Kenyan range grasses. Ph.D. Thesis, Texas A&M University, College Station, TX, USA.
- Woie, B.M. 1986. Effects of defoliation on range grasses. p. 263-270. *In*: R.M. Hansen, B.M. Woie and R.D. Child (eds.). *Range Development and Research in Kenya*. Winrock International Institute for Agricultural Development, Morrilton, AR, USA.
- WRI. 1994. World Resources 1994-95. World Resources Institute, Oxford University Press, Oxford, New York, NY, USA.
- Wu, X.M., N.F. Wu, X.Z. Qian, R.G. Li, F.H. Huang, and L. Zhu. 1998. Phenotypic and genotypic changes in rapeseed after 18 years of storage and regeneration. *Seed Sci. Res.* 8 (Supplement): 55-64.
- Yeh, F.C. and T. Boyle. 1997. POPGENE, Microsoft Windows-based Software for *Population Genetic Analysis. Release 1.2*. A joint project development by Francis C. Yeh, University of Alberta and Tim Boyle, Centre for International Forestry Research, Bogor, Indonesia.
- Young, A. 1997. *Agroforestry for Soil Management*. 2nd Edition. ICRAF / CAB International, Wallingford, UK.

Appendix 4.1: Copy of the survey questionnaire on natural pasture degradation administered to pastoral and agro-pastoral communities in Makueni, Kajiado and Taita-Taveta districts in 1999.



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Questionnaire No. _____

Time: Start _____

End _____

Geographical Position _____

SOCIO-ECONOMIC SURVEY OF NATURAL PASTURE IMPROVEMENT PROBLEMS IN RANGELANDS OF KENYA.

Instructions: Fill in as appropriate

Section A. (Background information)

1. Date of Survey: _____
2. Recorder _____
3. Name/Sex of farmer: _____ M/F
4. Educ. Level _____
5. Other Occupations _____
6. Relationship to Head of Household _____
7. District _____
8. Division _____
9. Location _____
10. Sub-Location _____
11. Village _____
12. Family size: 12.1 Adults (>18 Years) _____ 12.2 Male _____ 12.3 Females _____
- 12.4 Children (6-18 Years) _____ 12.5 Males _____ 12.6 Females _____
- 12.7 Children (<6 Years) _____ 12.8 Males _____ 12.9 Females _____
- 12.10 No. in residence (including relatives): _____ 12.11 Family members: 12.11.1 Males _____ 12.11.2 Females _____
- 12.12 Relatives: 12.12.1 Males _____ 12.12.2 Females _____
- 13.0 No. of employees: 13.1 Permanent _____ 13.2 Casual _____
- 14.0 Farm size (acres) _____ 15.0 Type land tenure _____
- 16.0 Land uses:
 - 16.1 Approximate area under cultivation (acres): 16.1.1 Food crops _____
 - 16.1.2 Cash crops _____
 - 16.2 What is the area under livestock? 16.2.1 Natural pastures _____
 - 16.2.2 Improved pasture _____

Section B. (Instructions: Fill in & tick as appropriate)

17.0 Which species of livestock are you keeping now?

☐ Cattle

No. Breeds

☐ Sheep

No. Breeds

☐ Goats

No. Breeds

☐ Donkeys

No. Breeds

☐ Camels

No. Breeds

☐ Others (specify):

No. Breeds

No. Breeds

No. Breeds

No. Breeds

18.0 Where do you graze your livestock?

18.1 Wet season

☐ Only within my farm

☐ Communally on extensive areas

☐ Both

☐ Other (Specify)

18.2 Dry season

☐ Only within my compound

☐ Communally on extensive areas

☐ Both

☐ Other (Specify)

19.0 Who grazes: and waters each of these livestock species?

Livestock species	Grazing	Watering	Comments
Cattle			
Sheep/Goats			
Cattle Calves			
Lambs/Kids			
Donkeys			
Poultry			
Others (specify)			

20.0 Who makes the decision as to where to graze?

Section C.

21.0 Does part of your land with natural pasture have extensive patches without grass?

- ☐ No (Go to 48.3)
- ☐ Yes (Go to 38.1)

21.1 If YES, what are the major causes of these bare patches?

- A) _____
- B) _____
- C) _____
- D) _____

21.2 If YES, what extent of your land is bare?

- ☐ Less than quarter
- ☐ Between a quarter and a half of the pastureland.
- ☐ More than half of the pastureland.

21.3 If YES, what has been the trend over the years?

- ☐ Increasing
- ☐ Decreasing
- ☐ No change

21.4 If NO, what is the reason(s)

- i) _____
- ii) _____

22.0 Are you aware of any techniques of reducing the bare patches? Yes/No.

- A) _____
- B) _____
- C) _____
- D) _____

22.1 If YES, how did you find out about the above techniques?

- ☐ Seminar / workshop
- ☐ Extension demonstrations.(indicate where) _____
- ☐ Neighbor's experience
- ☐ Other (specify): _____

22.2 Who attended, if seminar/workshop or demonstration? Husband / Wife / Both. (Please circle)

23.0 Which of the above-mentioned denudation reducing techniques have you attempted?

- A) _____
- B) _____
- C) _____
- D) _____

23.1 Of the various attempted techniques, who did what? (Fill the table below)

Technique	Adult		Child		Worker	
	Husband	Wife	Male	Female	Male	Female

24.0 In case reseeding was one of the techniques attempted, what problems were encountered?

- A) _____
- B) _____
- C) _____
- D) _____

25.0 Do you know of any plant species important as livestock feed that may have disappeared from your pasture? **Yes / No**

25.1 If YES, list them in the table below.

Type	Species Name	Common Name	Vernacular Name	Remarks
Grasses				
1.				
2				
3.				
4				
Legumes				
1.				
2				
3.				
4				
Trees				
1.				
2				
3.				
4.				

25.2 What caused the disappearance of the above named plants?

25.3 Are those plants still present somewhere else? **Yes / No.**

25.4 If YES, where?

26.0 In case of reseeded, what species were used? (Include vernacular names and collect samples where possible).

Type	Species Name	Common Name	Vernacular Name	Remarks
Grasses				
1.				
2				
3.				
4				
Legumes				
1.				
2				
3.				
4				
Trees				
1.				
2				
3.				
4.				

26.1 What inputs were required for the reseeding?

- a) _____
b) _____
c) _____

26.2 Who acquired the above inputs?

Type of input	Husband	Wife	Male child	Female child	Other (specify)

26.3 What were the sources of planting materials and how far were they from your homestead? (Fill table below).

Type of material	Source of material	Distance from Homestead (km)

26.4 Was anything paid for the planting materials? **Yes/No**

26.5 If YES, how much? KSh. _____ per _____

26.6 Are these seed sources adequate to satisfy your needs? **Yes/No**

26.7 If NO, would you be willing to undertake seed production, on your farm? **Yes/No**

26.8. If NO, What are the reasons?

27.0 In the reseeding, who did what? (Fill table below)

Type of Reseeding Activity	Adult		Child		Worker	
	Male	Female	Male	Female	Male	Female

28.0 How was the re-seeded pasture area taken care of?

28.1 And who decides on how the area is to be used?

☐ Husband ☐ Wife ☐ Child (M/F)

29.0 Do you know how to harvest and process pasture-reseeding materials?

Yes / No

29.1 If YES, have you attempted to do so? **Yes / No.**

29.2 If NO, why?

30.0 Do you know of anyone outside your homestead who has used any techniques to rehabilitate denuded pastureland? **Yes / No.**

30.1 If YES, what is/are the name(s) of the farmer(s)?

30.2 If YES, what technique(s) was/were used?

30.3 Was / were the attempts successful? **Yes / No/ Do not know**

30.4 How far away is the farm from yours? _____ (Km)

30.5 If NO, what was / were the reason(s)?

31.0 Would you be willing to set aside a small part of your land for research trials on the existing pasture problems/ **Yes / No.**

32.0 If NO, give reasons

33.0 In case of new technologies, how should such information be disseminated to farmers and/or pastoralists?

☐

On-farm demonstrations

☐

Seminars/Workshops

☐

Extension farm visits

☐

Publications (Pamphlets, Bulletins, etc.)

☐

Other (specify): _____

Appendix Table 4.2. Correlation matrix

	Education	Occupation	Family	Farm	Pasture	Improve	Cattle	Sheep	Goats	Denudation	Extent
Education	1 . 353										
Occupation	0.251 <0.0001 353	1 . 353									
Family	-0.247 <0.0001 353	-0.103 0.054 353	1 . 353								
Farm	-0.052 0.332 353	-0.028 0.596 353	0.103 0.052 353	1 . 353							
Pasture	-0.046 0.391 353	-0.043 0.421 353	0.084 0.115 353	0.288 <0.0001 353	1 . 353						
Improved	0.012 0.818 353	-0.014 0.796 353	0.121 0.023 353	-0.010 0.856 353	-0.010 0.851 353	1 . 353					
Cattle	-0.127 0.017 353	0.083 0.121 353	0.181 0.001 353	0.025 0.635 353	0.006 0.906 353	-0.014 0.788 353	1 . 353				
Sheep	-0.164 0.002 353	-0.118 0.027 353	0.212 <0.0001 353	-0.013 0.804 353	-0.018 0.735 353	-0.028 0.598 353	0.583 <0.0001 353	1 . 353			
Goats	-0.163 0.002 353	0.150 0.005 353	0.233 <0.0001 353	-0.010 0.846 353	-0.012 0.821 353	-0.001 0.981 353	0.544 <0.0001 353	0.821 <0.0001 353	1 . 353		
Denude	-0.073 0.169 353	0.040 0.451 353	0.160 0.003 353	0.044 0.408 353	0.42 0.431 353	-0.016 0.760 353	0.105 0.049 353	0.134 0.011 353	0.135 0.011 353	1 . 353	
Extent	-0.117 0.131 268	-0.118 0.054 268	0.043 0.481 268	-0.049 0.711 347	0.060 0.329 268	0.065 0.290 268	-0.061 0.319 268	-0.060 0.331 268	-0.063 0.305 268	.a . 268	1 . 268

^a Could not be computed because at least one of the variables was constant.

Appendix Table 5.1

Microorganisms identified around germinating seeds of four re-seeding experimental grasses during viability tests in petri dishes at KARI Kiboko.

Sample ID	Rep	Pathogen / Organism identified	Remarks
Cenchrus ciliaris	1	<i>Fusarium moniliforme</i> <i>Fusarium graminearum</i> <i>Penicilium sp.</i>	Pathogenic fungus Pathogenic fungus Pathogenic / Saprophytic storage fungus
	2	<i>Fusarium moniliforme</i> <i>Fusarium graminearum</i> <i>Phoma sorghina</i> <i>Penicilium sp.</i> <i>Chaetomium</i>	Pathogenic fungus Pathogenic fungus Pathogenic fungus Pathogenic / Saprophytic storage fungus Saprophytic fungus
	3	<i>Fusarium moniliforme</i> <i>Fusarium graminearum</i> <i>Alternaria sp.</i> <i>Curvularia sp.</i> <i>Penicilium sp.</i>	Pathogenic fungus Pathogenic fungus Pathogenic fungus Pathogenic fungus Pathogenic / Saprophytic storage fungus
	4	<i>Fusarium graminearum</i> <i>Bipolaris longipes</i> <i>Curvularia sp.</i>	Pathogenic fungus Pathogenic fungus Pathogenic fungus
Enteropogon macrostachyus	1	<i>Aspergillus sp.</i> <i>Penicilium sp.</i>	Pathogenic / Saprophytic storage fungus Pathogenic / Saprophytic storage fungus
	2	<i>Aspergillus sp.</i> <i>Curvularia sp.</i> <i>Fusarium moniliforme</i>	Pathogenic / Saprophytic storage fungus Pathogenic fungus Pathogenic fungus
	3	<i>Rhizoctonia solani</i> <i>Aspergillus sp.</i> <i>Penicilium sp.</i>	Pathogenic fungus Pathogenic / Saprophytic storage fungus Pathogenic / Saprophytic storage fungus
	4	<i>Aspergillus sp.</i> <i>Penicilium sp.</i> <i>Cladosporium sp.</i>	Pathogenic / Saprophytic storage fungus Pathogenic / Saprophytic storage fungus Pathogenic / Saprophytic storage fungus
Chloris roxburghiana	1	<i>Fusarium moniliforme</i> <i>Bipolaris sorghina</i> <i>Rhizoctonia solani</i> <i>Alternaria sp.</i> <i>Penicilium sp.</i> <i>Culvularia sp.</i>	Pathogenic fungus Pathogenic fungus Pathogenic fungus Pathogenic fungus Pathogenic / Saprophytic storage fungus Pathogenic fungus
	2	<i>Phoma sorghina</i> <i>Culvularia sp.</i>	Pathogenic fungus Pathogenic fungus
	3	<i>Fusarium moniliforme</i> <i>Aspergillus sp.</i> <i>Culvularia sp.</i> <i>Penicilium sp.</i>	Pathogenic fungus Pathogenic / Saprophytic storage fungus Pathogenic fungus Pathogenic / Saprophytic storage fungus
	4	<i>Penicilium sp.</i>	Pathogenic / Saprophytic storage fungus
Eragrostis superba	1	<i>Aspergillus sp.</i> <i>Rhizopus sp.</i> <i>Alternaria sp.</i>	Pathogenic / Saprophytic storage fungus Pathogenic / Saprophytic storage fungus Pathogenic fungus
	2	<i>Fusarium moniliforme</i> <i>Fusarium graminearum</i> <i>Rhizopus sp.</i> <i>Penicilium sp.</i>	Pathogenic fungus Pathogenic fungus Pathogenic / Saprophytic storage fungus Pathogenic / Saprophytic storage fungus
	3	<i>Rhizopus sp.</i> <i>Penicilium sp.</i> <i>Aspergillus sp.</i>	Pathogenic / Saprophytic storage fungus Pathogenic / Saprophytic storage fungus Pathogenic / Saprophytic storage fungus
	4	<i>Fusarium moniliforme</i> <i>Aspergillus sp.</i> <i>Rhizopus sp.</i>	Pathogenic fungus Pathogenic / Saprophytic storage fungus Pathogenic / Saprophytic storage fungus

Appendix Table 5.2 Mean daily seed germination (%) of two seed lots, lot 1 from 2000 short rainy season and lot 2 from 2001 long rainy season comprising four rangeland grasses, two harvesting methods, four storage types and stored over various periods at KARI Kiboko during 2001-2002.

Storage period	Lot 1 (Mean $\pm$ SE)	Lot 2 (Mean $\pm$ SE)	Significance
0	2.77 $\pm$ 0.138	2.65 $\pm$ 0.131	ns*
2	3.18 $\pm$ 0.254	3.25 $\pm$ 0.157	ns
4	3.23 $\pm$ 0.150	3.07 $\pm$ 0.159	s
8	3.90 $\pm$ 0.297	4.66 $\pm$ 0.249	s
12	3.86 $\pm$ 0.313	3.45 $\pm$ 0.219	ns
18	4.89 $\pm$ 0.371	3.48 $\pm$ 0.206	s
24	3.76 $\pm$ 0.283	3.18 $\pm$ 0.261	s
36	4.18 $\pm$ 0.306	3.65 $\pm$ 0.294	ns
48	3.54 $\pm$ 0.225	4.23 $\pm$ 0.391	s
72	3.62 $\pm$ 0.289	3.19 $\pm$ 0.205	ns
Total	3.46 $\pm$ 0.073	3.73 $\pm$ 0.088	s

* s/ns refers to presence or not of significant difference at $p < 0.05$ level when comparing lot 1 and 2 row-wise.

Appendix Table 7.1 Analysis of variance of soil moisture .

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	143	5367.38	37.53	2.47	<0.0001
Error	405	6158.51	15.21		
Corrected Total	548	11525.88			
	<u>R-Square</u>	<u>Coeff. Var.</u>	<u>Root MSE</u>	<u>MOISTURE Mean</u>	
	0.47	47.01	3.900	8.30	

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Date	5	2102.46	420.49	27.65	<0.0001
Site	2	96.85	48.42	3.18	0.0424
Depth	1	145.64	145.64	9.58	0.0021
Treatment	3	46.22	15.41	1.01	0.3868
Site*Treatment	6	70.21	11.70	0.77	0.5942
Treatment*Depth	3	81.87	27.29	1.79	0.1476
Date*Treatment	15	284.80	18.99	1.25	0.2324
Date*Depth	5	240.83	48.17	3.17	0.0081
Date*Site	10	323.23	32.32	2.13	0.0217
Site*Depth	2	3.77	1.88	0.12	0.8835
Site*Treatment*Depth	6	68.67	11.45	0.75	0.6076
Date*Site*Treatment	30	641.11	21.37	1.41	0.0793
Date*Site*Depth	10	180.10	18.01	1.18	0.2995
Date*Site*Treatment*Depth	45	647.04	14.38	0.95	0.5754

Significance of treatments and their interaction effects measured at the 0.05 level

Appendix Table 7.2a. Analysis of variance of total seedling population of four grasses (TOTAL) re-seeded at Kavatini in Makueni and Merueshi in Kajiado during 1999-2002.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	110	17972.43	163.39	5.60	<0.0001
Error	420	12245.79327	29.16		
Corrected Total	530	30218.23			
	R-Square	Coeff. Var.	Root MSE	TOTAL Mean	
	0.60	144.217	5.40	3.74	
Source	DF	Type III SS	Mean Square	F Value	Pr > F
DATE	6	1248.18	208.03	7.13	<0.0001
SITE	1	896.10	896.10	30.73	<0.0001
REP	1	583.38	583.38	20.01	<0.0001
TRT	3	6452.43	2150.81	73.77	<0.0001
DATE*SITE	6	1388.05	231.34	7.93	<0.0001
DATE*REP	6	469.57	78.26	2.68	0.0144
DATE*TRT	18	2288.16	127.12	4.36	<0.0001
SITE*TRT	3	812.81	270.94	9.29	<0.0001
REP*TRT	3	577.32	192.44	6.60	0.0002
SITE*REP	1	245.32	245.32	8.41	0.0039
DATE*REP*TRT	18	758.19	42.12	1.44	0.1067
DATE*SITE*TRT	18	1423.96	79.11	2.71	0.0002
SITE*REP*TRT	3	237.99	79.33	2.72	0.0441
DATE*SITE*REP	6	404.07	67.35	2.31	0.0332
DATE*SITE*REP*TRT	17	822.43	48.38	1.66	0.0475

Significance of treatments and their interaction effects measured at the 0.05 level

Table 7.2b. Analysis of variance of seedling population of *Chloris roxburghiana* (CHRO) re-seeded at Kavatini in Makueni and Merueshi in Kajiado during 1999-2002.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	110	2121.050289	19.282275	2.64	<.0001
Error	420	3066.257342	7.300613		
Corrected Total	530	5187.307631			
	R-Square	Coeff Var	Root MSE	CHRO Mean	
	0.41	230.392	2.702	1.17	
Source	DF	Type III SS	Mean Square	F Value	Pr > F
DATE	6	141.51	23.59	3.23	0.0041
SITE	1	126.40	126.40	17.31	<0.0001
REP	1	27.70	27.70	3.79	0.0521
TRT	3	466.25	155.42	21.29	<0.0001
DATE*SITE	6	157.88	26.31	3.60	0.0017
DATE*REP	6	55.54	9.26	1.27	0.2710
DATE*TRT	18	400.22	22.23	3.05	<0.0001
SITE*TRT	3	83.85	27.95	3.83	0.0100
REP*TRT	3	31.08	10.36	1.42	0.2366
SITE*REP	1	39.89	39.89	5.46	0.0199
DATE*REP*TRT	18	226.86	12.60	1.73	0.0325
DATE*SITE*TRT	18	229.58	12.75	1.75	0.0296
SITE*REP*TRT	3	29.60	9.87	1.35	0.2572
DATE*SITE*REP	6	24.45	4.08	0.56	0.7635
DATE*SITE*REP*TRT	17	116.76	6.87	0.94	0.5257

Significance of treatments and their interaction effects measured at the 0.05 level

Table 7.2c. Analysis of variance of seedling population of *Cenchrus ciliaris* (CECI) re-seeded at Kavatini in Makueni and Merueshi in Kajiado during 1999-2002.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	110	760.73	6.92	3.56	<0.0001
Error	420	815.52	1.94		
Corrected Total	530	1576.25			
		R-Square	Coeff Var	Root MSE	CECI Mean
		0.48	246.42	1.39	0.57
Source	DF	Type III SS	Mean Square	F Value	Pr > F
DATE	6	64.33	10.72	5.52	<0.0001
SITE	1	38.63	38.63	19.90	<0.0001
REP	1	25.38	25.38	13.07	0.0003
TRT	3	123.15	41.05	21.14	<0.0001
DATE*SITE	6	37.38	6.23	3.21	0.0043
DATE*REP	6	27.29	4.55	2.34	0.0309
DATE*TRT	18	94.27	5.24	2.70	0.0002
SITE*TRT	3	29.75	9.92	5.11	0.0018
REP*TRT	3	32.36	10.79	5.55	0.0010
SITE*REP	1	8.37	8.37	4.31	0.0385
DATE*REP*TRT	18	73.92	4.11	2.11	0.0050
DATE*SITE*TRT	18	50.39	2.80	1.44	0.1079
SITE*REP*TRT	3	17.15	5.72	2.94	0.0328
DATE*SITE*REP	6	27.85	4.64	2.39	0.0278
DATE*SITE*REP*TRT	17	96.30	5.67	2.92	<0.0001

Significance of treatments and their interaction effects measured at the 0.05 level

Table 7.2d. Analysis of variance of seedling population of *Enteropogon macrosatchyus* (ENMA) re-seeded at Kavatini in Makueni and Merueshi in Kajiado during 1999-2002.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	110	1555.96	14.15	3.32	<0.0001
Error	420	1788.38	4.26		
Corrected Total	530	3344.33			
		R-Square	Coeff Var	Root MSE	ENMA Mean
		0.47	221.77	2.06	0.93

Source	DF	Type III SS	Mean Square	F Value	Pr > F
DATE	6	119.03	19.84	4.66	0.0001
SITE	1	103.36	103.36	24.27	<0.0001
REP	1	10.20	10.20	2.40	0.1225
TRT	3	361.16	120.39	28.27	<0.0001
DATE*SITE	6	170.94	28.49	6.69	<0.0001
DATE*REP	6	43.26	7.21	1.69	0.1211
DATE*TRT	18	219.54	12.20	2.86	<0.0001
SITE*TRT	3	119.40	39.80	9.35	<0.0001
REP*TRT	3	15.72	5.24	1.23	0.2981
SITE*REP	1	3.40	3.40	0.80	0.3719
DATE*REP*TRT	18	77.95	4.33	1.02	0.4388
DATE*SITE*TRT	18	223.42	12.41	2.91	<0.0001
SITE*REP*TRT	3	6.13	2.04	0.48	0.6965
DATE*SITE*REP	6	24.92	4.15	0.98	0.4414
DATE*SITE*REP*TRT	17	107.39	6.32	1.48	0.0964

Significance of treatments and their interaction effects measured at the 0.05 level

Table 7.2e. Analysis of variance of seedling population of *Eragrostis superba* (ERSU) re-seeded at Kavatini in Makueni and Merueshi in Kajiado during 1999-2002.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	110	2772.47	25.20	4.91	<0.0001
Error	420	2156.43	5.13		
Corrected Total	530	4928.90			
	<u>R-Square</u>	<u>Coeff Var</u>	<u>Root MSE</u>	<u>ERSU Mean</u>	
	0.56	210.696	2.2	1.08	

Source	DF	Type III SS	Mean Square	F Value	Pr > F
DATE	6	301.09	50.1809015	9.77	<0.0001
SITE	1	5.34	5.34	1.04	0.3086
REP	1	113.61	113.61	22.13	<0.0001
TRT	3	844.24	281.41	54.81	<0.0001
DATE*SITE	6	216.53	36.09	7.03	<0.0001
DATE*REP	6	121.10	20.18	3.93	0.0008
DATE*TRT	18	386.43	21.47	4.18	<0.0001
SITE*TRT	3	20.20	6.73	1.31	0.2702
REP*TRT	3	106.13	35.38	6.89	0.0002
SITE*REP	1	21.26	21.26	4.14	0.0425
DATE*REP*TRT	18	176.07	9.78	1.91	0.0142
DATE*SITE*TRT	18	224.25	12.46	2.43	0.0010
SITE*REP*TRT	3	32.51	10.84	2.11	0.0982
DATE*SITE*REP	6	172.28	28.71	5.59	<0.0001
DATE*SITE*REP*TRT	17	214.90	12.64	2.46	0.0011

Significance of treatments and their interaction effects measured at the 0.05 level

Appendix Table 7.3a.
Analysis of variance of *Cenchrus ciliaris* (CECI) dry matter (gm⁻²) production.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	90	50037.39	555.97	2.08	<0.0001
Error	247	66069.21	267.49		
Corrected Total	337	116106.60			
	<u>R-Square</u>	<u>Coeff Var</u>	<u>Root MSE</u>	<u>CECI Mean</u>	
	0.43	247.737	16.355	6.60	

Source	DF	Type III SS	Mean Square	F Value	Pr > F
DATE	5	1457.89	291.58	1.09	0.3664
SITE	1	7785.38	7785.38	29.11	<0.0001
TRT	3	10577.42	3525.81	13.18	<0.0001
REP	1	335.69	335.69	1.25	0.2637
TRT*REP	3	596.54	198.85	0.74	0.5271
SITE*TRT	3	6708.38	2236.13	8.36	<0.0001
DATE*TRT	15	5213.38	347.56	1.30	0.2027
SITE*REP	1	342.90	342.90	1.28	0.2586
DATE*REP	5	187.89	37.58	0.14	0.9827
DATE*SITE	5	977.14	195.43	0.73	0.6011
SITE*TRT*REP	3	285.91	95.30	0.36	0.7846
DATE*SITE*TRT	15	6435.37	429.03	1.60	0.0731
DATE*SITE*REP	4	177.58	44.40	0.17	0.9555
DATE*TRT*REP	15	2618.68	174.58	0.65	0.8290
DATE*SITE*TRT*REP	11	1045.57	95.05	0.36	0.9714

Significance of treatments and their interaction effects measured at the 0.05 level

Appendix Table 7. 3b.

Analysis of variance of *Chloris roxburghiana* (CHRO) dry matter (gm⁻²) production.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	90	50369.73	559.66	2.81	<0.0001
Error	247	49257.28	199.42		
Corrected Total	337	99627.01			
	R-Square	Coeff Var	Root MSE	CHRO Mean	
	0.51	327.510	14.12	4.31	
Source	DF	Type III SS	Mean Square	F Value	Pr > F
DATE	5	1674.77	334.95433	1.68	0.1400
SITE	1	1677.42	1677.42	8.41	0.0041
TRT	3	7077.72	2359.24	11.83	<0.0001
REP	1	1616.25	1616.25	8.10	0.0048
TRT*REP	3	2177.40	725.80	3.64	0.0134
SITE*TRT	3	1540.59	513.53	2.58	0.0545
DATE*TRT	15	5853.17	390.21	1.96	0.0189
SITE*REP	1	2056.33	2056.33	10.31	0.0015
DATE*REP	5	2125.428	425.08	2.13	0.0623
DATE*SITE	5	2229.35	445.87	2.24	0.0514
SITE*TRT*REP	3	4920.90	1640.30	8.23	<0.0001
DATE*SITE*TRT	15	12806.95	853.80	4.28	<0.0001
DATE*SITE*REP	4	617.47	154.37	0.77	0.5430
DATE*TRT*REP	15	11606.96	143.26	0.72	0.7205
DATE*SITE*TRT*REP	11	1575.86	143.26	0.72	0.7205

Significance of treatments and their interaction effects measured at the 0.05 level

Appendix Table 7.3c. Analysis of variance of *Enteropogon macrostachyus* (ENMA) dry matter (gm⁻²) production.

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	90	26077.54	289.75	2.90	<0.0001
Error	247	24687.56	99.95		
Corrected Total	337	50765.10			
	R-Square	Coeff Var	Root MSE	Mean	
	0.51	275.130	10.00	3.63	
Source	DF	Type III SS	Mean Square	F Value	Pr > F
DATE	5	878.14	175.63	1.76	0.1223
SITE	1	2652.52	2652.52	26.54	<0.0001
TRT	3	4493.50	1497.84	14.99	<0.0001
REP	1	916.17	916.17	9.17	0.0027
TRT*REP	3	1086.09	362.03	3.62	0.0137
SITE*TRT	3	4050.28	1350.10	13.51	<0.0001
DATE*TRT	15	2303.55	153.57	1.54	0.0929
SITE*REP	1	125.53	125.53	1.26	0.2635
DATE*REP	5	462.37	92.47	0.93	0.4652
DATE*SITE	5	486.64	97.33	0.97	0.4344
SITE*TRT*REP	3	143.73	47.91	0.48	0.6969
DATE*SITE*TRT	15	4365.18	291.01	2.91	0.0003
DATE*SITE*REP	4	857.85	214.46	2.15	0.0758
DATE*TRT*REP	15	4718.27	314.55	3.15	<0.0001
DATE*SITE*TRT*REP	11	1678.70	152.61	1.53	0.1222

Significance of treatments and their interaction effects measured at the 0.05 level

Appendix Table 7.3d. Analysis of variance of *Eragrostis superba* (ERSU) dry matter (gm⁻²) production.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	90	22090.40	245.44888	1.58	0.0032
Error	247	38430.20	155.59		
Corrected Total	337	60520.60			
	R-Square	Coeff Var	Root MSE	ERSU Mean	
	0.37	350.460	12.47349	3.56	
Source	DF	Type III SS	Mean Square	F Value	Pr > F
DATE	5	822.58	164.52	1.06	0.3847
SITE	1	2069.96	2069.96	13.30	0.0003
TRT	3	3097.21	1032.40	6.64	0.0003
REP	1	407.23	407.23	2.62	0.1070
TRT*REP	3	972.78	324.23	2.08	0.1029
SITE*TRT	3	2260.85	753.62	4.84	0.0027
DATE*TRT	15	3675.63	245.04	1.57	0.0811
SITE*REP	1	127.32	127.32	0.82	0.3666
DATE*REP	5	470.14	94.03	0.60	0.6967
DATE*SITE	5	563.26	112.65	0.72	0.6060
SITE*TRT*REP	3	905.53	301.84	1.94	0.1237
DATE*SITE*TRT	15	2062.72	137.52	0.88	0.5830
DATE*SITE*REP	4	583.61	145.90	0.94	0.4426
DATE*TRT*REP	15	1290.67	86.05	0.55	0.9080
DATE*SITE*TRT*REP	11	897.50	81.59	0.52	0.8860

Significance of treatments and their interaction effects measured at the 0.05 level

Appendix Table 7.3e. Analysis of variance of total dry matter (gm²) production of the four experimental grasses.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	91	165017.63	1813.38	4.27	<0.0001
Error	244	103731.40	425.13		
Corrected Total	335	268749.03			
	R-Square	Coeff Var	Root MSE	TOTAL Mean	
	0.61	176.71	20.62	11.67	

Source	DF	Type III SS	Mean Square	F Value	Pr > F
DATE	5	7713.72	1542.75	3.63	0.0035
SITE	1	19532.80	19532.80	45.95	<0.0001
TRT	3	39679.80	13226.60	31.11	<0.0001
REP	2	8602.79	4301.40	10.12	<0.0001
TRT*REP	3	10640.37	3546.79	8.34	<0.0001
SITE*TRT	3	16266.98	5422.33	12.75	<0.0001
DATE*TRT	15	22950.15	1530.01	3.60	<0.0001
SITE*REP	1	4650.54	4650.54	10.94	0.0011
DATE*REP	5	4659.30	931.86	2.19	0.0558
DATE*SITE	5	4302.16	860.43	2.02	0.0759
SITE*TRT*REP	3	6834.53	2278.18	5.36	0.0014
DATE*SITE*TRT	15	16317.36	1087.82	2.56	0.0015
DATE*SITE*REP	4	2649.64	662.41	1.56	0.1861
DATE*TRT*REP	15	12248.66	816.58	1.92	0.0219
DATE*SITE*TRT*REP	11	3751.11	341.01	0.80	0.6379

Significance of treatments and their interaction effects measured at the 0.05 level

Appendix Table 7.3f. Analysis of variance of other perennial grasses' dry matter (gm⁻²) production.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	90	21006.34	233.40	1.93	<0.0001
Error	247	29885.64	121.00		
Corrected Total	337	50891.98			
	R-Square	Coeff Var	Root MSE	Mean	
	0.41	165.285	11.00	6.66	
Source	DF	Type III SS	Mean Square	F Value	Pr > F
DATE	5	4905.61	981.12	8.11	<0.0001
SITE	1	228.90	228.90	1.89	0.1702
TRT	3	142.39	47.47	0.39	0.7587
REP	1	888.40	888.40	7.34	0.0072
TRT*REP	3	201.35	67.12	0.55	0.6454
SITE*TRT	3	98.65	32.88	0.27	0.8457
DATE*TRT	15	3049.83	203.32	1.68	0.0552
SITE*REP	1	202.44	202.44	1.67	0.1970
DATE*REP	5	1820.17	364.03	3.01	0.0118
DATE*SITE	5	1010.52	202.11	1.67	0.1423
SITE*TRT*REP	3	320.51	106.84	0.88	0.4505
DATE*SITE*TRT	15	1231.58	82.11	0.68	0.8047
DATE*SITE*REP	4	989.99	247.50	2.05	0.0886
DATE*TRT*REP	15	2916.06	194.40	1.61	0.0723
DATE*SITE*TRT*REP	11	858.96	78.09	0.65	0.7888

Significance of treatments and their interaction effects measured at the 0.05 level

Appendix Table 7.3g. Analysis of variance of annual grass dry matter (gm²) production.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	90	169903.23	1887.81	2.47	<0.0001
Error	247	189027.58	765.29		
Corrected Total	337	358930.81			
	R-Square	Coeff Var	Root MSE	Mean	
	0.47	160.59	27.66	17.23	

Source	DF	Type III SS	Mean Square	F Value	Pr > F
DATE	5	18748.63	3749.73	4.90	0.0003
SITE	1	34713.60	34713.60	45.36	<0.0001
TRT	3	1393.99	464.66	0.61	0.6109
REP	1	484.02	484.02	0.63	0.4272
TRT*REP	3	3129.42	1043.14	1.36	0.2546
SITE*TRT	3	6682.12	2227.37	2.91	0.0351
DATE*TRT	15	19083.19	1272.21	1.66	0.0590
SITE*REP	1	5937.65	5937.65	7.76	0.0058
DATE*REP	5	11813.95	2362.79	3.09	0.0101
DATE*SITE	5	19461.38	3892.28	5.09	0.0002
SITE*TRT*REP	3	1740.63	580.21	0.76	0.5186
DATE*SITE*TRT	15	19426.29	1295.09	1.69	0.0528
DATE*SITE*REP	4	7817.66	1954.42	2.55	0.0396
DATE*TRT*REP	15	11624.95	775.00	1.01	0.4424
DATE*SITE*TRT*REP	11	4572.53	415.69	0.54	0.8727

Significance of treatments and their interaction effects measured at the 0.05 level

Appendix Table 7.3h. Analysis of variance of forbs dry matter (gm⁻²) production.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	90	3205499.83	35616.67	3.00	<0.0001
Error	247	2932140.47	11871.01		
Corrected Total	337	6137640.30			
	R-Square	Coeff Var	Root MSE	Mean	
	0.52	110.455	108.95	98.64	

Source	DF	Type III SS	Mean Square	F Value	Pr > F
DATE	5	1517629.23	303525.85	25.57	<0.0001
SITE	1	358532.47	358532.47	30.20	<0.0001
TRT	3	84043.99	28014.66	2.36	0.0721
REP	1	40758.84	40758.84	3.43	0.0651
TRT*REP	3	33615.84	11205.28	0.94	0.4200
SITE*TRT	3	86740.02	28913.34	2.44	0.0653
DATE*TRT	15	284872.68	18991.51	1.60	0.0741
SITE*REP	1	53683.47	53683.47	4.52	0.0344
DATE*REP	5	282668.87	56533.77	4.76	0.0004
DATE*SITE	5	267905.91	53581.18	4.51	0.0006
SITE*TRT*REP	3	10003.01	3334.34	0.28	0.8392
DATE*SITE*TRT	15	177597.48	11839.83	1.00	0.4584
DATE*SITE*REP	4	70668.29	17667.07	1.49	0.2063
DATE*TRT*REP	15	218188.85	14545.92	1.23	0.2528
DATE*SITE*TRT*REP	11	61345.56	5576.87	0.47	0.9207

Significance of treatments and their interaction effects measured at the 0.05 level

Appendix Table 8.1 DNA concentration ($\text{ng}\mu\text{l}^{-1}$) extracted using the CTAB technique for *Chloris roxburghiana* accessions from four ecosites in southern Kenya rangelands.

SAMPLE	SITE							
	Kiboko		Kavatini		Merueshi		Kimala	
	A	B	A	B	A	B	A	B
1.	1270	8690	850	910	630	540	1290	480
2	830	660	750	670	690	170	1340	50
3	1240	1650	680	1400	700	2170	560	1540
4	1250	1790	810	890	1000	1000	1730	1250
5	3950	1860	1910	2790	1160	1000	930	900
6	2280	2420	860	1460	490	490	2030	1520
7	1740	1610	1600	1360	1100	1000	830	1080
8	1030	230	760	890	490	740	1080	870
9	1380	2060	460	940	500	670	1010	1460
10	890	1820	830	980	500	620	1950	1780
11	1170	1850	2840	1500	1000	910	1360	1580
12	920	1370	940	990	340	490	1920	1460
13	1320	1390	1430	1420	470	690	930	700
14	2550	810	910	1190	490	660	800	1830
15	880	1490	900	1210	690	730	1320	980
16	1170	1140	1910	1500	640	460	120	1270
17	450	640	1380	1220	620	580	750	890
18	1520	1410	1540	1180	790	690	1110	700
19	790	820	1610	970	890	850	1210	970
20	580	1450	1310	880	930	1370	1080	1200
21	900	940	2170	1800	1080	1070	1040	520
22	1830	1480	1950	1790	840	960	880	1220
23	1010	960	2110	1270	780	880	1190	1170
24	50	800	1970	260	970	540	900	1690
25	920	770	1710	2970	1070	1050	10	1310

Appendix Table 8.2 List of selected primers, their concentrations (Pmol μl^{-1}) and dilution rates as used for the RAPDs analysis of *Chloris roxburghiana* grass.

	Primer	Stock Concentration	Amount used (μl)	Amount water added to make 200 μl
1	1207	149.3	6.7	193.3
2	1212	50.3	19.9	180.1
3	1481	13.0	76.9	123.1
4	1558	99.2	10.1	189.9
5	4996	682.0	1.5	198.5
6	4997	6.0	200	Nil
7	4998	6.0	200	Nil
8	4999	6.0	200	Nil
9	5006	6.0	200	Nil

Appendix Table 8.3 Polymorphic (P) and monomorphic (M) bands produced by various primers for the four population accessions of *Chloris roxburghiana* grass.

Primer	Site	Fragment Number																											
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
IL4996	KIB	P	P	M	P																								
	KAV	P	P	P	P	P																							
	MER	P	P	P	M	P	M	P	P																				
	KIM	P	P	M	P	P	P	P																					
IL1558	KIB	P	P	P	P	P	M	P	P	P	P	P																	
	KAV	P	P	P	P	P	P	P	P	P	P	P	P																
	MER	P	P	P	P	P	P																						
	KIM	P	P	P	P	M	P	P	P	P	P																		
IL4998	KIB	P	P	P	P	P	P																						
	KAV	P	P	P	P	P	P																						
	MER	P	P	P	P	P																							
	KIM	P	P	P	P	P	P																						
IL1481	KIB	P	P	P	M	M	P	P	P	P																			
	KAV	P	P	P	P	M	P	P	P	P																			
	MER	P	M	P	P	P	P	M	P	P	P	P	P																
	KIM	P	P	P	P	P	M	P	P	P	P	P																	
IL1207	KIB	P	P	P	P	P	P	P	P	P	P	P	P	P															
	KAV	P	P	P	P	P	P	M	P	P	P	M	P	P															
	MER	P	M	P	P	P	P	P	P	P	P	P	P	P	P	M	M	M	M	M	P	P							
	KIM	P	P	P	P	P	P	P	P	P	P	P	M	M	P	M	M	P											
IL4999	KIB	P	P	P	M	M	P	P	P	P	P	P																	
	KAV	P	P	P	P	P	M	P	P	M	P	P	P	P															
	MER	P	P	P	M	P	P	M	P	P	P	P	M	P	P	P													
	KIM	P	M	P	P	M	P	P	P	P	P	P	M	P	P	P													
IL4997	KIB	P	P	P	M	P	P	P																					
	KAV	P	P	M	P	P	P	P	P	P																			
	MER	P	P	P	P	P	P	P	P	P	P	P																	
	KIM	P	P	P	M	P	P	P	P	P	P	P																	
IL5006	KIB	P	P	P	M	P	M																						
	KAV	P	P	P	P	M	P	P	P	P	P																		
	MER	P	P	P	P	P	P	P	P	P	P	M	P	P	P														
	KIM	P	P	P	P	P	P	P	P	P	P	P	M	P	M														
IL1212	KIB	P	P	P	P	P	P	P	P	P	P	P	P	M															
	KAV	P	P	P	P	P	P	P	P	P	M	P	P																
	MER	P	P	P	P	P	P	P	P	P	M	P	M	P	P	P	P	M	P	P	P								
	KIM	P	P	P	P	M	P	P	P	P	P	P	P	M	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P

Appendix Table 8.4 Within population polymorphic RAPD loci for nine primers

Primer ID	Site				Total No. of Bands
	Kiboko	Kavatini	Merueshi	Kimala	
IL 4998	6	6	5	6	23
IL 4996	3	5	6	6	20
IL 1558	10	11	6	10	37
IL 1481	8	8	11	11	38
IL 4997	6	9	12	12	39
IL 4999	10	12	14	13	49
IL 5006	4	10	13	12	39
IL 1207	13	13	19	14	59
IL 1212	11	11	20	28	70
Total No. of Bands	71	85	106	112	374