EFFECT OF INTRODUCED FORAGE LEGUMES ON DRY MATTER PRODUCTION, NUTRITIVE QUALITY AND SOIL FERTILITY OF NATURAL PASTURES OF SEMI-ARID RANGELANDS OF KENYA

BY

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DECLARATION

I hereby declare that the work contained in this thesis is my original work and has not been submitted for a degree in any other University

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DEDICATION

This thesis is dedicated, foremost, to my dear parents Julius Macharia and Phyllis Wanjiku for laying the foundation of my education and who have always inspired me to achieve the highest academic degree. The thesis is also dedicated to my wife Lucy and children Diana and Dennis for giving me a lot of support and encouragement while I stressfully concentrated on the study.

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LIST OF ABBREVIATIONS AND ACRONYMS

ACZ	Agro-climatic zone
ADF	Acid detergent fibre
ADL	Acid detergent lignin
ADS	Acid detergent solution
ANOVA	Analysis of variance
AOAC	Association of Official Analytical Chemists
ASAL	Arid and semi-arid lands
CC	Cell contents
CEC	Cation exchange capacity
CP	Crude protein
CWC	Cell wall contents
DM	Dry matter
FAO	Food and Agriculture Organization
HCL	Hydrochloric acid
IAEA	International Atomic Energy Agency
IVDMD	*In-vitro* dry matter digestibility
KARI	Kenya Agricultural Research Institute
KLDP	Kenya Livestock Development Programme
LR	Long rains
LRNP	Legume Research Network Project
NARL	National Agricultural Research Laboratories
NDF	Neutral detergent fibre
NDS	Neutral detergent solution
NP	National pasture
RCBD	Randomized complete block design
SMP	Soil Management Project
SR	Short rains
TLU	Tropical livestock unit
WUE	Water use efficiency

ABSTRACT

A two phase study was carried out in the semi-arid rangelands of Kajiado District, Kenya, between October, 2002 and February, 2005. The major objective was to determine the effect of introduced forage legumes on production of natural pastures as a means of improving the quantity and quality of livestock feed while improving soil fertility. The specific objectives were: i) to screen potential forage legumes and select best performing ones for integration into natural pastures; ii) to determine the effect of defoliation interval and height on dry matter production of grass/legume mixed pastures; iii) to determine the effect of forage legumes on quality improvement of grasses in natural pastures; iv) to determine the effect of forage legumes on soil fertility improvement; and v) to determine moisture extraction by grasses and legumes in mixed pastures. During legume screening, five forage legumes were sown as monoculture stands in a Randomized Complete Block Design (RCBD). These were *Neonotonia wightii* (Arn.) Lackey (Glycine), *Macroptilium atropurpureum* (DC) Urb. (Siratro), *Stylosanthes scabra* var. *seca* Vog. (Stylo), *Lablab purpureus* cv. Rongai (L.) Sweet (Dolichos) and *Mucuna pruriens* (L.) DC (Velvet bean). The legumes were screened for their ability to grow and survive under semi-arid conditions, increase of dry matter (DM) and litter production, and ability to enhance soil fertility. Data on DM production were collected at 2 and 4 months intervals at ground level and 15 cm heights of defoliation. Data on litter production were collected at the peak of long dry season in August, 2003. Soil samples for fertility analysis were collected at 0-15 cm soil depth before sowing the legumes and at end of experiment. The screening experiment showed that Glycine, Siratro and Stylo withstood the semi-arid climatic conditions due to their perennial growth habit and produced high DM rate of 10.31, 7.81 and 3.52 t ha^{-1} yr^{-1}, respectively. Glycine, Siratro and Stylo produced high organic matter through litter fall which upon decomposition improved soil fertility by increasing soil pH, carbon, nitrogen and potassium. These legumes possessed deep tap roots and withstood heavy grazing and were self-propagating through dispersal of seeds. These three legumes were, therefore, selected for further integration with grasses in natural pastures in line with the first objective.

The grass/legume integration experiment was RCBD split-split plot in a factorial arrangement. The factors were namely; two defoliation heights (15 and 30 cm) and three defoliation intervals (2, 4 and 6 months), and seven treatments. Treatments were natural pasture (NP), monoculture of

Glycine, Siratro and Stylo, and grass/legume mixture of NP+Glycine, NP+Siratro and NP+Stylo. Of the three legumes, Glycine had the lowest initial establishment, but by the third season it produced more DM than Siratro because it developed more and longer stems per plant while Siratro developed fewer and shorter stems per plant. In nearly all treatments, the highest DM production was after harvesting herbage at 15 cm height at an interval of two months, results obtained in relation to the second objective. Inclusion of Glycine and Siratro into natural pasture resulted in a combined DM production that was 40 and 42 % higher than DM production of natural pasture, respectively. Grasses in natural pasture had lowest crude protein (CP) content of 7.1 %, but when integrated with Glycine, Siratro and Stylo, the CP went up to 14.3, 11.9 and 10.2 %, respectively, during the vegetative stage. Moreover, grasses mixed with legumes had lower fibre content (especially lignin) and higher digestibility than those in natural pastures and especially at the senescent stage. This means that introduction of legumes into natural pastures improves forage quality of grasses and hence quality of livestock feed, results related to the third objective of the study. Results towards the fourth objective showed that except for soil pH, there was a decrease in all the other soil nutrients analyzed which was attributed to production of less organic residues from legumes compared to the screening experiment. Burning and herbage slashing before sowing of legumes had no significant effect on DM production. Burning herbage significantly increased soil P while the increase in pH, K and Ca was not significant. Burning resulted in a significant decrease in soil organic C and N..

Results towards the fifth objective showed that significant differences in soil moisture extraction by grasses and legumes occurred from 30 cm soil depth down the profile. Monoculture Glycine, Siratro and Stylo extracted more soil moisture as compared to natural pastures and mixed pastures of NP+Glycine, NP+Siratro and NP+Stylo. Establishment of grass/legume mixed pastures through sowing on well prepared seed beds produced highest DM followed by legumes sown on furrows and bands. The least DM was obtained when legumes were sown after raking soils as most legume seedlings failed to establish.

This study therefore concluded that Glycine, Siratro and Stylo proved to be high quality forage legumes suitable for up-scaling into other similar natural pastures of semi-arid rangelands of Kenya.

CHAPTER ONE: INTRODUCTION

1.1 Background

Rangelands are characterized by physical limitations such as low and erratic precipitation, pronounced seasonality of herbage production, are unsuited for cultivation and are a source of wood, wildlife products and forage for free ranging native and domestic animals (Da Silva and Carvalho, 2005). Most of the world's rangelands support grazing or browsing animals in a variety of systems ranging from commercial livestock enterprises on privately owned or controlled land, through commercial enterprises on communally owned and controlled land to subsistence farming, either sedentary or nomadic (Kirkman and Carvalho, 2003). Despite forage quality being almost invariably poor for most of the year, rangeland conservation and productivity is critical for large and small commercial livestock production enterprises and for the livelihoods of livestock keepers (Pengelly *et al.*, 2003).

In East Africa, a rangeland is defined as "uncultivated land carrying natural or semi-natural vegetation that supports grazing and browsing animals'' (Herlocker, 1999). The majority of rangelands in Kenya are found in the arid and semi-arid lands (ASAL). However, some range areas have potential for agriculture or other development (for example, parts of Transmara District in south-western Kenya), but due to cultural reasons, livestock production dominates. Semi-arid areas have natural vegetation characterized by dry forms of woodland and grassland, often an *Acacia-Themeda* association and other forms of deciduous or semi-evergreen bushland. Arid areas on the other hand are lands suited to agriculture only where fertile soils receive run-on; these are typically dominated by *Commiphora, Acacia* and allied genera, mostly growing in a shrubby habit. Perennial grasses such as *Cenchrus ciliaris* L. and *Chloris roxburghiana* Schult may dominate the natural pasture but they succumb readily to harsh management (Herlocker, 1999).

In Kenya, rangelands are estimated to occupy about 455,408 km^2, which is about 85 % of the country's total land surface (Sombroek *et al*., 1982). These rangelands support over 25 % of the total human population and are important in the Kenyan economy in terms of livestock production and wildlife conservation (Ottichilo *et al*., 2000). Rangelands in Kenya support 2.53 million cattle, 5.29 million sheep and goats, 608,500 camels and 72,300 donkeys (Ottichilo *et al*., 2000). Livestock production in rangelands is mainly for beef production and is largely based on pastoral grazing systems (Herlocker, 1999; Ottichilo *et al*., 2000). In addition to livestock, these rangelands have a large wildlife population (about 80 % of the total wildlife in Kenya). Tourism, which is one of the major foreign exchange earners in Kenya (GoK, 2002) is dependent mainly on wildlife viewing and photography.

The natural succession of vegetation in the rangelands of eastern Africa is towards woody vegetation (Pratt and Gwynne, 1977). The only exception is where rainfall is very low or soil-water conditions are unfavourable for growth of trees and shrubs, e.g. in eastern Serengeti Plains of Tanzania. The other major constraints to woody vegetation completely dominating the East African rangelands are burning and clearing while overgrazing often leads to faster bush encroachment. Herlocker *et al.* (1999) noted that prescribed and controlled burning continues to be a valuable tool in the management of rangeland vegetation, livestock production and wildlife habitats within East Africa. Overall, fires have been a major factor in shaping the relatively open and grassy rangelands of East Africa. Moreover, to sustain grass production, fires have been used as a tool by pastoralists and ranchers in removing accumulated and dead herbaceous materials which have lost their nutritive value. Burning has also been used to reduce woody vegetation cover that affects availability of the grass fodder and might act as hiding areas for predators. In addition, Ker *et al.* (1978) reported that fires may also be used to kill ticks and other harmful parasites.

High demands are exerted on these rangelands as Campbell *et al.* (2003) found out in Loitokitok Division of Kajiado District. The authors found out that, in 1973 the area under rangelands was about 160,847 ha or about 95 % of the division. However, by year 2000, the area under rangelands had diminished to 138,871 ha which was a 13.7 % decline. This decline in rangeland areas was attributed primarily to expansion of irrigated and rain-fed agriculture into areas previously classified as rangeland. In addition the area had experienced rapid and extensive land use changes in response to a variety of economic, cultural, political, institutional and demographic processes.

1.2 Problem statement

1.2.1 Low forage quantity and quality of natural pastures

Livestock production in the rangelands of much of Kenya is limited by the quantity and quality of forage (ASAL, 1998). This is attributed to the amounts of rainfall received as it is the single most important climatic factor affecting forage production in the rangelands (Wijngaarden, 1985; Shaabani and Herlocker, 1993). This implies that erratic rainfalls that are received in the rangelands result in intermittent forage production which is usually not enough for livestock, especially during the dry periods of the year (Bekure *et al.*, 1991). The inter-seasonal fluctuations of fodder production in the rangelands result in emaciated animals due to shortage of fodder in the dry season and plenty of grazing resources after onset of the rainy season (Plates 1and 2). To cope with forage deficits during the dry seasons and drought periods, herders move livestock away to other places in search of pasture and water while the rest of the homestead remains at a particular place.

Dry matter production studies in Kajiado District by Too (1985) and De Leeuw (1991) showed that production was far below the amount needed to sustain livestock throughout the year. Results by Too (1985) showed that the rangeland at Kiboko Research Station was producing less than 1 t ha^{-1} yr^{-1} dry matter. These results are close to those obtained by De Leeuw (1991) for Olkarkar, Merueshi and Mbirikani group ranches in the eastern part of Kajiado District, that showed that productivity was less than 0.5 t ha^{-1} yr^{-1} at the end of the dry season except in river valleys and in grasslands on Vertisol soils, where yields reached 1 t ha^{-1} yr^{-1}. After the rains, productivity ranged between 0.4 t ha^{-1} yr^{-1} in Mbirikani ranch (located in southern part of the district) to 1.1 t ha^{-1} yr^{-1} in Olkarkar ranch (located in northern part of the district).

Plate 1: Emaciated calves due to shortage of fodder during the dry season

Plate 2: Plenty of fodder for livestock after a rainfall season

De Leeuw (1991) noted that a 250 kg tropical livestock unit (TLU) needs to consume 2.3 t dry matter (DM) annually for maintenance. This is on the assumption that it will consume an average daily DM intake of 2.5 % of its body weight which translates to 6.25 kg of DM daily. A tropical livestock unit is an expression of animal biomass equated to 250 kg which is equivalent to one mature zebu cow or 10 sheep or 12 goats or 2 donkeys or 1 horse or 0.8 camels (Bekure *et al.*, 1991).

De Leeuw (1991) reported that leaf crude protein content fell from about 10 % during the young stage of grass growth to about 5 % at maturity. However, a minimum of between 7 and 8 % crude protein content is required by ruminants to meet their feed requirements, but high producing animals (e.g. dairy cows) require levels approaching 13-14 % crude protein content. This implies that crude protein content of mature pastures of Kajiado District is not capable of maintaining livestock throughout the year.

1.2.2 Low soil fertility of semi-arid rangelands

In semi-arid eastern Kenya, the rapid increase in population densities, continuous cultivation and overgrazing have contributed to the depletion of soil fertility and severe soil erosion resulting in low yielding croplands and pastures (Njarui *et al.*, 2004). The infertility of the soils, particularly lack of N, is the main contributory factor to the low productivity of such tropical soils (Giller, 2001). In addition, frequent fires that occur especially during the dry seasons in savanna regions of the tropics lead to considerable losses of nitrogen in gaseous form to the atmosphere (Brady, 1984). However, in fields not subjected to fires, nitrogen losses from grasslands will usually be far lower than those from cultivated soils. Some forms of tillage, particularly in arid and semi-arid areas encourage oxidation of organic matter throughout the tilled profile resulting in release of carbon to the atmosphere rather than its build-up in the soil (Nyathi *et al.*, 2003). This leads to reduced production of crops or pastures and lower carbon inputs to the soil in subsequent periods because less root matter, leaf litter and crop residues are returned to the soil.

Low soil fertility, besides moisture availability, is one of the major limitations to maximum plant production in the semi-arid to arid areas (Sombroek *et al.*, 1982). Wijngaarden (1985) also noted that nutrient supply is often a limiting factor for plant growth in semi-arid climates. Moreover, plants needed an optimal supply of various minerals to make optimal use of available soil moisture. Wijngaarden (1985) found that in rangelands, nitrogen and phosphorus were the most limiting nutrients to primary production at a rainfall of more than 300 mm per growing period. In addition, majority of the soils in Mashuru Division of Kajiado District were low in organic matter and were all deficient in nitrogen (Waruru, 2000). However, phosphorus and potassium were found to be adequate in all soils. The study recommended that nitrogen and organic matter should be added to the soils to enhance agricultural production.

1.3 Justification of study

The low quantity and quality of pastures in semi-arid rangelands of Kenya remains a challenge to range managers and scientists. This is because livestock production based on natural pastures remains a key livelihood strategy to the inhabitants of many ASAL districts. The current lifestyle of many pastoral people, for example the Maasai, where livestock and herders move in search of pasture and water, presents problems as the areas for free-range grazing continue to become limited. Thus, ways have to be found to improve the productivity (quality and quantity) of the natural pastures in the semi-arid rangelands of Kenya.

One way of improving the productivity of rangelands is to integrate forage legumes into the natural pastures especially in the smallholder livestock production systems. This would in effect enhance forage production, increase amount of protein available for the grazing animals and prolong grazing periods as legumes remain green long after grasses have dried up during the dry season (Skerman *et al.*, 1988; Kinyamario and Macharia, 1992). Legumes have the potential to improve the quality and quantity of pasture swards through fixation of atmospheric nitrogen (Guretzky *et al.*, 2004). Legumes also contain higher crude protein content than grasses and therefore their integration with grasses has the potential to improve the dry matter yield and forage quality of natural pastures.

In terms of soil improvement, legumes have the potential to improve soil fertility through a slow release of nitrogen from decomposing leaf residues, roots and nodules which results in increased sward productivity after nitrogen transfer to the companion grasses (Guretzky *et al.*, 2004; Cherr *et al.*, 2006). The slow release of nitrogen could be better synchronized with plant uptake than with sources of inorganic N, thereby increasing nitrogen uptake efficiency and forage production while reducing nitrogen leaching losses. Thus integration of forage legumes into natural pastures can be an option to improve the soil fertility through addition of organic residues and soil nutrients, particularly nitrogen.

In view of the above, this study was carried out with the major aim of introducing forage legumes into natural pastures as a way of improving the quality and quantity of fodder while improving the soil fertility of natural pastures. The ultimate goal is to enhance livestock production potential in the semi-arid rangelands of Kenya.

1.4 Objectives of the study

1.4.1 Overall objective

To study the effect of introduced forage legumes on forage quality and quantity of natural pastures as a means of improving livestock feed of semi-arid rangelands of Kenya.

1.4.2 Specific objectives

1. To screen potential forage legumes and select best performing ones for integration into natural pastures of semi-arid rangelands of Kenya,
2. To determine the effect of defoliation intensity (defoliation interval and height) on dry matter production of grass/legume mixed pastures,
3. To determine the effect of forage legumes on quality improvement of grasses in natural pastures,
4. To determine the effect of forage legumes on soil fertility improvement, and
5. To determine moisture extraction by grasses and legumes in mixed pastures.

1.5 Research hypotheses

1. Only hardy forage legumes will adapt to the harsh climatic and edaphic conditions of semi-arid rangelands,

2. Suitable defoliation interval and height results in increased dry matter production of grass/legume mixed pastures,
3. Forage legumes improve the nutritive quality of pasture grasses when grown together,
4. Forage legumes improve soil fertility of natural pastures, and
5. Grasses and legumes extract soil moisture from different soil depths and are therefore able to co-exist.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

With increasing demand for food as human population increases, there is need to increase productivity of each unit of agricultural land without degrading the natural resources for food production. Sustainable production is measured not by total output in a short period of time, but by the average output over an infinitely long period (generations) which can be sustained without depleting the renewable resource on which production depends (Dumanski, 1984 cited by Ingram and Swift, 1989). For a sustainable yield and quality production of forage, appropriate steps should be taken to maintain balanced diet necessary for successful animal production (Aucamp, 2000). It is precisely in this role that the forage legumes could play an important part, as they have high nutritive value and will satisfy protein needs of highly productive animals grazing in the natural pasture.

The main factor limiting pasture production in Africa's rangelands is the low soil nitrogen (Tarawali and Mohamed-Saleem, 1995). The authors recommended integration of legumes into livestock production systems so as to reduce this deficiency through nitrogen release or recycling from legume residues and animal manure. The study also noted that low protein content of natural pastures in rangelands is a serious constraint to livestock nutrition for up to six months of the year especially during dry seasons. During the dry season, animals lose weight, milk production is low and there is a high calf mortality and low conception rate. Thus integration of forage legumes into natural pastures is considered a promising option for development of an economically viable livestock production system in rangelands.

The importance of legumes as arable fodder, pasture crops and as components of natural grasslands depend on their ability to fix atmospheric nitrogen in symbiosis with *Rhizobium* bacteria found in the legume root nodules (Skerman *et al.*, 1988; Tarawali and Mohamed-Saleem, 1995; Pamo and Mubeteneh, 1995, Shelton *et al.*, 2005). The bacterium infects roots of legumes and transforms atmospheric nitrogen into a form utilizable directly by legumes and associated plants. The bacteria, on the other hand, depend on the legume for basic nutrients needed to sustain their life functions. In a grass/legume mixed pastures, the nitrogen fixed by legumes stabilizes the soil nitrogen content in the root zone to a greater extent than when grasses are grown alone. Legume species are added to grass pastures to:

i) Increase amount of crude protein available for grazing animals. This is particularly important when grasses begin to mature and during dry seasons when they are dry and highly lignified (Crowder and Chheda, 1982),

ii) Increase animal performance in terms of live weight gains, milk production and reproduction Meissner *et al.*, 2000),

iii) Extend the grazing period into the dry season. Many legumes remained green throughout much of the dry period and even when legume plants become brown, or even withered, their nutritive value is maintained at a much higher level than that of grasses (Skerman *et al.*, 1988),

iv) Provide N for companion grasses especially in tropical pastures where nitrogen is a limiting factor. Forage legumes can fix ample amounts of N needed to sustain N economy of pastures provided the legume component constituted at least 20 % of above ground dry matter (Thomas and Lascano, 1995),

v) Provide shading effect and thus less soil water loss and baking of the soil surface (Karuku *et al.*, 2006),

vi) Improve soil structure through addition of organic matter and increased microbial activity (Karuku *et al.*, 2006),,

vii) Suppress weeds (Gachene and Mwangi, 2006),

viii) Increase cation exchange capacity (CEC) of soils (Tarawali and Mohamed, 1995), and

ix) Increase soil water holding capacity (Karuku *et al.*, 2006),.

In addition, most legume species have tap-roots that penetrate deeper into the soil than the fibrous roots of grasses (Crowder and Chheda, 1982). The enlarged root section just below the crown of many legumes also provides a nutrient and water reserve during stress periods.

2.2 Effect of fire on vegetation and soils of natural pastures

2.2.1 Effect of fire on vegetation

Fire plays an important role in grazing land ecosystems (Manoharan and Paliwal, 1995; Herlocker, 1999; Trollope, 2004; Kitzberger *et al.*, 2005). Grassland fires have profound effects on composition of grasslands, reduction of natural bushland, and nature of the soil surface (Manoharan and Paliwal, 1995). Fire is considered as a low input and economical tool to stimulate new grass growth which is of higher quality (Boonman, 1993; Mnene, 1995; Kirkman and Carvalho, 2003). After a fire, the fresh regrowth provides high quality forage when compared to the old and stemmy forage accumulated over seasons. Too (1985) also noted that pasture grasses *Themeda triandra* Forsk, *Hyparrhenia filipendula* (Hochst. *ex* Steud.) Stapf and

Chloris roxburghiana Schult became stemmy, coarse and unpalatable when mature. However, after a burn, the young regrowth is palatable and nutritious. In South Africa, Kirkman and Carvalho (2003) found that the grass quality of a burned veld was substantially greater than that of unburned veld, with consequent improvements in animals' performance in terms of weight gain per animal.

Combining a rotational deferment grazing system with burning has the potential to provide optimum pasture conditions (Mnene, 1995). Accordingly, the Maasai community uses fire only when grazing has been insufficient to prevent accumulation of old growth (Too, 1985). This entails a single annual burn around March, which is usually at the end of dry season, when conditions are most suited to burning, thus achieving the greatest impact. Too (1985) recommended that pastures which were not intensively grazed should be burned periodically to maintain their vigour, palatability and nutritive content. If grazing is sufficient to prevent accumulation of old growth, burning needs not be annual and would probably suffice if used every 2-3 years to prevent bush encroachment. In Tamil Nadu, India, Manoharan and Paliwal (1995) reported an increase of above ground biomass productivity from 6.0 to 6.8 t ha^{-1} yr^{-1} after burning. However, fire reduced the litter productivity from 4.5 to 2.2 t ha^{-1} yr^{-1}. Herlocker (1999) also noted that grasslands in eastern Kenya usually reverted back to bushland or thicket if not burned at least after every five years.

Fire also influences vegetation composition and species dominance in rangelands as it encourages regrowth of species that were adapted to burning (Herlocker, 1999). Grasses were not as sensitive to fire like most woody plants. Wolfson and Tainton (2000) attributed this to the location of growth points of grasses which were better protected from fire and tended to sprout earlier after a burn. For example, the perennial grass *Themeda triandra* dominates fire-climax grasslands in northern Tanzania and southern Kenya (Bogdan, 1977). In the absence of fire, it is gradually replaced by other grasses, for example *Pennisetum stramineum* or woody vegetation. In some areas, if too frequently burnt, it is replaced by the even more fire-tolerant *Heteropogon contortus* (L.) Beauv. *ex* R. & Sch. This was also noted by Mnene (1995) who reported the composition of *T. triandra* in the natural pasture as 3.3 %, but after burning, its composition increased to 7.8 %. Other grasses which increased after burning included *Dichanthium insculpta* (from 13.5 to 16.1 %) and *Digitaria macroblephara* (from 65.3 to 68.1 %). However, the composition of *Chloris roxburghiana* decreased from 4.1 to 1.8 %, implying that fire had a detrimental effect on its growth. Snyman (2003) also reported that *Digitaria eriantha* and *Cymbopogon plurinodis* decreased after burning by 16 and 33%, respectively, while *Eragrostis chloromelas* and *Setaria sphacelata* increased by 28 and 49%, respectively. Frequent burning could reduce perennial grass cover and increase the amount of annual grasses, forbs and bare soil (Wijngaarden, 1985). In addition, repeated burning in the low fertility lands of south-east Asia and Africa resulted in dominance by the tall rhizomatous grass *Imperata cylindrica* (L.) Beauv that is difficult to eradicate (Humphreys, 1978).

2.2.2 Effect of fire on soils

Although controlled burning is necessary in certain dry areas to limit bush encroachment and to maintain the grass cover, burning destroys enormous quantities of organic matter thereby causing loss of important plant nutrients such as nitrogen and sulphur through volatilization (Grace *et al*., 2006). These two elements are lost as gaseous oxides into the atmosphere. Fire also acts as a mineralizing agent to increase short term availability of nutrients for plant growth (Manoharan and Paliwal, 1995). However, the effects of fire on nutrient dynamics were dependent upon the inter-relationships of fire behaviour, micro-climate, biomass consumed by fire, and vegetation composition and structure.

Burning increased soil pH and base status of Zambian soils with low organic matter content and base saturation (Trapnell *et al.,* 1976 as quoted by Boonman, 1993). Fire also promoted the return of bases brought down in litter from the tree canopy, while termites depleted this return by consuming un-burnt litter whereby the derived bases gradually became concentrated in large termite mounds. In each case, the organic matter content of the soil was kept at a very low level. Boonman (1993) noted that burning subjected the soil to high temperatures and bareness causing organic matter loss and drying-out of the topsoil. In addition, raindrop impacts and hoof treading by livestock on the bare surface between the remaining tufts of grass worsen the topsoil structure still further by causing soil compaction. This reduces water infiltration into the soil because of soil compaction and lack of protective mulch against run-off (Manson *et al.,* 2007).

In three different fallow areas under traditional slash and burn for finger millet farming, Msaky *et al.* (1996) noted important changes in soil chemical properties after clearing and burning. The soil pH increased after burning mainly due to the alkaline nature of the ash and in addition, available phosphorus and exchangeable calcium, magnesium and potassium also increased. The study also reported a decrease in concentration of nutrients with time on the soil's surface layers, indicating leaching towards subsurface layers.

Legume plant residue acts as an energy dissipater which absorbs rain-drop impacts thereby preventing dispersal of soil aggregates (Karuku *et al.*, 2006). The study noted that the water infiltration rate of the soil is maintained at a higher level under dead or live mulch because:

i) Structural porosity of the soil was maintained, hence there was no surface sealing and crust formation,

ii) Macro-pores open to the soil surface remained intact and functional in transmitting water through the soil, and

iii) Biological activity of soil fauna was maintained which further provided additional pores for water conduction.

2.4 Evaluation of forage legumes for adaptability in natural pastures of semi-arid rangelands

The primary criteria for selection of a legume for pasture improvement is that it should give a large yield of good quality fodder rich in protein, but equally important, the legume should be able to establish and persist in the sward (Prasad, 1995; Giller, 2001). Thus the legume must not only be well adapted to the environmental conditions of a given region, but must also be compatible with dominant grasses in the pasture under grazing. Therefore the survival of the legume was dependent on competition for resources such as light, moisture and nutrients, but must also withstand stress from herbivory. For example, *Desmodium uncinatum* (Jacq.) DC could not withstand a soil moisture stress caused by a seasonal total rainfall of less than 600 mm in Kibwezi, Makueni District (Macharia, 1994). The ability to re-grow rapidly following defoliation also strongly influences persistence and tolerance to fire which is an important factor for consideration in areas managed by burning (Giller, 2001). Thus climbing or shrubby legumes (e.g. *Centrosema* and *Pueraria* species) were most suitable for introduction into tall grass swards such as of *Panicum*. However, the low-growing stoloniferous or rhizomatous legumes (e.g. *Arachis pintoi*) were most suitable for mixing with spreading grasses such as *Brachiaria* (Giller, 2001).

In order to raise a grass and legume mixture, information is needed on the species compatibility when grown as mixtures (Crowder and Chheda, 1982). Of particular importance is early seedling vigour, habit of growth, peak herbage production, time of flowering and seed development. Crowder and Chheda (1982) recommended that with seeds of equal viability, the ratio of legume to grass should be about 3:2 so as to minimize competition from grasses which grow and establish more rapidly than legumes. It was also essential for legumes to produce large quantities of seeds for self-propagation and survival in grass pasture (Giller, 2001).

Legumes have a wide variation in optimum soil conditions and specific requirements for growth than do grasses and therefore, great care needs to be taken in choosing legume species for use in a grass/legume system (Skerman *et al*., 1988). Numerous leguminous species have adapted themselves to arid and semi-arid conditions in different ways. For example, adaptability by annuals is usually achieved through germination, growth and setting seed during the short rainy season. Such plants are regarded as drought avoidance species (e.g. *Stylosanthes humilis* H.B.K.). The drought resistant perennials adapt themselves by becoming deciduous, i.e. they shed their leaves at onset of the dry season. Others are deep-rooted and draw their water from deep-lying water tables. Most drought resistant plants have large and deep root systems and small above ground parts. Siratro (*Macroptilium atropurpureum* (DC) Urb.) and Glycine (*Neonotonia wightii* (Arn.) Lackey) are some drought resistant perennial legumes that have a deep, well developed root system (Skerman *et al*., 1988).

The following characteristics are essential for the successful establishment of tropical pasture legumes (Lascano and Peters, 2007):

i) Persistence in a pasture in spite of competition from associated grasses, and persistence during periods of climatic stress was essential. In addition to vigour, the capacity to regenerate, better palatability than grasses, growth rhythm and ability to compete for water and nutrients were all important factors in persistence,

ii) Tolerance to the range of soil conditions found in most tropical countries was essential if legumes were to be widely adaptable. The *Stylosanthes* cultivars, Siratro, Calopo, Centro and *Desmodium* have this adaptability, but legumes like *Neonotonia wightii* are adapted to specific soil conditions,

iii) High production of seed which can be harvested easily,

iv) Resistance to diseases and pests, and

v) Be non-toxic to livestock.

The plant population of a legume species during establishment phase ensured availability of animal feed, soil organic matter and plant cover (Pamo and Mubeteneh, 1995). While conducting a study on establishment and adaptability of forage legumes in Cameroon, Pamo and Mubeteneh, (1995) noted that *Macroptilium atropurpureum*, *Desmodium intortum* (Mill.) Urb, *Dolichos axilaris*, *Macrotyloma axillare* (E.Mey.) Verdc and *Neonotonia* suppressed weeds and decreased water runoff and soil erosion. The legumes' also had ability to frequently root at nodes when in contact with the soil which enabled them source soil nutrients from a larger surface area than the weeds.

Gachene and Makau (1997) carried out a legume screening study with the aim of identifying promising legume species that could perform well under semi-arid conditions of Machakos District. The study found out that in terms of dry matter production and resistance to drought, *Mucuna pruriens, Crotalaria ochroleuca, Lablab purpureus* (L.) Sweet, *Canavalia ensiformis* (L.) DC and *Crotalaria juncea* L. were among the best performing species out of 23 test legumes. The deep-rooted species, namely *Mucuna pruriens, Lablab purpureus* cv. Rongai, *Canavalia ensiformis* and *M. atropurpureum* cv. Siratro, were able to utilize soil moisture in the lower soil horizons than the other legumes. The study therefore recommended the following fodder species for Machakos area: *Mucuna pruriens, Glycine wightii* (Wight & Arn.) Verdc, *Macroptilium atropurpureum, Crotalaria ochroleuca* and *Cajanus cajan* (L.) Millsp, a pulse and an excellent fodder in pastures (Purseglove, 1987). These best species were chosen on the basis of:

i) Tolerance to moisture stress,

ii) Ability to nodulate under low soil moisture conditions,

iii) Resistance to pest and disease attack,

iv) Ability to produce viable seeds,

v) Utilization as fodder or for soil conservation, and

vi) Providing a good ground cover which was necessary for erosion control and regulation of surface soil temperatures.

Njarui *et al.* (2000) also identified Stylo *(Stylosanthes guianensis* (Aubl.) SW.), Siratro *(Macroptilium atropurpureum)*, Velvet bean (*Mucuna pruriens)*, Lablab *(Lablab purpureus)* and Glycine *(Neonotonia wightii)* as supplementary feed for dual purpose goats in the semi-arid regions of eastern Kenya. These species were well adapted to the climate and soils of the region, and produced high biomass. The authors also noted that animals fed on these legumes produced manure of higher quality than that from animals fed on grasses alone.

2.5 Contribution of forage legumes to dry matter production and forage quality of natural pastures

2.5.1 Dry matter production

Legume species are integrated with grass pastures principally to raise forage quality and quantity due to their ability to fix atmospheric nitrogen (Wassermann *et al.*, 2000). Legumes also ensure stability of pasture production due to different growth patterns of both grass and legume species. It has been demonstrated that the dry matter production of grass/legume mixed pastures usually exceeded that of grass alone when no inorganic fertilizer nitrogen is added (Thomas and Lascano, 1995; Njarui and Wandera, 1997). Crowder and Chheda (1982) also quoted studies done in Hawaii where *Desmodium canum* (J.F. Gmel.) Schinz & Thall (Kaimi Clover) mixed with Pangola grass increased the dry matter productivity of the grass in monocultures from 3.78 to 7.51 t ha^{-1} yr^{-1} for grass/legume mixed pasture. In the same study, *D. intortum* (Greenleaf Desmodium) mixed with Pangola grass produced dry matter of 10.63 t ha^{-1} yr^{-1} as compared to 3.78 t ha^{-1} yr^{-1} that was produced by grasses grown in monoculture stands.

Macharia (1994) found that integration of *Desmodium uncinatum* legume with *Chloris roxburghiana* grass in Kibwezi area resulted in *C. roxburghiana* monoculture stands producing 7.2 t ha^{-1} yr^{-1} dry matter while that of grass/legume mixed plots was 8.0 t ha^{-1} yr^{-1}. The study concluded that *D. uncinatum* significantly ($P \leq 0.05$) increased herbage quantity of *C. roxburghiana* probably because the grass benefited from increased soil nitrogen that may have been contributed by the legume. Nnadi and Haque (1986) also found that the total productivity per unit of land was usually greater for legume/grass mixtures than for sole crops. Thomas and Lascano (1995) further reported that in Colombian savannas, grass/legume mixed pastures increased by 50 % the animals' live weight gains per head. In the same study, the dry matter production per hectare in mixed grass/legume pastures increased by 20-30 % compared with pure grass pastures. A study conducted by Njarui and Wandera (1997) at Katumani, Kenya, reported a higher dry matter productivity of 4.04 t ha^{-1} yr^{-1} from a Napier/*Macrotyloma axillare* cv. Archer mixed pasture as compared to 2.42 t ha^{-1} yr^{-1} obtained from Napier in monocultures.

Dry matter production of grass/legume mixed pastures in different regions of the world varies widely due to a number of factors (Crowder and Chheda, 1982). Such factors are the species of grasses and legumes, inherent soil fertility, percentage of legume, available soil moisture, intensity of defoliation (interval and height), light intensity and temperature. In general, legumes become established more slowly than grasses so that the latter may predominate for 1 or 2 years.

2.5.2 Forage quality

Forage quality generally refers to digestibility, crude protein, secondary compounds and mineral content (Stuth *et al.*, 1995). Digestibility is related to relative proportions of cell contents and composition of cell wall components especially structural carbohydrates. An outstanding feature for grazing animals in a grass/legume association was increased crude protein content in available herbage as compared to grass alone and the constancy of crude protein found in the legume component. For example, studies in Hawaii showed that crude protein content of *Desmodium intortum* ranged from 17.0 to 21.0 % over the season when mixed with Pangola grass (Crowder and Chheda, 1982). The level of crude protein in grasses ranged from 7.6 to 13.6 % while in association with the legume as compared to 5.9 to 10.2 % while in pure stand with no addition of inorganic nitrogen. This shows the advantage of mixing grasses with legumes for increased forage quality.

There are two main pathways for cycling of fixed N, namely through litter fall and excreta from animals (Giller, 2001). The relative importance of each pathway will depend on palatability of the legumes being considered. For example, cattle tend to preferentially graze grasses in mixed pastures during the rainy season when their forage quality is high. Legumes such as *Calopogonium muconoides* Desv and *Chamaecrista rotundifolia* are not eaten until availability and quality of the grasses decline. Exceptions are the highly palatable species such as *Arachis pintoi* Krap & Greg which are consumed throughout the year (Giller, 2001). Thus with less palatable legumes such as *Calopogonium*, fixed N will become available to the associated grass through litter fall and decomposition during the wet season. Moreover, nitrogen transfers through animal manure will thus be of importance after being taken up by grasses during the dry season. Legume herbage has higher sustained N levels over a period of time than grasses over the same period (Wassermann *et al.*, 2000). This was attributed to the "built-in" supply of N in effectively nodulated legumes so that fluctuation within the plant was largely independent of the N in the soil. This reservoir maintained a rather constant supply of nitrogen as the plants aged. For example, the decline of nitrogen concentration in Siratro with increasing age of leaves and stems was quite insignificant over a 16-week regrowth period as it changed from 4.63 % at four weeks to 4.12 % at 16 weeks of growth (Crowder and Chheda, 1982).

One of the major factors limiting livestock production in semi-arid regions of eastern Kenya is the quality of available fodder (Njarui and Wandera, 1997). The study noted that Napier and Panicum fodder grasses were increasingly being adopted as feeds by small-scale dairy farmers but usually their quality deteriorated quickly after maturity. The study found that when intercropped with forage legumes, these fodder grasses provided forages of high quality than grass alone and consequently had a potential to improve livestock production. It was therefore concluded that forage legumes intercropped with Napier and Panicum had a greater potential as animal feed in semi-arid areas where natural pasture was of poor quality.

Other benefits from legumes included the ability to improve nutrient cycling in the ecosystem via increased litter quality and greater amounts of nutrient passing though the animal system (Thomas and Lascano, 1995). This study noted that soil biological activities were enhanced by legume residues and exudates during mineralization processes. In addition, the study found that some legumes had the ability to control ticks in animals e.g. *Stylosanthes* (Thomas and Lascano, 1995). Boonman (1993) also reported that tropical legumes have a lower initial *in-vitro* dry matter digestibility than grasses, but the rate of decline was lower than that of grasses. For example, grasses younger than 60-70 days of regrowth had higher digestibility than in Trifolium, Medicago, Glycine, Stylo and Desmodium legumes. However, after 100 days of re-growth, the situation was usually reversed. The study added that legumes were also valued for their high contents of calcium, sulphur and phosphatic minerals.

The major disadvantages of legumes in pastures was their lack of persistence under intensive grazing which, depending on legume species and its acceptability to animals, could result in the legume being grazed out of the pasture within a few years (Skinner *et al.*, 2004). On the other hand, some tropical legumes such as *Desmodium ovalifolium* contain high amounts of anti-quality factors such as tannins. These compounds reduce the legume's acceptability by animals due to reduction in palatability and digestibility, resulting in the legume dominance in the pasture. *Lablab purpureus* is also known to cause bloat to livestock at the young and rapidly growing stage of the crop and should not be more than 20-30% in the animal diet (Muinga *et al.*, 2006).

2.6 Effect of defoliation on growth and dry matter production

Productivity of all plants depend on their capacity to photosynthesize and hence their ability to produce new biomass (Mburu and Gitari, 2006). Young plants with few leaves have limited growth capacity and as more leaves accumulate and leaf area increase, the growth rate rises. Therefore, if defoliation is practiced too early or too frequently, it could lower dry matter production by reducing leaf area and light interception, resulting in slow growth rates. Moreover, when grass plants are about to shift from vegetative to reproductive developmental stage, heavy grazing could prevent formation of flowering shoots, thus promoting further growth of leaves and production of more secondary branches. The implication is that more defoliation may increase tiller recruitment and hence more dry matter production in grasses (Tomlinson and O'Connor, 2005).

The effect of leaf removal on plant growth is dependent on whether whole or only part of the leaf is removed, the stage of development of the leaf which is removed, and extent to which leaf area of the plant as a whole is reduced (Wolfson, 2000). Complete removal of green leaves will make initial regrowth dependent on carbohydrate reserves, leading to a reduced growth rate. Stem morphology (including woodiness) of pasture legumes vary greatly among different species even though they have one common feature which differentiate them from grasses making them respond differently to defoliation (Wassermann *et al.*, 2000). While both grasses and legumes have their primary growing points terminal to the stem, the terminal growing point in legumes is completely exposed to removal by even light grazing (except in some prostrate legumes). In grasses, the apex remains low to the ground during vegetative growth in most species, where they readily escape defoliation damage. In the long term, grasses adapt to defoliation by producing lateral tillers which upon decapitation by defoliation, will readily be replaced by new tillers growing from lateral buds produced lower down the stem. However, the ability to produce lateral tillers varies considerably from species to species (Wassermann *et al.*, 2000).

Different grass species may respond differently to different intensities of defoliation. For example, *Themeda triandra* is sensitive to intense and frequent defoliation during the growing season while *Sporobolus fimbriatus* Nees is well adapted to severe defoliation (Wolfson, 2000). On the other hand, stoloniferous legumes such as *Trifolium repens* L. (White Clover) and *T. fragiferum* (Strawberry Clover) and rhizomatous legumes such as *Coronilla varia* (Crown

Vetch) and *Lotus uliginosus* (Big trefoil) tended to be reasonably tolerant to heavy grazing as their lateral apical growth points usually remained close to or below the soil surface. The response of legumes to defoliation depended on the physiological stage of growth of the plant at the time it was defoliated and on the quantity of important plant parts retained by the plant such as plant reserves, active stem apices and active photosynthetic parts (Eckard and Wassermann, 2000).

Herbivory is one of the major biotic factors that play a central role in plant community dynamics because herbivores exert both direct and indirect effects on plants, which affects all aspects of plant growth, reproduction, and status in the plant community (Al-Rowaily *et al*., 1995). Responses of plants to herbivory include slow or decreased growth and fecundity depending on the severity of removal. Intensive grazing reduces plant shoot and root biomass making the plant more vulnerable to soil moisture stress which results in deterioration of range pasture productivity (Walton, 1983; Wolfson, 2000). Defoliation affects the pattern and growth rate of roots, probably by reducing the photosynthetic products available as reserves (Snyman, 2005). Depending on severity of leaf removal, the result is either a slowing down or a complete stoppage of root growth. When 50 % or more of aboveground growth of *Chloris gayana* Kunth (Rhodes grass) was harvested, a proportion of the roots stopped growing and root growth stopped completely when 80 or 90 % of aboveground growth was removed (Wolfson, 2000). Too (1985) also found that the intensity, frequency, season of use, plant phenological stage and plant parts removed during defoliation influenced herbage production.

Management of pastures is the judicious ecological manipulation of factors in order to increase outputs in the most economically advantageous way, but as a rule, tropical pasture species should not be grazed too closely (Skerman *et al.*, 1988). For example, herbage removal should not be lower than 15-20 cm as damage to the legume may result. Too (1985) citing Woie (1984) noted that a six-week interval was sufficiently long enough to permit development of a large number of grass tillers to ensure continued growth rate. However, while severe defoliation reduced survival of range forage plants, light defoliation may enhance their survival through reduced plant density that caused self and mutual shading by parent plants or other old individuals in the stand (Wolfson, 2000).

Studies have shown that animal grazing led to continuous but partial defoliation, was more selective, less severe and removed herbage at varied heights while mechanical removal or clipping frequently resulted in removal of all herbage above a certain stubble height from all plants (Musyoka, 1991). Clipping is also non-selective and does not consider mineral distribution through faeces and urine and soil surface compaction caused by grazing animals. However, clipping has been used widely in grazing studies and information from such studies applied in grazing systems management (Woie, 1984; De Leeuw (1991). Al-Rowaily *et al.* (1995) noted that clipping had certain shortcomings as a method of simulating grazing effects on plant growth. The major problem with clipping is the poor extent to which it actually resembles the pattern and frequency of defoliation under actual grazing. However, clipping studies could generate useful baseline information about critical periods of defoliation in plant species. But, it is necessary to recognize the difference between the processes of grazing and clipping in order to draw appropriate conclusions and applications from experimental results.

2.7 Contribution of forage legumes to soil fertility

A number of studies (for example Grace *et al.*, 2006; Mugwe *et al.*, 2007; Okalebo *et al.*, 2007) have noted that low soil fertility in arid and semi-arid lands was a major constraint to primary production under rain-fed conditions. Njarui and Mureithi (2006) also found that when there was little organic matter in the soils, as was the case with soils of arid and semi-arid lands which were mainly sandy in nature, nitrogen was the most limiting nutrient to primary productivity. In these ecosystems, nitrogen-fixing plants have a major role to play in the accumulation of nitrogen in microbial and plant biomass and in soil organic matter.

Legumes are unique in their ability to fix the limitless supply of atmospheric nitrogen through a symbiotic relationship with N-fixing *Rhizobium* bacteria which form nodules on the legume's roots (Giller and Wilson, 1991; Wassermann *et al.*, 2000). By supplying the bacterium with carbohydrates, the host plant became independent of soil nitrogen. Nodules vary in size among different legumes, meaning different nitrogen fixing abilities (Wasserman *et al.*, 2000). The interiors of active nodules are pink to deep red, changing to green as the nodules decayed, while ineffective nodules appear translucent or white inside (Skerman *et al.*, 1988).

Nitrogen is quantitatively the most important element taken up by pasture plants from the soil and its availability, together with soil moisture supply, are usually the major factors determining productivity of tropical pastures (Miles and Manson, 2000). There are several known mechanisms of nitrogen transfer from legumes to grasses. Direct transfer involves an exchange of nitrogen between legume plants and grass roots, either concurrently with fixation, or more importantly, after a phase of nodule decomposition in the soil. Nodule senescence is reportedly stimulated by defoliation and adverse environmental conditions and is characteristically more rapid than that of remaining root material (Miles and Manson, 2000; Cherr *et al.*, 2006). Other important mechanisms of nitrogen transfer from legumes to grasses include decomposition of ungrazed, senescent, or trampled leaf and stem components of legumes and through animal ingestion of herbage and redistribution in dung and urine (Crowder and Chheda, 1982). Exudates from legume roots also contained nitrogen in form of simple amino-acids (Giller, 2001).

Mineralization of legume residues releases nitrogen more gradually over a longer period of time than from inorganic fertilizers, reduces nitrate leaching and improves efficiency of nitrogen uptake by companion crops (Nyambati *et al.*, 2006). In situations where there is poor nodulation and N-fixation, legumes exploit soil nitrogen reserves rather than contributing to them. Thomas and Lascano (1995) reported that a range of N-fixation rate of 15-158 kg N ha^{-1} yr^{-1} could maintain the N-balance in soils of tropical pastures. However, the amounts vary with rate of pasture utilization and rates of recovery of nitrogen via the main recycling processes of litter return and decomposition, plant internal recycling and animal excretion. Other beneficial effects after application of leguminous mulches and cover crops is the increase of snails and earthworms which are beneficial during nutrient recycling (Bautista-Zuniga *et al.*, 2008).

Various authors have reported varying amounts of N fixed by legumes. For example, Chikowo *et al.* (2007) reported that *Sesbania sesban* and *Acacia angustissima* legumes in Zimbabwe could fix more than 150 kg N ha^{-1} yr^{-1} on a clay loam soil. The study also reported that N input after decomposition of litter of *Mucuna pruriens*, 96% was from N_2 fixation. Mafongoya *et al.* (2007) reported N fixation rate of 280 and 157 kg N ha^{-1} yr^{-1} by *Tephrosia candida* and *T. vogelii*, respectively, in southern Africa. In Kenya, Kihara *et al.* (2007) reported that Mucuna could fix >100 kg N ha^{-1} yr^{-1}. Also, Keya (1974) reported a legume contribution of 100 kg N ha^{-1} yr^{-1} to the soil in Kitale, provided the legume consisted of 30-40 % of the grass/legume mixture. Skerman *et al.* (1988) reported that *Centrosema pubescens* Benth had a nitrogen fixing ability of 100 kg ha^{-1} yr^{-1} in the top 15 cm of the soil, *Neonotonia wightii* 160-170 kg N ha^{-1} yr^{-1} and *Macroptilium atropurpureum* 100-175 kg N ha^{-1} yr^{-1}.

2.8 Ecology of legume species used in this study

The five legume species used in the present study were selected since they had performed well as green manure legumes in cultivated agriculture in terms of improvement of soil fertility, dry matter production and as livestock feed in semi-arid regions of Kenya (Gachene and Makau, 1997; Njarui and Wandera, 1997; Mureithi *et al.*, 1998; LRNP, 1999). A description of the legumes' ecological attributes is provided below as described by Duke (1981) and Skerman *et al.* (1988):

i) *Neonotonia wightii* Arn. Lackey

This legume is commonly called Glycine and is a herbaceous perennial with a strong tap root and trailing, climbing and twining stems. The stems are woody at the base and may reach 4.5 m in length and often sprout from a crown below the soil surface. It is a native of tropical Africa and in Kenya, it grows from coastal lowlands up to 2,450 m above sea level (a.s.l.) with best performance in areas with 750 mm annual rainfall. Glycine also performs well in deep and well drained soils with a pH of 5.0 to 7.1. The legume is small seeded and the percentage of hard seeds is quite high (about 70 %). Once seeds are sown, germination and establishment of seedlings is slow at the beginning but later becomes quite vigorous in growth and the plants may cover the soil in two months after germination. Production of dry matter of 8 to 10 t ha^{-1} yr^{-1} has been reported in Campinas, Brazil, and a crude protein content of 26.5 % in the leaves has been reported in Kenya (Skerman *et al*., 1988).

ii) *Macroptilium atropurpureum* (DC) Urb

This species is commonly called Siratro and is a deep rooting herbaceous perennial with trailing stems from a basal crown. The stems may root anywhere along their length especially on moist clay soils but rarely on drier sandy soils. In Kenya, Siratro grows at elevations of up to 1,600 m a.s.l. but has a faster growth at elevations lower than 610 m a.s.l. The legume performs well with a rainfall of between 615 and 850 mm. Siratro is drought tolerant because of its deep rooting habit and performs well in well drained soils with a pH range of 4.5 to 8.0. Siratro nodulates well with native soil *Rhizobia*. The percentage of hard seeds is about 40 % and after germination, the seedlings establish rapidly. Siratro may produce up to 8 t ha^{-1} yr^{-1} dry matter and contain 17 to 20 % crude protein.

iii) *Stylosanthes scabra* Vog

This species is commonly called Shrubby Stylo and it grows up to 2 m height, is a shrubby perennial and is erect to sub-erect with strong to woody stems. It is a native of South America and grows from sea level to 600 m a.s.l. and in addition performs well in areas with 500 to 600 mm annual rainfall. The species is very drought tolerant because of its deep penetrating tap root. Shrubby Stylo is well suited to low fertility, acidic and sandy loam soils. The seedlings are slow growing during the first season but once established, the legume is a very strong competitor with companion species. The legume has a high percentage of hard seeds when freshly ripened but the seeds soften with time. After grazing, the regrowth is normally from buds located on the aerial stems which, being hard and woody, are rarely removed by livestock. When mown, strong and rapid regrowth occurs from crown buds located slightly below ground level. The legume may produce a dry matter of 1 to 9 t ha^{-1} yr^{-1}.

iv) *Mucuna pruriens* (L.) DC

This species is commonly called Velvet bean and is a herbaceous annual with vigorously growing and trailing vines of 3 to 18 m length. It is grown mainly for green manure or temporary pasture. It is a native of southern Asia and Malaysia and requires a hot moist climate for maximum growth. In Kenya, Velvet bean grows from sea level to 2,100 m a.s.l. with a rainfall range of 650 to 2,500 mm. The legume tolerates a wide range of soils, from sandy to clay soils and will grow on soils of low acidity. It is non-specific in its *Rhizobium* requirements and has a good germination rate of 99 %. Growth of Velvet bean is slow to start, but when established, the legume covers the soil rapidly, thereby smothering weeds effectively. Velvet bean produces dry matter of 3 to 6 t ha^{-1} yr^{-1} after 90 to 100 days after planting.

v) *Lablab purpureus* cv. Rongai (L.) Sweet

The species is commonly called Rongai Dolichos or the Hyacinth bean and is a herbaceous annual or short-term perennial legume with vigorously twining 3 to 6 m long stems. It is spread throughout the tropics especially in Africa as a food crop, forage for livestock and green manure. It grows from sea level to 2,000 m a.s.l. but performs better at lower elevations with a rainfall as low as 400 mm. It also performs well in well drained sandy to heavy textured soils with a pH range of 5.0 to 7.5. The legume does not easily nodulate with native *Rhizobia* and therefore, it is preferable to treat the seeds with *Rhizobia* of the cowpea strain. The legume does not establish well in natural pastures unless they are cultivated. It has a minimum germination of 90 % and contains about 10 % hard seeds. Besides fixing nitrogen through the nodules, it also supplies large amounts of nitrogen through leaf litter drop and decay. It can yield up to 5.4 t ha^{-1} yr^{-1} dry matter and 23.4 % crude protein during the first harvest. However, the legume does not withstand heavy grazing of the stems and may cause bloat in animals fed solely on the crop.

CHAPTER THREE: MATERIALS AND METHODS

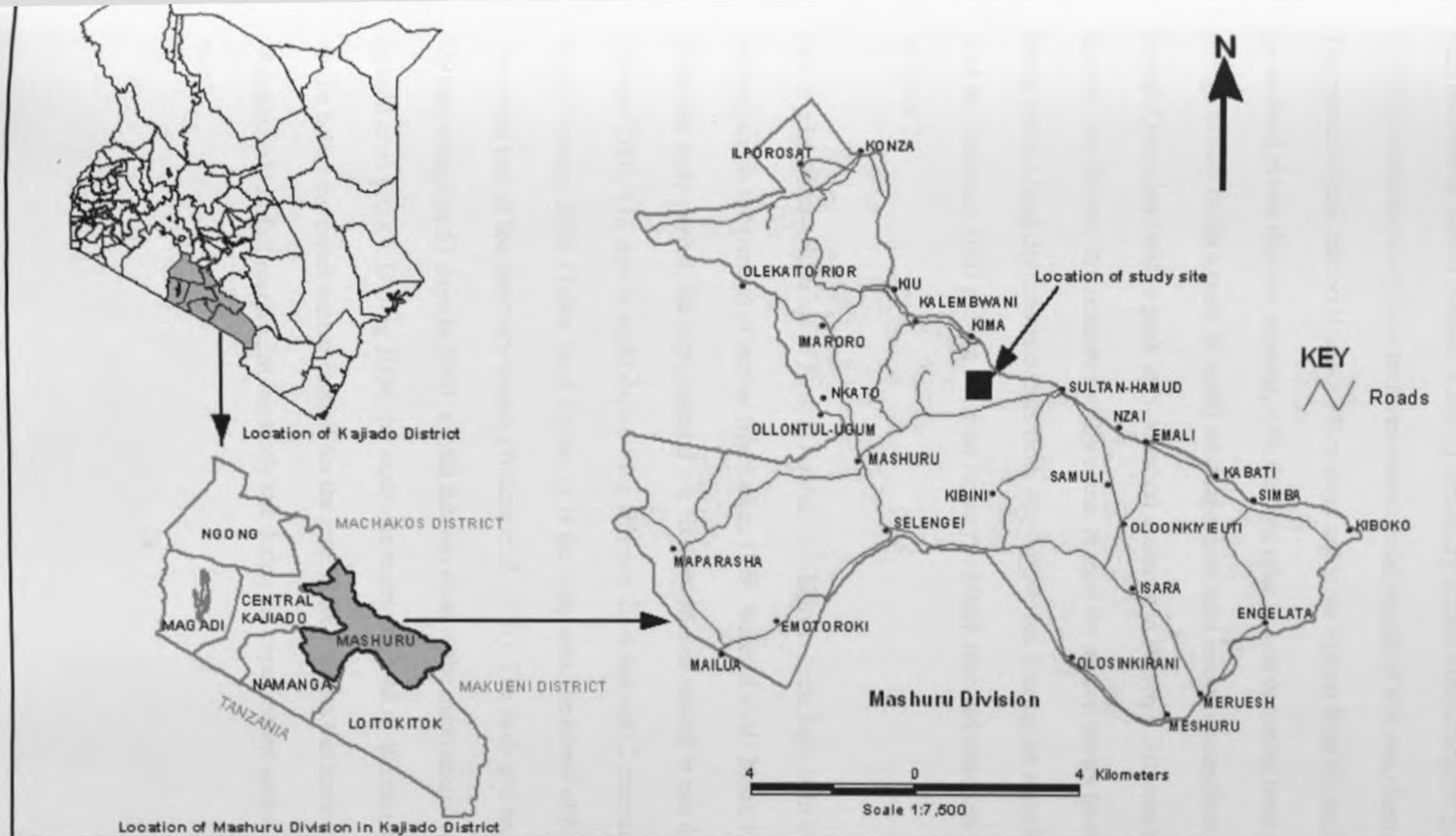
3.1 Introduction

This chapter describes location of the study area and the various materials and methods that were used to characterize the soils, vegetation, dry matter production and nutritive quality of dominant herbaceous species. Further, the various experiments that were conducted to select best performing legumes which involved studies on legume seed viability, nodulation characteristics, rooting patterns, dry matter production, litter production and effect of legumes on soil fertility improvement are described. Also described are the various experiments that were conducted to determine the effect of introduced legumes on improvement of natural pastures of semi-arid rangelands of Kenya. Description is made of the materials and methods used during the determination of dry matter production and forage quality of grass/legume mixed pastures. Also described are materials and methods used to determine the effect of the legumes on soil fertility improvement and extraction of soil moisture by grasses and legumes fro mixed pastures.

3.2 Description of the study area

3.2.1 Location and definition of the study area

The study was carried out at Sultan Hamud (2° 01'S and 37° 19'E) in Mashuru Division of Kajiado District (Figure 1) which was located at an altitude of 1280 m above sea level (a.s.l.). Mashuru Division with an area of approximately 2,999 km^2 is one of six divisions of the district and it borders Makueni and Machakos Districts to the north-east. In Kajiado District, it borders Loitokitok Division to the south, part of Namanga Division to the west and Central Division to the west. Mashuru Division has a population of 35,666 people composed of 7,333 households and a population density of 12 persons per km^2 as per 1999 population census (GoK, 2001).



Source: Macharia *et al.* (2001)

Figure 1: Map of Kenya showing location of study site in Mashuru Division, Kajiado District

The study site was in agro-climatic zone (ACZ) V which is classified as semi-arid and rainfall is the major limiting factor to primary production (Sombroek *et al.*, 1982). The mean annual temperature ranges from 21.6 to 24.0° C (Jaetzold *et al.*, 2006). The mean annual rainfall for 15 years recorded at Sultan Hamud, Kasikeu Secondary School Meteorological Station (Station 9137032) shows the study area receives mean annual rainfall of 838 mm (Jaetzold *et al.*, 2006). The meteorological station is about 3 Km away and is the nearest from the study site. The rains are received in two distinct seasons, with the long rains season occurring from end of March through to May (with a peak in April) while the short rains season occurs from end of October through December (with a peak in November) as shown in Figure 2. Between the two rainfall seasons, two distinct dry seasons usually occur. A short dry season occurs from January to March while a long dry season occurs from May to October. During the experimental period, the short dry season in 2003 did not occur as January to March received reasonable rainfall as shown in Figure 2.

Like in other semi-arid areas of Kenya, rainfall variability is quite high, both in the total amount received and in the time(s) of arrival (Herlocker, 1999; Jaetzold *et al.*, 2006). For example, during the study period, the experimental site received 16 mm rainfall in two days during February 2003, 116 mm in eight days during February 2004 and only 2 mm rainfall in three days during February 2005 (Table 1and Figure 2). In the study area, the month of February is considered part of the short dry season (Bekure *et al.*, 1991). The study site received a total of 729 mm rainfall in 57 days in 2003, a total that was close to the mean annual rainfall reported by Jaetzold *et al.* (2006). During 2004, the study site received a total of 602 mm in 52 days which was far below the mean annual rainfall for the area. Table 1 shows that more than 50% of the total seasonal rainfall received at the study site during the experimental period fell in a single month.

Table 1: Summary of seasonal rainfall received at study site during the experimental period

Year	Season	Seasonal rainfall (mm)	Rain days	Peak rainfall month	% seasonal rainfall
2002	SR	300	26	December	55
2003	LR	363	27	May	57
	SR	315	25	November	67
2004	LR	226	18	April	85
	SR	219	21	December	57

SR = Short Rains Season; LR = Long Rains Season

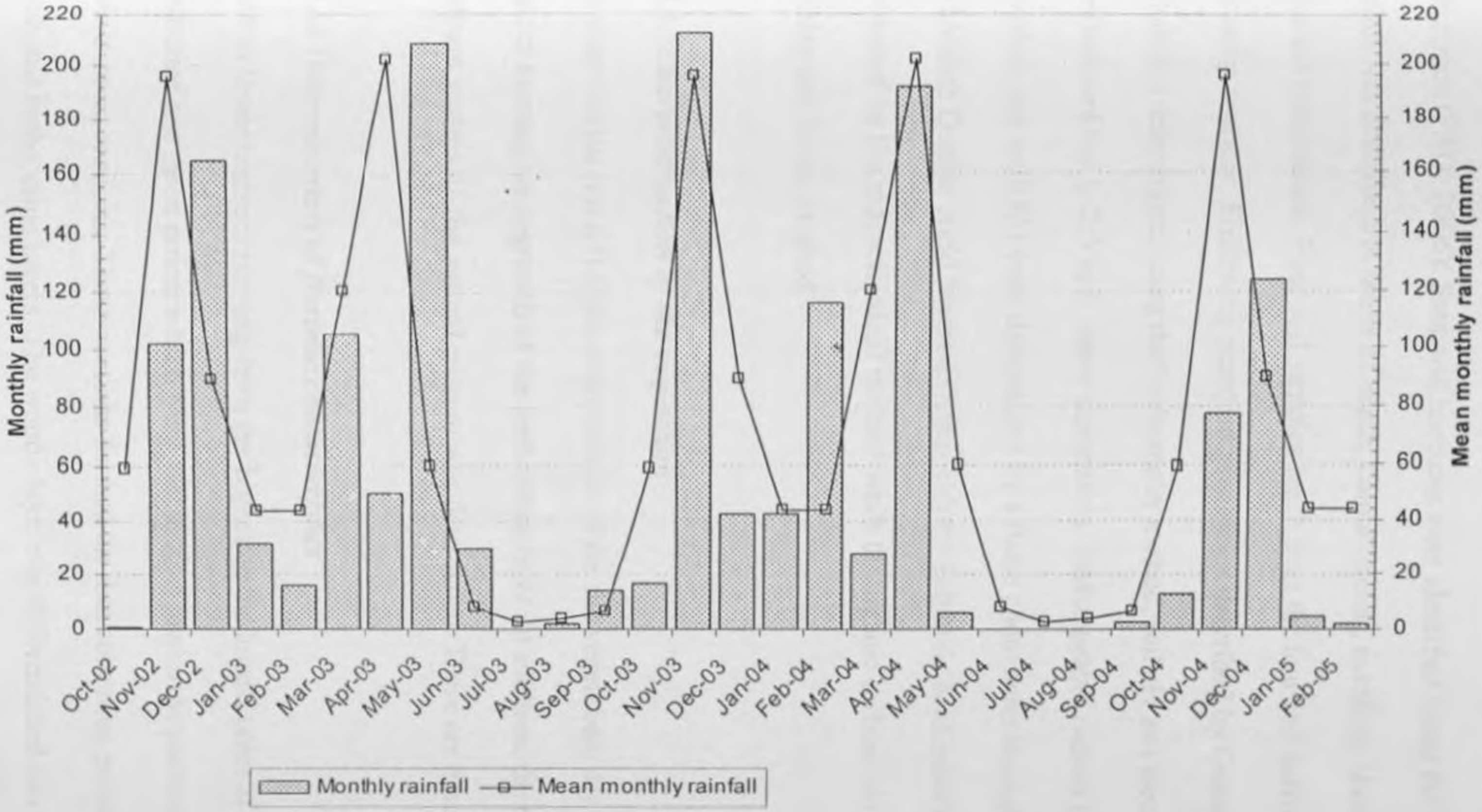


Figure 2: Total monthly and mean monthly rainfall (mm) distribution during the experimental period

3.2.2 Characterization of the soils

A 2 m deep soil profile pit was dug and soil description made following the Guidelines for Soil Description (FAO, 2006). Four soil horizons were identified along the profile pit and each horizon was described in terms of depth, colour (moist), mottling, texture, cutans, structure, pores and consistence. Four soil samples (each from the four soil horizons) were collected for laboratory analysis. Following standard procedures described by Okalebo *et al.* (2002) soil texture was determined using the hydrometer method, soil pH and electrical conductivity (EC) were measured in 1: 2.5 soil: water suspension. Exchangeable cations (calcium, magnesium, potassium and sodium) were determined by a flame photometer through a single extraction using the Mehlich Double Acid Method (Hydrochloric-Sulphuric acid extract). Total nitrogen was determined by the macroKjedahl method while the organic carbon was determined through the Walkley and Black method.

3.2.3 Characterization of the vegetation

The study carried out a floristic composition of the site vegetation, dry matter production and effect of burning on regrowth of the herbaceous layer. In addition, the nutritive quality of some dominant grasses of the natural pasture was determined. These are described below:

3.2.3.1 Determination of floristic characteristics

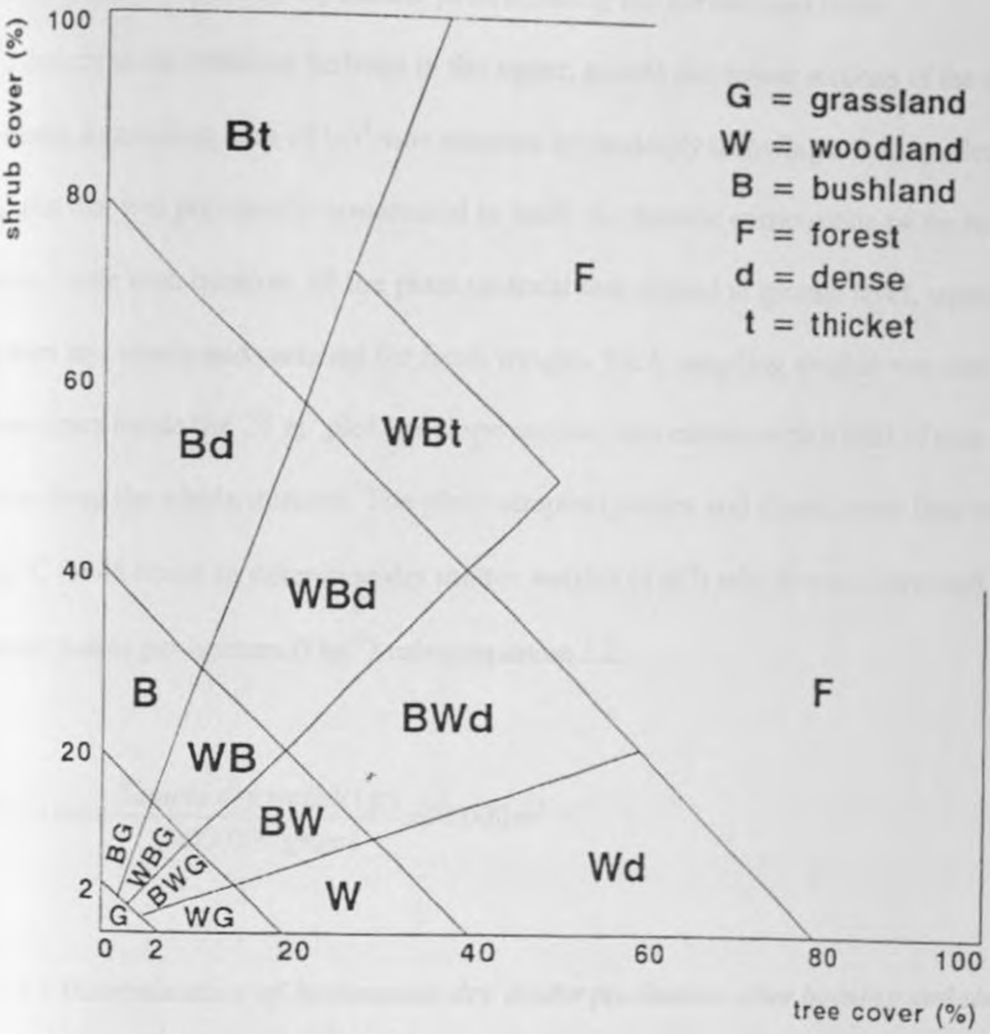
A 300 m linear transect running from the highest to the lowest point of the study site was demarcated and three points which were 100 m apart marked to partition the upper, middle and lower transect sections. These sections formed the data collection points to characterize the woody and herbaceous layers. The woody layer was differentiated into trees and shrubs, whereby, the trees were those single and multi-stemmed plants which were more than 6 m tall while shrubs were categorized as those single and multi-stemmed woody plants which were less than 6 m in height (Wijngaarden, 1985). The species names and authorities of the trees and shrubs were identified according to Beentje (1994). The names and authorities of the herbs (non-woody species) were identified according to Agnew (1974) while those of grasses were identified according to Bogdan (1976).

The floristic composition of the herbaceous layer was determined in a demarcated plot measuring 25 m^2 at each slope section. A line intercept method using a 25 m tape was used to measure the crown diameter of each species intercepted along the tape as a projection of the basal diameter as described by Gils and Zonneveld (1983). The total coverage for each species was then calculated as percentage cover of the total sampling plot using equation 3.1.

$$\%Cover = \frac{D}{L}x100 \qquad \textit{(Equation 3.1)}$$

Where, D is the total intercept lengths for one species; L is the total length of line transect.

The physiognomy of the vegetation was determined in an area of one hectare by estimating percentage cover of the woody species. The cover was estimated as the vertical projection onto the ground of all above-ground parts of all trees and shrubs and expressed as a percentage of the sampling area. The physiognomy of vegetation was derived through use of 'Key to Physiognomic Classes' as described by Wijngaarden (1985). This classification is based on percentage cover of trees and shrubs and is presented as a two dimensional graph (Figure 3).



Source: Wijngaarden (1985)

Figure 3: Key to physiognomic classes of vegetation at the study site

3.2.3.2 Determination of dry matter production of the herbaceous layer

To determine the standing herbage in the upper, middle and lower sections of the demarcated transect, a sampling area of $1 m^2$ was selected by randomly throwing a $1\ m^2$ quadrat inside the 25 m^2 plot that was previously demarcated to study the floristic composition of the herbaceous layer. Inside each quadrat, all the plant material was clipped at ground level, separated into grasses and weeds and weighed for fresh weights. Each sampling quadrat was then replicated three times inside the $25\ m^2$ plot per slope section, thus ending with a total of nine sampling areas along the whole transect. The plant samples (grasses and dicots) were later oven-dried at 105°C for 48 hours to determine dry matter weights ($g\ m^{-2}$) which were converted into dry matter tonnes per hectare ($t\ ha^{-1}$) using equation 3.2.

$$DM\,(t\,ha) = \frac{Sample\ dry\ weight\,(g)}{1{,}000{,}000\ grams} x 10{,}000\,m^2 \qquad (Equation\ 3.2)$$

3.2.3.3 Determination of herbaceous dry matter production after burning and slashing of the natural pasture

In a plot measuring 34 x 62 m, herbage in half of the plot was subjected to burning while herbage in the other half was slashed to ground level. The burning and slashing treatments were conducted at end of the long dry season in the month of October at onset of the short rainfall season. After three months (end of the rains season) all the above ground plant material in the burned and slashed plots was clipped to ground level and separated into grasses and dicots. The samples were later oven-dried and dry matter weights calculated as described in Section 3.3.2.2.

3.2.4 Nutritive quality of common species in the natural pasture

Within a radius of 100 m around the study enclosure, eight common grasses and two legumes were identified and sampled for laboratory analysis. Many hand-plucks of leafy material were collected from each species and mixed into a composite sample. The grass species were *Dichanthium insculpta, Hyparrhenia filipendula, Themeda triandra, Cenchrus ciliaris, Digitaria macroblephara, Eragrostis superba* Peyr, *Chloris roxburghiana* and *Pennisetum mezianum* Leeke. The legumes found growing in the natural pasture were *Neonotonia wightii* and *Rhynchosia malacophylla*. In the laboratory, the samples were oven-dried at 60°C for 72 hours, milled and analyzed for crude protein, ash, *in-vitro* dry matter digestibility and fibre content, following standard procedures as follows:

3.2.4.1 Determination of crude protein content

Samples of ground plant material were analyzed for percent nitrogen using the three stage micro-Kjeldahl technique that involved digestion, distillation and titration (AOAC, 1995). The digestion process involved boiling samples weighing 2 grams (in three replicates) mixed with concentrated sulphuric acid and selenium catalyst in Kjeldahl tubes on a heated digestion block for one hour. This process transformed nitrogen compounds into sulphate of ammonia and the acid sample solutions were left to cool overnight. Thereafter, the acid solutions were distilled by making them strongly basic with 40 % sodium hydroxide, then adding phenolphthalein indicator and then heating the solution. Released ammonia was trapped for 20-30 minutes, then distilled into standardized hydrochloric acid and cooled. Finally, samples were titrated with sodium hydroxide and the amount of alkali neutralized by ammonia noted against a blank sample. The amount of percent Kjeldahl nitrogen was then calculated and a conversion factor of 6.25 used to obtain percent crude protein content as follows:

$$\%N = \frac{(a-b)0.2xVx100}{1000xWxAl} \qquad \textit{(Equation 3.3)}$$

$$\%\,Protein = \%\,N\;x\;F \qquad \textit{(Equation 3.4)}$$

Where, N = Nitrogen; a = titration volume for blank; b = titration volume for sample; V = final volume of the digestion; W = weight of the sample taken; Al = aliquot of the solution taken for analysis; and F = Conversion Factor (6.25) for correction of nitrogen to protein.

3.2.4.2 Determination of ash content

A sample weighing 2 grams of ground plant material was placed on silica-dishes and then ignited to 600°C in a muffle furnace to burn-off all organic material as described by AOAC (1995). The ash was then cooled in a dessicator to room temperature and percent weight calculated as shown in equation 3.5 below:

$$Ash\,(\%) = \frac{W3-W1}{W2-W1}x100 \qquad \textit{(Equation 3.5)}$$

Where, $W1$ = weight of empty dish; $W2$ = weight of dish + sample; and $W3$ = weight of dish + ash.

3.2.4.3 Determination of in-vitro dry matter digestibility

The ground plant material was analyzed for ***in-vitro*** dry matter digestibility (IVDMD) using the two stage 48 hours fermentation method (Tilley and Terry, 1963). This method approximates digestion in an artificial environment when rumen conditions of ruminants are simulated in a test-tube. Fresh rumen fluid was collected from a fistulated steer, sieved through cheese cloth and collected in a flask which had been warmed and flushed with CO_2. The first fermentation stage involved mixing forage samples weighing 0.5 grams with sieved rumen fluid and adding artificial saliva to act as a buffer. This mixture formed an inoculum. Oxygen in the inoculum was then flushed with CO_2 to maintain anaerobic conditions for the rumen micro-organisms. Samples were mixed with inoculum and fermented in a 39°C water bath for 48 hours. Samples were then subjected to a second fermentation stage which involved digesting cell walls through addition of 20% hydrochloric acid and 5% pepsin enzyme. The samples were again fermented in a 39°C water bath for 48 hours. Sample contents were thereafter filtered through previously weighed Gooch crucibles using hot distilled water. Finally, the samples were oven-dried at 105°C, cooled in a dessicator, weighed and percent dry matter disappearance calculated against the initial weight of the sample as follows:

$$IVDMD\ (\%) = \frac{IW - FW}{IW} x100 \qquad \textit{(Equation 3.6)}$$

Where, IW = initial weight of sample; and FW = final weight of inoculum after digestion.

3.2.4.4 Determination of fibre content

Sample fibre content was analyzed according to procedures described by Van Soest (1963). The author stated that forages were made up of two basic dietary fractions i.e. cell contents (CC) and cell wall contents (CWC). Cell contents are comprised of lipids, sugars, water soluble carbohydrates, starch, soluble protein and non-protein nitrogen. These contents are soluble in neutral detergents and therefore almost completely degraded by enzymes secreted in an animal's digestive tract. Cell contents were extracted using a Neutral Detergent Solution (NDS) which left an insoluble portion of CWC comprised of:

i) A fibre fraction made up of an insoluble portion in neutral detergent (NDF) and another insoluble portions in acid detergent (ADF), and

ii) Acid detergent lignin (ADL).

The procedure for determination of the three cell wall contents (NDF, ADF and ADL) involved a three stage procedure as follows:

Neutral Detergent Fibre

Neutral detergent fibre (NDF) determination involved boiling 1 gram of ground plant material in a Neutral Detergent Solution (NDS) in sprout-less beakers for one hour to extract cell contents. The solution was then filtered into previously weighed filtering crucible on a filter manifold using a low vacuum pump while rinsing any particles left on the beakers with hot water. The residues were then put in a 105°C oven for an overnight stay and then cooled in a dessicator. The NDF residue now contained hemicellulose and cellulose, lignin and fibre-bound proteins (Crowder and Chheda, 1982). Percent NDF content was then calculated as follows:

$$NDF\ (\%) = \frac{W2 - W1}{W3xDM} x100 \qquad \textit{(Equation 3.7)}$$

Where, *W1* = weight of empty crucible; *W2* = weight of crucible + residue; *W3* = weight of sample; and *DM* = dry matter content of sample.

Acid Detergent Fibre

Determination of acid detergent fibre (ADF) was almost similar to that of NDF. However, instead of using NDS, an Acid Detergent Solution (ADS) was used to boil the NDF residue in a crucible (all inside the boiling solution) for one hour. Crucibles were then removed from the boiling solution and residue solution filtered into other crucibles using a low vacuum pump, and later oven-dried at 105°C overnight. The residue was cooled in a dessicator, weighed and percent ADF calculated as follows:

$$ADF\ (\%) = F2 - F1x100 \qquad \textit{(Equation 3.8)}$$

Where, *F1* = initial crucible weight + sample; and *F2* final crucible weight + sample

Acid Detergent Lignin

Acid detergent lignin (ADF) residue contains cellulose, lignin and acid insoluble ash (Van Soest, 1963). To extract cellulose, ADF residue was added 72% H_2SO_4 and stirred every hour for three hours in crucibles. Acid was added whenever it went low in the crucibles so as to always cover the residue. After three hours, the acid was thereafter filtered using a low vacuum pump and sample contents rinsed with hot water until free from acid. The contents were then dried at

105°C overnight and weighed after cooling in a dessicator. The residue was then ignited in a muffle furnace at 600°C to remove the lignin fraction, cooled and weighed. What remained in the crucibles was therefore acid insoluble ash which provided an approximation of the total minerals (Crowder and Chheda, 1982). Percent detergent lignin (ADL) was then calculated as follows:

$$ADL\,(\%) = \frac{L}{SxDM} x100 \qquad \textit{(Equation 3.9)}$$

Where, L = loss upon ignition after H_2SO_4 treatment; S = air dry sample weight and DM = dry matter content of sample.

3.3 Legume screening

3.3.1 Selection of experimental legumes

This study was conducted to select forage legumes suitable for integration into natural pastures of semi-arid rangelands of southern Kenya. The objective was to select forage legumes which would withstand the climatic and edaphic conditions of the semi-arid rangelands and at the same time enhance the quantity and quality of grasses in natural pastures. The following forage legumes were selected for the study:

1. *Neonotonia wightii* (Arn.) Lackey (Glycine)
2. *Macroptilium atropurpureum* (DC) Urb. (Siratro)
3. *Lablab purpureus* cv. Rongai (L.) Sweet (Dolichos)
4. *Mucuna pruriens* (L.) DC (Velvet bean), and
5. *Stylosanthes scabra* var. *seca* Vog. (Shrubby Stylo)

These legumes were selected for reasons described in Section 2.8, Chapter 2. In addition, they were found to perform well in other semi-arid regions of Kenya with an annual rainfall of between 600 and 750 mm (LRNP, 1999). Therefore, they were selected for experimentation in the current study to determine their effect on grassland productivity in terms of improvement of dry matter production, nutritive quality and soil fertility of natural pastures of Kenyan semi-arid rangelands.

These legume screening studies were conducted under field conditions at the Sultan Hamud site, and also under glasshouse conditions at National Agricultural Research Laboratories (NARL), Nairobi, Kenya. The seeds used in this study were sourced from the Legume Research Network Project (LRNP). Plate 3 shows the five experimental legumes planted as pure stands at the peak of a growing season.

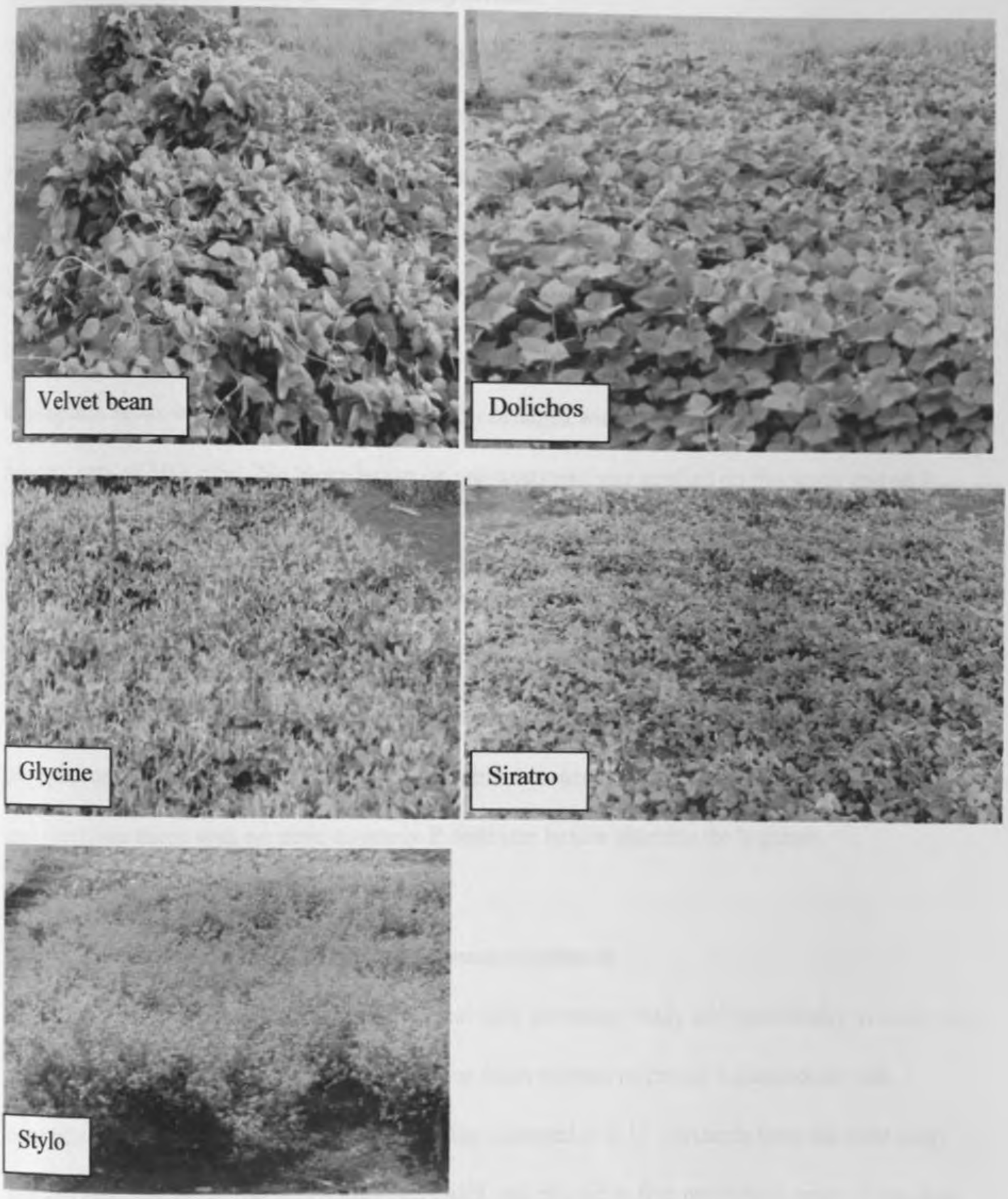


Plate 3: Experimental legumes planted as pure stands at the Sultan Hamud study site

3.3.2 Experimental design of the field experiment

The field study was conducted in an enclosure which measured 27 x 27 m and fenced with chain-link wire to keep out grazing animals. The treatments, which were the five legume species, were randomly assigned to experimental plots measuring 6 x 3 m (with 1 m buffer zone all round) and replicated three times in a randomized complete block design (RCBD) as described by Steel *et al.* (1997). In March 2002, well prepared seedbeds were made by removing all vegetative material and breaking up the big soil clumps. At the onset of the long rainy season in April 2002, the legume seeds were sown in furrows of 10 cm depth with an inter-row spacing of 20 cm at a seeding rate of 30 kg/ha. No inoculation or pre-treatment was applied on the seeds and no P fertilizer was applied on the plots. Studies conducted by Boonman (1993) and Mureithi *et al.* (1998) in Kenya had shown that legumes nodulated effectively since most soils contained promiscuous *Rhizobium* bacteria of the cowpea type which inoculated most legume species. In addition, studies conducted in Kakamega, Kabete and Kisii (Ojiem *et al.*, 2000) showed that phosphorus had no significant effect on both biomass accumulation and nodulation of legumes and therefore there was no need to apply P fertilizer before planting the legumes.

3.3.3 Experimental design of the glasshouse experiment

This study was conducted to complement the field screening study and specifically to study the nodulation habit of the experimental legumes when planted in pots in a glasshouse with controlled environmental conditions. Soil was collected at 0-15 cm depth from the field study site and transported to the glasshouse at NARL and placed in five pots which were 17 cm deep and 19 cm in diameter. Similarly, no inoculation or pre-treatment was applied on the seeds and no P fertilizer was applied in the pots for the same reasons given in Section 3.3.2. The pots were replicated three times and placed on benches in RCBD (Steel *et al.*, 1997).

3.3.4 Determination of seed germination

A seed germination test was conducted for the five experimental legumes to determine the viability of the seeds sourced from LRNP. Other seeds tested included those of *Chloris roxburghiana* (Horsetail grass), *Cenchrus ciliaris* (African Foxtail grass) and *Eragrostis superba* (Maasai Love grass) which were some of the dominant grasses growing at the field study site. The grass seeds used were harvested from the nearby Kiboko Range Research Station. In addition, seeds of *Rhynchosia malacophylla* (Rhynchosia), one of the two naturally growing pasture legumes at the field study site, were harvested from the natural pasture and a seed germination test conducted.

Ten seeds of the big-seeded legumes (Velvet bean and Dolichos) were placed in a Petri-dish each lined with moist cotton wool. The small-seeded legumes (Glycine, Siratro, Stylo and Rhynchosia) and the grass seeds were placed in lots of 100 seeds per species in a Petri-dish which were then replicated three times, placed on benches in the laboratory under room temperature of average 24°C and kept moist all the time. After emergence of seed radicle and shoot, seeds were considered germinated and discarded. Observations and recordings were done on a daily basis for three weeks, and seeds which did not germinate during the three weeks period were considered not viable.

3.3.5 Determination of nodulation and growth characteristics in the glasshouse experiment

Ten seeds of each experimental legume were planted in a pot and upon germination, the seedlings were thinned to five plants per pot and watered twice weekly with about 30 mm of water which was just enough to soak the soil. Legume plants were allowed to grow for two months, and thereafter, the soil was wetted and removed carefully with low pressure water to prevent sloughing-off the legume nodules and roots. Nodules on each plant were counted and nodule colour observed after splitting the nodules into two halves to determine whether they had pink colour (due to hemoglobin) which was an indicator that the nodules were fixing nitrogen (effective nodulation). Skerman *et al.* (1988) stated that distinctive nodule pink colour provided a reliable and ready means of identification of nodules that were fixing atmospheric nitrogen. Plant material was also separated into shoots, roots and nodules. The length of shoots, tap and lateral roots were measured and dry matter of shoots, roots and nodules determined using a Sartorius Basic (Model BA310S) analytical balance after oven-drying the materials at 105°C for 48 hours (AOAC, 1995).

3.3.6 Determination of rooting characteristics

The study was conducted in the field site, five months after planting the legumes during their second season of growth. Other plant species included in the study were the indigenous legume *Rhynchosia malacophylla* and the grasses *Chloris roxburghiana* and *Themeda triandra*. Each species was excavated to a depth of 1.2 m and carefully removed with the soil mass which was then carefully removed to expose the roots (Plate 4). Lengths of the roots were measured to determine the rooting depth and observations made on the rooting patterns of the legume and grass species, location of the lateral roots (in case of legumes) and fibrous roots (in case of grasses).

Plate 4: Excavation and removal of a Stylo plant to study the rooting characteristics

3.3.7 *Determination of dry matter production*

When Siratro, Dolichos and Stylo started flowering two months after planting, four 1 m^2 sub-plots were demarcated at each experimental plot. These sub-plots became permanent data collection points to determine the dry matter production by the five experimental legumes for the whole duration of the experiment. The four sub-plots were randomly assigned two intervals of clipping (2 and 4 months) and two heights of clipping (ground level and 15 cm above ground) as shown in Table 2. From each sub-plot, the plant material inside the plot boundaries was harvested using a hand clipper at the respective interval and intensity. Dry matter weights were then determined using a Sartorius CP 2202S-OCE analytical balance after oven-drying the clipped material at 105°C for 48 hours (AOAC, 1995). Dry matter weights were then converted into tonnes per hectare using equation 3.2 (Section 3.2.3.2).

Table 2: Harvesting intensities used to determine dry matter production of legumes during the screening phase

Plot	Harvesting interval (months)	Harvesting height	Defoliation intensity
1	2	Ground level	Short interval, heavy defoliation
2	4	Ground level	Long interval, heavy defoliation
3	2	15 cm	Short interval, light defoliation
4	4	15 cm	Long interval, light defoliation

3.3.8 Determination of litter production

This study was conducted to determine litter drop of the experimental legumes at the peak of the long dry season which occurred between June and October in the study area. Data were collected during the month of August, 2003 after the legumes started shedding their leaves. At each experimental plot, a 1 m^2 sub-plot that was different from the ones described in Section 3.3.7 was demarcated to collect the litter dropped by each legume species. Litter was collected and weighed using a Salter Classic Plus scale (Metric Version) on a daily basis for three weeks. Mean weights were then calculated and expressed as grams per square metre.

3.3.9 Determination of soil fertility

Three soil samples were randomly collected from each experimental plot at 0-15 cm depth at the beginning of the study using a soil auger. Samples were then mixed and a composite soil sample of about one kilogram was taken for laboratory soil fertility analysis. A similar sampling procedure was used to collect another batch of soil samples at end of the study period. Soil samples were analysed for pH, organic carbon and macronutrients consisting of nitrogen, phosphorus, potassium and calcium. Standard laboratory methods were used as described by Okalebo *et al*. (2002) as follows:

pH (H_2O)

Soil pH was measured in a 1:2.5 soil: water suspension ratio. The suspensions were made by adding 2.5 volumes of distilled water into 1 volume of fine soil. After stirring and letting the suspension stand for 1 hour, readings were done using a calibrated pH meter with a glass-and calomel electrode (Model Sartorius PP-15).

Total Organic Carbon

Determination of total organic carbon involved digestion (oxidation) of 1 gram ground soil with 10 ml 5 % potassium dichromate solution and 5 ml concentrated sulphuric acid (H_2SO_4) at 150°C for 30 minutes. After cooling, 50 ml of 0.4% barium chloride was added and the solution allowed settling overnight so as to leave a clear supernatant solution. The absorbance of an aliquot of the supernatant solution for each sample and a blank was then measured colorimetrically at 600 nm using VIS-NIR Spectrophotometer PU 8670. The content of total organic carbon expressed as percent carbon was then calculated as follows:

$$\% Carbon = \frac{(a-b)x0.10}{w} \text{ x } 100 \qquad \textit{(Equation 3.10)}$$

Where a = concentration of chromic (Cr^{3+}) in the sample, b = the concentration of chromic (Cr^{3+}) in the blank and w = the weight of soil taken for analysis.

Total nitrogen

Total nitrogen was determined by the micro-Kjeldahl method which involved digestion and conversion of organic nitrogen in the soil into ammonia (NH_4+). The digestion mixture consisted of 10 ml sulphuric acid (H_2SO_4) and sodium sulphate (Na_2SO_4) which increases the temperature of digestion to about 350°C. A selenium catalyst was then added so as to promote oxidation of organic matter by the sulphuric acid. A scalar SANPLUS Segmented Flow Analyzer 4000 was then used to automatically read the concentrations of N in the samples at 660 nm. In this method, total soil nitrogen was determined except inorganic nitrogen in the form of nitrate (NO_3-) and nitrite (NO_2-) (Okalebo *et al.*, 2002). Percent total nitrogen (%N) was calculated using equation 4.2 as follows:

$$\%N = \frac{(vs - vb)\ x100}{w x 10{,}000} \qquad \textit{(Equation 3.11)}$$

Where *vs* = concentration of N in the sample digest (ppm); *vb* = concentration of N in the blank digest (ppm); *w* = weight of soil sample taken for digestion; 10, 000 = conversion factor for ppm to percent.

Available Phosphorus, Potassium and Calcium

Macronutrients of phosphorus, potassium and calcium were determined through a single extraction using the Mehlich Double Acid Method (Hydrochloric acid-Sulphuric acid extract) as described by Okalebo *et al.* (2002). The extracting solution was a mixture of 0.1N HCL and 0.025 NH_2SO_4. A mixture of 1:5 soil: extracting solution with activated charcoal was shaken for one hour and filtered by a medium speed filter paper. Concentration of phosphorus was then determined colorimetrically using VIS-NIR Spectrophotometer PU 8670. Potassium and calcium were determined using a Corning 400 flame photometer.

3.3.10 Data analysis

Determination of the treatment effects in respective experiments was carried out by subjecting data to analysis of variance (ANOVA) using MSTAT-C computer program (Bricker, 1990). Significant treatment means at $P \leq 0.05$ were then separated using Student-Newman-Keul's Test (S-N-K). Statistical analyses were conducted on the following data:

i) Nodulation and growth characteristics

ANOVA was conducted as a one-factor RCBD, factor being the treatments (legume species) for the following data: Number of nodules, dry matter (nodules, roots, shoots) and length (tap roots, lateral roots and shoots).

ii) Dry matter of forage legumes

ANOVA was conducted as a four-factor RCBD, factors being treatments (legume species), seasons, harvesting interval and height.

iii) *Litter yield*

ANOVA was conducted as a one-factor RCBD, factor being the treatments (legume species).

iv) Soil fertility

ANOVA was conducted as a two-factor RCBD, factors being treatments and time (beginning and end of experiment).

3.4 Legume integration into natural pastures

3.4.1 Experimental design and plot layout of grass/legume mixed pasture

Based on results from the legume screening studies, a grass and legume integration experiment was set up during the short rainy season in October, 2002, with the aim of integrating herbaceous Glycine and Siratro legumes into natural pasture. Later, during onset of the next long rainy season in March, 2003, it became prudent to integrate the erect and shrubby Stylo legume into the natural pasture to study and compare its performance with the two herbaceous legumes.

Therefore, another adjacent plot was enclosed to integrate Stylo into the natural pasture. In the two adjacent enclosures, the natural pasture was dominated by the grasses *Dichanthium insculpta*, *Digitaria macroblephara*, *Hyparrhenia filipendula*, *Themeda triandra* and the herbs *Indigofera spinosa* and *I. volkensii*.

The integration of Glycine and Siratro into the natural pasture was conducted in an enclosure measuring 34 x 62 m to keep away livestock and other large herbivores. Before laying out the experimental plots and treatment allocation, herbage in half of the enclosure was slashed to about 5 cm height using a sharp slasher. Herbage in the other half was burned with a back fire with the objective of studying the effect of burning on pasture production and soil properties. The experiment was set up in RCBD split-split plot in a 2 x 3 x 5 factorial arrangement replicated three times (Steel *et al.*, 1997). The factors considered were:

i) 2 defoliation heights (15 and 30 cm heights) as the main plots

ii) 3 harvesting intervals (2, 4 and 6 months) as the sub-plots

iii) 5 treatments as the sub-sub plots

During plot lay out, each replicate consisting of 30 plots was divided into two halves. Each half, consisting of 15 plots, was then randomly assigned to either a 15 or 30 cm defoliation height (thereby becoming two main plots). Each half was then sub-divided into three sub-plots in which the three harvesting intervals were then randomly assigned. Finally, each of the three subplots was again sub-divided into five smaller plots (sub-sub-plots) each measuring 3 x 4 m in which the five treatments were randomly assigned as follows:

i) Glycine monoculture

ii) Siratro monoculture

iii) Natural pasture (NP)

iv) NP + Glycine mixed pastures

v) NP + Siratro mixed pastures

The integration of Stylo into natural pastures was conducted in a 34 x 41 m enclosure where herbage was slashed before plot layout and treatment application. The experimental design was RCBD split-split plot in a 2 x 3 x 3 factorial arrangement replicated three times (Steel *et al.*, 1997). The factors considered were:

i) 2 defoliation intensities (15 and 30 cm heights) as main plots

ii) 3 harvesting intervals (2, 4 and 6 months) as sub-plots

iii) 3 treatments as sub-sub plots

As in the Glycine/Siratro enclosure, each replicate consisted of 30 plots in which half of them were assigned to either a 15 or 30 cm defoliation height, thereby becoming the main plots. Each of the main plots was then sub-divided into three sub-plots which were randomly assigned to any of the three harvesting intervals. Finally, each sub-plot was again subdivided into three smaller plots (sub-sub-plots) in which the three treatments were randomly assigned as follows:

i) Stylo monoculture

ii) Natural pasture (NP)

iii) NP + Stylo mixed pastures

The plots planted as monoculture stands were first dug to 15 cm depth, big soil clumps broken up and all vegetative material removed from the plots to form well prepared seed beds. Furrows of 5 cm depth and 20 cm apart were then made for sowing the seeds. In grass/legume mixed pasture plots, bands of 20 cm width were cleared of vegetation. After digging furrows of 10 cm depth along the bands, legume seeds were then sown into the furrows at a rate of 30 kg/ha at onset of the rains and covered with soil. After one month, grasses and weeds were sheared to ground level with a hand clipper as they had grown tall thereby shadowing the legume seedlings and so as to offer the legume seedlings time and space to establish in the natural pasture. Thereafter, the legume seedlings were allowed to establish for one rainfall season (see Plates 5, 6 and 7) before commencement of data collection. Weeding of plots was done regularly by uprooting and discarding the weeds.

Plate 5: Shrubby Stylo planted along bands dug in the natural pasture at the study site

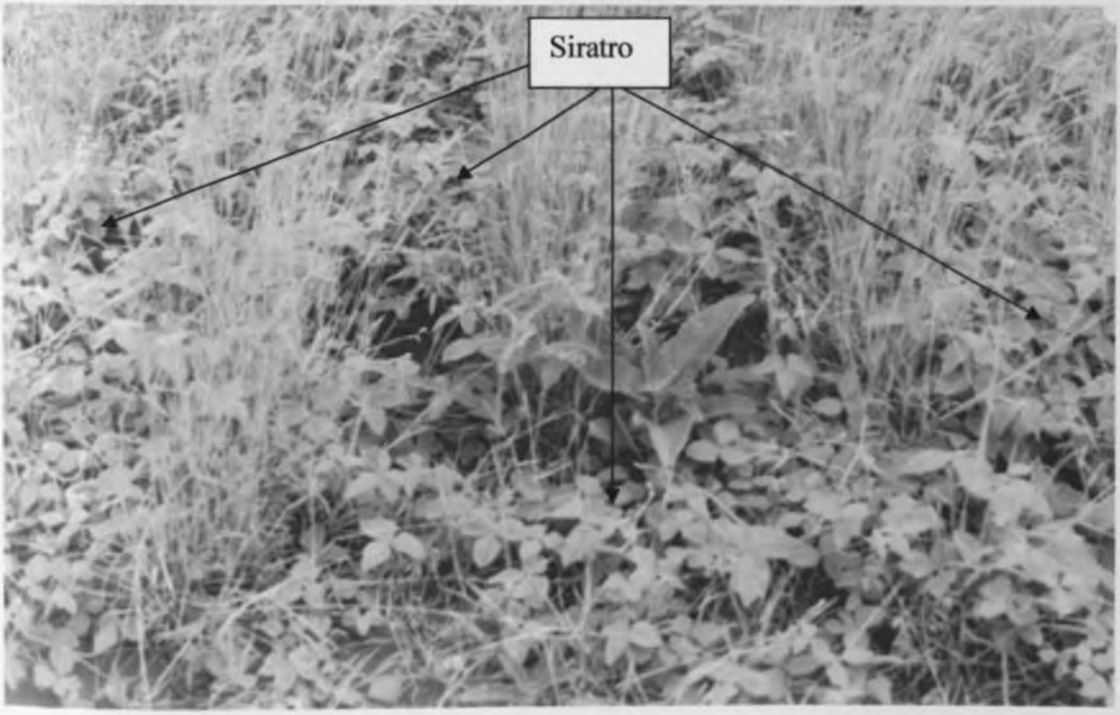


Plate 6: Siratro planted along bands dug in the natural pasture at the study site

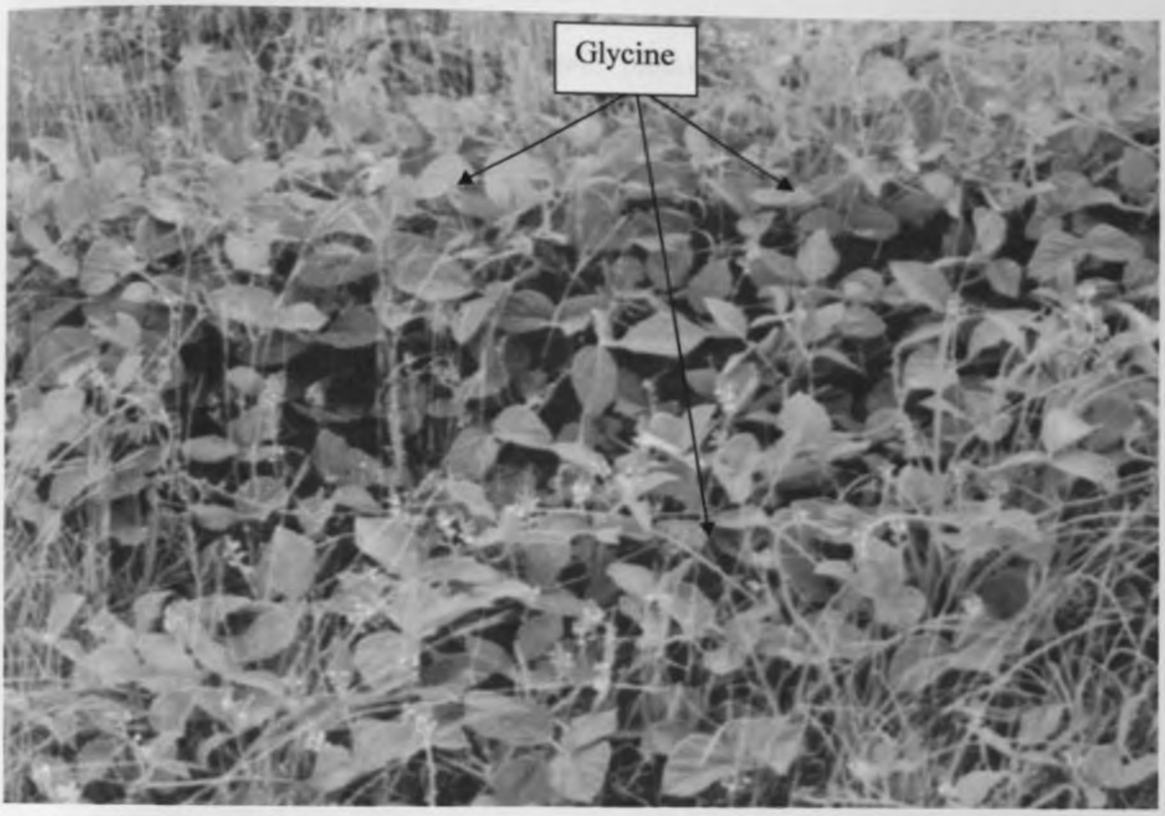


Plate 7: Glycine planted along bands dug in the natural pasture at the study site

3.4.2 Determination of dry matter production

Biomass data collection from Glycine and Siratro plots commenced in February 2003 (one season after planting) while collection of data from Stylo plots commenced in June 2003 (one season after planting). At each plot, a $1m^2$ quadrat area was marked to collect data for the entire period of the study. Plant materials were harvested using a hand clipper at the respective defoliation height (15 and 30 cm) and interval (i.e. after 2, 4 and 6 months). In mixed pastures, plant materials harvested were separated into grass and legume components. The plant samples (grasses and legumes) were later oven-dried at 105°C for 48 hours to determine dry matter weights which were converted into dry matter tonnes per hectare (t ha^{-1}) as described in Section 3.2.3.2.

3.4.3 Determination of forage quality

Plant samples were collected during the fourth season after planting by hand-plucking leafy material from each experimental plot. The first batch of samples was collected in April, 2004 when plants were at the vegetative stage of growth, i.e. before flowering. The second batch of samples was collected in May, 2004 when plants had flowered (especially grasses and Siratro). The third and last batch of samples were collected in July, 2004 when plants were at senescent stage (grasses were already drying). In the grass/legume mixed pastures, the samples were separated into grass and legume components. The purpose of sampling at three stages of plant growth was to compare the nutritive content of grasses and legumes at the three stages of growth. Thereafter, the samples were oven-dried at low temperatures of 60°C for 72 hours to prevent change of the original chemical composition (AOAC, 1995). After cooling, the plant material was ground and sieved in a 1 mm mesh and analyzed for crude protein, ash, *in-vitro* digestibility and fibre contents following methods described in Section 3.2.4.

3.4.4 *Determination of soil fertility*

3.4.4.1 Collection of soil samples

Prior to planting of Glycine and Siratro in the slashed and burned plots, soil samples were collected at 0-15 cm depth in November, 2002. The aim was to determine effect of burning herbage on soil chemical properties and compare the burning treatment with slashing treatment (the control). Three samples were collected from each plot, mixed and about 1 kilogram of composite soil taken for laboratory analysis. Sampling was replicated three times in both slashed and burned plots. A similar soil sampling procedure was conducted in Stylo plots before planting in April, 2003. In February, 2005, at end of the experiment, a similar batch of soil samples were collected at 0-15 cm depth from each plot for laboratory analysis.

3.4.4.2 Analysis of soil samples

All soil samples were analyzed at NARL and the following parameters determined; pH, organic carbon, nitrogen, phosphorus, potassium and calcium. The sample pre-treatment and analytical procedures followed those explained in Section 3.3.9 as described by Okalebo *et al.* (2002).

3.4.5 *Determination of soil moisture extraction*

Soil moisture content was determined between March and September, 2004, a period covering a short dry season, long rains and long dry season. Access tubes of PVC material were installed to 120 cm depth in plots where plants were harvested bimonthly at 15 cm height and replicated three times. The tubes were installed during the dry season using a soil auger, tops covered to prevent any entry of soil and water, and soil around the tubes allowed to settle for two weeks. Soil moisture content was read at an interval of 15 days using a Neutron Probe (Model CPN 503 DR Hydroprobe, see Plate 8) at 0-15, 15-30, 30-45, 45-60 and 60-90 cm interval depths.

At the start of reading soil moisture, a standard count rate (volumetric concentration of hydrogen nuclei in the air surrounding the neutron) was taken according to procedures described by IAEA (2001). Thereafter, the neutron detector was lowered into the access tubes for measurement of actual count rate at all the predetermined depth intervals. In addition to neutron probe measurements, a soil auger was used to collect another set of soil samples from each plot at depths that corresponded to depths for the neutron probe data collection. These soil samples were later oven-dried at 105°C to constant weight for gravimetric soil moisture content (weight/weight). The bulk densities of the soils (disturbed samples) were also determined in the laboratory. These data, in addition to the gravimetric soil moisture, were used in the calibration of the neutron probe. According to IAEA (2001), the neutron probe only measures slow neutrons thereby making it difficult to describe the interactions between slow neutrons and soils. Finally, a calibration curve was necessary to convert neutron counts to volumetric soil water content using the linear equation 3.12:

$$\Theta = a + b(\frac{R}{Rs}) \qquad \textit{(Equation 3.12)}$$

Where, Θ = the volumetric moisture content, a = the intercept; b = the slope; R= the actual count rate, R_s = the standard count rate, and R/R_s are the count ratio.

Plate 8: The Neutron Probe model used during soil moisture data collection

To conduct an analysis of variance of the volumetric soil moisture, data from three representative dates were selected. These were in March, 2004 (dry soil conditions), April 2004 (wet soil conditions) and in May 2004 (dry soil conditions). During the analysis of variance, soil moisture for 0-15 cm depth was not considered because of extremely low soil moisture values which were due to loss of neutrons to the atmosphere (IAEA, 2001).

3.4.6 Determination of best legume integration methods

3.4.6.1 Experimental design, plot layout and treatment allocation

The experiment was conducted in a 53 x 21 m enclosure using RCBD with a split-plot arrangement in 4 x 4 with three replications (Steel *et al.,* 1997). In the enclosure, a block measuring 17 x 21 m was subdivided into four main plots which were randomly allocated to Glycine, Siratro, Stylo and Rhynchosia legumes. The block was then replicated three times and in each replicate, the main plots were again sub-divided into four sub-plots which were 3 x 3 m in size. Each sub-plot was then randomly allocated to either of four legume integration methods namely; bands, furrows, raking or sowing. Legume seeds were sown at a rate of 30 kg/ha. The experimental plots had 1 m all round buffer paths while the replicates were 2 m apart. In each replicate, there were 16 treatment combinations as follows:

i)	Natural Pasture + Glycine x (bands, furrows, raking, sowing)	= 4
ii)	Natural Pasture + Siratro x (bands, furrows, raking, sowing)	= 4
iii)	Natural Pasture + Stylo x (bands, furrows, raking, sowing)	= 4
iv)	Natural Pasture + Rhynchosia x (bands, furrows, raking, sowing)	= 4

Land preparation and sowing of legumes using the four integration methods was conducted as follows:

Bands

These were 20 cm wide strips with an inter-row spacing of 20 cm which were dug in the natural pasture with a hoe and all vegetative material removed. In so doing, the dense fibrous roots of grasses along the bands were broken up by the digging implement. Furrows of 10 cm depth were then dug along the bands and legume seeds sown along the furrows and covered with soil.

Furrows

The furrows were dug in the natural pasture to 10 cm depth with an inter-row spacing of 20 cm. The legume seeds were sown in the furrows and covered with soil. One advantage of furrows is that they were also used to control run-off while at the same time promoting soil moisture conservation.

Raking

The topsoil in the experimental plots was loosened through use of a metal rake which also formed small, shallow furrows. The legume seeds were then placed onto the furrows made at an inter-row spacing of 20 cm and seeds covered with soil.

Sowing

A well prepared seedbed was prepared through digging of the entire experimental plot to 15 cm depth, the big soil lumps broken up into an even surface and all vegetative material removed. The legume seeds were then planted into furrows of 10 cm deep and 20 cm apart and covered with soil. An equal seed mixture of *Cenchrus ciliaris*, *Chloris roxburghiana* and *Eragrostis* *superba* was sown in rows between the legume rows. The three grass species were some of the dominant grasses growing in the natural pasture at the study site. The seeds were sourced from Kiboko Range Research Station, about 45 km away. During planting, the grass and legume seeds were sown at the same time.

3.4.6.2 Determination of dry matter production of grass/legume mixed pastures

Data collection and determination of dry matter after every two months were conducted following methods described in Section 5.2.2

3.4.7 Data analysis

Analysis of variance (ANOVA) was conducted to determine the treatment effects in respective experiments using the MSTAT-C computer programme (Bricker, 1990). Significant treatment means were then separated at $P \leq 0.05$ using the Student-Newman-Keul's Test (S-N-K). The factors considered during analysis of variance for different experiments were as follows:

i) ANOVA on dry matter production was conducted using a 4-factor RCBD. The factors were treatments, height, interval and seasons.

ii) ANOVA on forage quality was conducted using a 3-factor RCBD. The factors were treatments, stage of growth and slash/burn effect.

iii) ANOVA on soil fertility of slashed/burned pasture was conducted using a 3-factor RCBD. The factors were treatments, beginning/end effect and slash/burn effect.

iv) ANOVA on soil fertility of grass/legume mixed pasture at beginning and end of experiment was conducted using a 2-factor RCBD. The factors were treatments and beginning/end effect.

v) ANOVA on soil moisture utilization was conducted using a 3-factor RCBD. The factors were treatments, depth and dates of sampling.

vi) ANOVA on effect of four legume integration methods on dry matter production of grass/legume mixed pastures was conducted using a 4-factor RCBD. The factors were methods, species, seasons and slash/burn effect.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This chapter provides results obtained after characterization of the study site in terms of soils, vegetation, dry matter production and nutritive quality of the herbaceous species. In Section 4.4 results obtained from the various experiments conducted to select best performing legumes are presented and discussed. In addition, the criteria used to select the best performing legumes for integration into natural pastures are discussed. Section 4.5 presents and discusses results obtained on legume establishment, dry matter production and nutritive content of grass/legume mixed pastures and the effect of the introduced legumes on soil fertility and soil moisture extraction by grasses and legumes in mixed pastures. Results on best legume integration methods are also presented and discussed.

4.2 Characteristics of the study site

4.2.1 Soils and physiography

The results of field soil profile description and laboratory soil analysis are presented in Table 2 and Appendix 1. The soils were well drained, very deep, dark reddish brown, friable clay to clay loam. The soil pH ranged from 4.9 to 5.5 which is categorized as acid to slightly acid (Landon, 1984). On the basis of laboratory analytical data and soil profile description, the soils of the study site were classified as Ferral-Haplic Lixisol (FAO, 1997). The physiographic unit of the site was an Erosional Plain with soils developed from various gneisses (Touber, 1983; Waruru, 2000). The general relief of the study site was gently undulating with a slope of 3%. The site had a heavy infestation of termite mounds to the magnitude of 208 mounds per km^2 which were likely to influence soil properties at the site.

Table 3: Physical and chemical characteristics of a soil profile pit dug at the study site

Horizon	Ah	Bt1	Bt2	Bt3
Depth (cm)	0-27	27-58	58-97	97-125
Sand (%)	39	39	45	37
Silt (%)	20	20	38	28
Clay (%)	41	41	17	35
Textural class	C	C	L	CL
pH-H_2O (1:2.5)	5.3	4.9	5.1	5.5
pH-KCL	4.8	4.7	4.9	5.6
EC (mmhos/cm)	0.05	0.05	0.06	1.40
C (%)	1.32	0.93	0.65	0.49
N (%)	0.17	0.13	0.11	0.11
CEC (me/100g)	11.1	9.4	9.2	7.8
Ca „	5.9	5.5	5.1	6.7
Mg „	2.8	2.5	2.3	2.0
K „	1.0	0.6	0.5	0.6
Na „	0.3	0.3	0.3	0.3
Sum „	10.0	8.9	8.2	9.6
Base Saturation (%)	90.09	94.68	89.13	123.08
ESP (%)	2.70	3.19	3.26	3.85

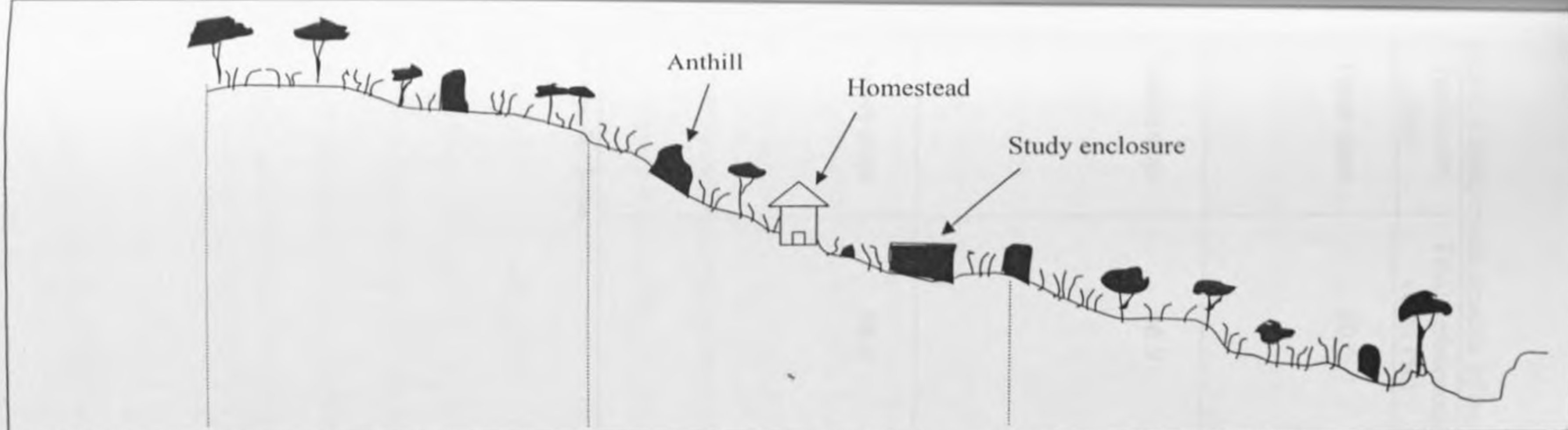
Ah = A horizon with an accumulation of organic matter; Bt1 = B horizon with silicate clay accumulation; Bt2 = B horizon with silicate clay accumulation; Bt3 = Argic B horizon with silicate clay horizon

4.2.2 Vegetation characteristics

4.2.2.1 Floristic characteristics of the natural pasture

The results of the inventory of all the woody (trees and shrubs) and herbaceous species encountered at the study site are presented in Appendix 2. The tree cover was estimated at 10% and the shrub cover 2% which resulted to the physiognomic class of wooded grassland. The dominant woody species was *Balanites glabra* Mildbr. & Schlecht while other scattered species present were *Acacia tortilis* (Forssk.) Hayne, *A. mellifera* (Vahl) Benth, *Lannea schweinfurthii* (Engl.) Engl. and *Commiphora campestris* Engl. A cross-sectional profile of the study site indicates that in the upper section of the hill, the woody species were dominated by shrubs while in the middle and lower sections, trees were dominant (Figure 4).

The number of herbaceous species increased as one moved from the upper section to the lower section of the hill (Figure 4 and Table 4). In addition, Table 4 shows the most common herbaceous species which had ≥2% cover. It can be noted that the lower section of the hill contained a higher number of herbaceous species and also the highest ground cover (68.2%) when compared with cover of the upper (50%) and middle (46.9%) sections of the transect. This may have been the reason why the farmer preserved the pasture in a fenced enclosure (*Olopololi*) to harvest and feed lactating cows, calves and sick animals left in the homestead after the other herd of livestock went away in search of pasture during the dry seasons.



SLOPE SECTION	Upper section	Middle section	Lower section	Dry river bed
COMMON WOODY SPECIES	Shrubby forms of *Balanites glabra, Acacia brevispica* and *Croton dichogamus.*	Tall forms of *Balanites glabra, Acacia tortilis, Acacia mellifera* and *Lannea stuhlmannii*. (Trees lopped to feed goats during dry seasons).	Tall forms of *Balanites glabra, Lannea stuhlmannii, Commiphora campestris, Acacia drepanolobium* and *Acacia seyal.*	
COMMON HERB SPECIES	*Dichanthium insculpta, Sporobolus pyramidalis, Digitaria macroblephara, Ipomoea kituiensis, Aloe secundiflora.*	*Dichanthium insculpta, Digitaria macroblephara, Indigofera spinosa, Hyparrhenia filipendula, Ipomoea kituiensis.*	*Hyparrhenia filipendula, Indigofera volkensii, Dichanthium insculpta, Themeda triandra, Indigofera spinosa, Digitaria macroblephara.*	
OTHER FEATURES	Abandoned Mica mine, Few anthills, Overgrazed.	Homestead, Overgrazed, Study enclosure, Many anthills, Livestock kraal.	Fenced *Olopololi*, Many anthills, Light grazing until dry season Fenced cultivated land.	

Figure 4: A diagrammatic cross-sectional profile of the study site

Table 4: Characteristic species of the herbaceous layer (≥2 % cover)

Position on slope	Total herbaceous cover (%)	Dominant species	Growth form	% Cover
Upper slope	50.0	*Dichanthium insculpta*	G	18.6
		Sporobolus pyramidalis	G	10.0
		Digitaria macroblephara	G	7.0
		Chloris roxburghiana	G	3.0
		Pennisetum mezianum	G	2.9
		Indigofera volkensii	D	2.6
Middle slope	46.9	*Dichanthium insculpta*	G	9.8
		Digitaria macroblephara	G	8.9
		Indigofera spinosa	D	6.2
		Hyparrhenia filipendula	G	5.0
		Chloris roxburghiana	G	3.6
		Pennisetum mezianum	G	3.0
		Indigofera volkensii	D	2.6
		Eragrostis superba	G	2.0
		Aristida keniensis	G	2.3
Lower slope	68.2	*Hyparrhenia filipendula*	G	16.0
		Indigofera volkensii	D	14.0
		Dichanthium insculpta	G	7.3
		Themeda triandra	G	6.0
		Indigofera spinosa	D	6.0
		Digitaria macroblephara	G	5.4
		Eragrostis superba	G	3.0
		Aristida keniensis	G	2.6
		Heteropogon contortus	G	2.1
		Harpachne schimperi	G	2.0

G = Grass; D = Dicot

During the study period, it was noted that the farmer on whose land the study was conducted pruned *Balanites glabra* during the dry season to feed sheep, goats and calves that had been left in the homestead. To fence the farm, homestead, livestock kraal and preserved pasture, the farmer used prunings from *Acacia tortilis*, *Acacia mellifera* and *Commiphora campestris*, which contributed to vegetation degradation.

4.2.2.2 Dry matter production of the herbaceous layer

The results showed that dry matter productivity of the grasses in the upper and middle transect sections were 6.18 and 6.13 t ha^{-1} yr^{-1}, respectively, yields which were not significantly ($P \geq 0.05$) different (Figure 5). Again, dry matter production of the dicots in the two sections was not significantly ($P \geq 0.05$) different. The dry matter productivity of the grasses in the lower transect section was 9.2 t ha^{-1} yr^{-1}, productivity which was significantly ($P \leq 0.05$) higher than that obtained in the upper and middle transect sections. In addition, dry matter production of the dicots was significantly ($P \geq 0.05$) higher than that obtained from the upper and middle transect sections. These results showed that total herbaceous cover and number of species increased as one moved down the slope from upper to middle and finally to lower section of the hill. Guretzky *et al.* (2004) reported a higher plant community composition and aboveground productivity at lower and less sloping positions of a slope gradient in Iowa, USA. The study attributed this topographic difference in plant community distribution to the spatial variations in soil water availability as related to soil depth and drainage patterns.

Dry matter production of the grasses in the upper, middle and lower transect sections were comparatively higher than those obtained by Wasonga *et al.* (2003) at Isinya, Kajiado District.

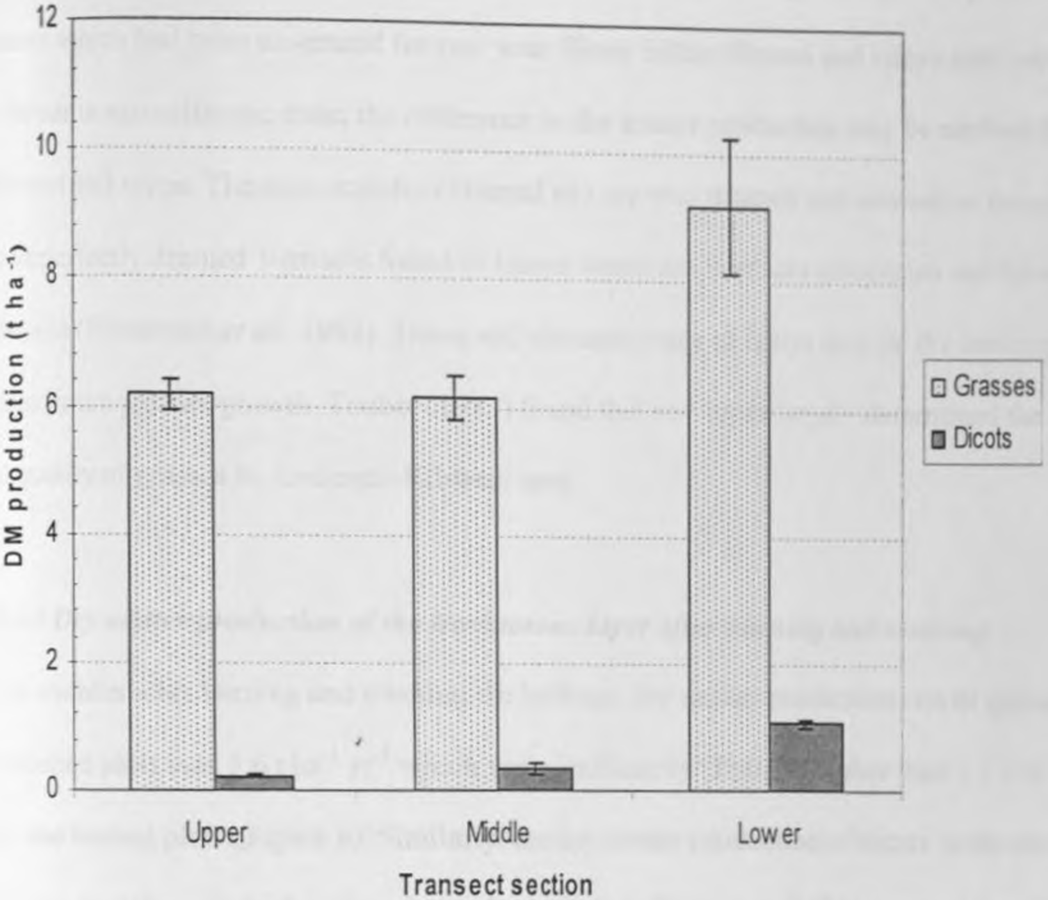


Figure 5: Dry matter production (t ha^{-1}) of the herbaceous layer at upper, middle and lower transect sections

The study obtained dry matter production rate of 3.1 t ha^{-1} yr^{-1} for grasses from a preserved pasture which had been un-grazed for one year. Since Sultan Hamud and Isinya sites are located in the same agro-climatic zone, the difference in dry matter production may be attributed to the different soil types. The soils at Sultan Hamud site are well drained and non-saline compared to the imperfectly drained Vertisols found at Isinya which are in places calcareous and have saline sub-soils (Sombroek *et al.*, 1982). These soil characteristics at Isinya may be the limiting factors to maximum pasture growth. Touber (1983) found that soil types largely determined the amount and quality of grasses in Amboseli-Kibwezi area.

4.2.2.3 Dry matter production of the herbaceous layer after burning and slashing

Three months after burning and slashing the herbage, dry matter production rate of grasses from the slashed plots was 5.6 t ha^{-1} yr^{-1} which was significantly ($P \leq 0.05$) higher than 3.3 t ha^{-1} yr^{-1} from the burned plots (Figure 6). Similarly, the dry matter production of dicots in the slashed plots was significantly higher than that in burned plots. Herlocker (1999) reported that grasses were generally less affected by fire due to the protected position of their growing points as compared to the dicots whose growing points are exposed.

The low dry matter production from burned plots may be explained by two reasons. First, fire may have killed or suppressed some grasses and dicots thereby making them not regenerate or making their recovery slow. Secondly, regeneration of grasses and dicots growing in the slashed plots may have occurred from many growing points located higher from the ground as compared to the fewer shoots that grew from grasses and dicots that had been burned to ground level.

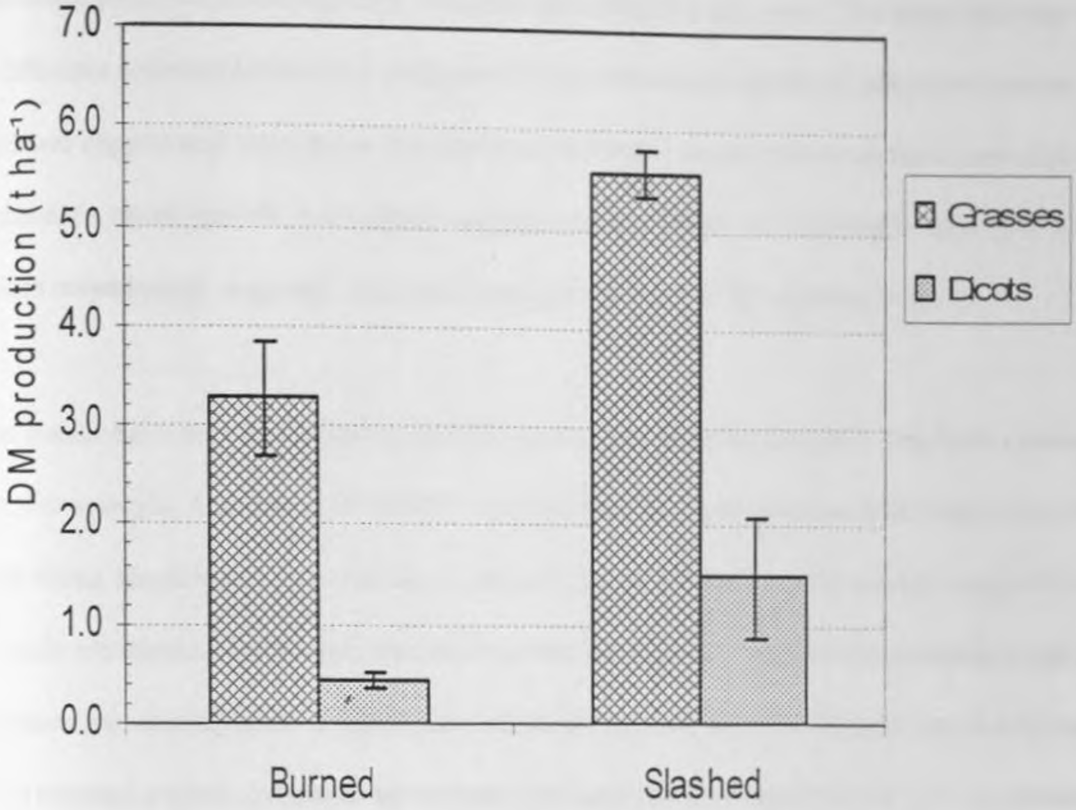


Figure 6: Dry matter production (t ha^{-1}) of the herbaceous layer after burning and slashing

These results are in conformity with those of Too (1985) who reported that dry matter production in unburned plots was twice as much that produced from burned plots. The study attributed this big difference between burned and unburned plots to the large amount of carryover material which was clipped and included in the unburned biomass compared to none from burned plots. Furthermore, the re-growth from unburned plots occurred from the clipping heights of 12.5 cm while in burned plots, regrowth occurred from ground level to the clipping height.

Other studies have reported higher grassland production from burned plots than from unburned plots. For example, Manson *et al.* (2007) reported that the moist grasslands of Drakensberg Park, South Africa, require frequent burning to remove old moribund material and encourage tillering. The study recommended frequent dormant-season burning of *T. triandra* to maintain a high tiller population and consequently a higher dry matter production. In India, Manoharan and Paliwal (1995) reported a mean annual above ground productivity of 6.8 and 6.0 t ha^{-1} yr^{-1} for burned and unburned plots, respectively. The amount of dry matter produced from burned pastures is dependent on the type of fire used and external morphology of grassland plants. Snyman (2003) found that the head fire had a greater flame height and rate of spread while the back fire had the highest intensity at ground level. The study noted that few months after the fire, the back fire had a larger impact on the vegetation than the head fire. Where there was sufficient fuel in form of dry grass, fire suppressed other vegetation types (unless they are fire tolerant) while favouring the growth of grasses (Herlocker, 1999).

4.2.2.4 Nutritive quality of some dominant herbaceous species

There were great variations in chemical composition of the different plant species sampled (Table5). All grasses had crude protein content below 7%, except *Cenchrus ciliaris* which had 8.1%. On the other hand, the legumes *N. wightii* and *R. malacophylla* recorded a crude protein content of 13.5 and 16.5%, respectively. According to Meissner *et al.* (2000), a minimum of between 7 and 8% crude protein content was required by ruminants to meet their feeding needs, but high producing animals (e.g. dairy cows) required levels approaching 13-14% crude protein content.

These results therefore show that the crude protein content of most grasses growing at the present study site fell below the minimum requirements for cattle, sheep and goats. The pasture legumes contained more crude protein than grasses, and thus adequately met the minimum requirements, even for requirements of dairy cows. Meissner *et al.* (2000) recommended that where crude protein content levels in forages were insufficient to meet the animal's requirements, protein needed to be supplemented. It therefore implies that animals that graze at the study site got protein supplementation from the herbaceous legumes and from leguminous *Acacia* species found there. Nyambati *et al.* (1996) reported that locally available leguminous trees found in the arid and semi-arid regions were important feed supplements to the poor quality roughages that were available to livestock, particularly during dry seasons.

Table 5: Nutritive quality of eight dominant grasses and two naturally growing legumes in the natural pasture at their flowering stage of growth

Species	CP (%)	Ash (%)	IVDMD (%)	NDF (%)	ADF (%)	ADL (%)
Grasses						
1. *Dichanthium insculpta*	3.9	12.4	42.4	63.8	39.2	4.3
2. *Hyparrhenia filipendula*	5.7	9.8	51.2	64.8	39.8	4.2
3. *Themeda triandra*	6.0	9.6	51.7	64.8	41.3	4.6
4. *Cenchrus ciliaris*	8.1	10.5	61.7	67.9	39.8	3.7
5. *Digitaria macroblephara*	5.6	9.2	59.6	65.1	41.7	5.0
6. *Eragrostis superba*	3.3	6.5	52.8	73.8	38.8	7.6
7. *Chloris roxburghiana*	5.1	8.5	44.2	74.8	39.3	6.7
8. *Pennisetum mezianum*	6.8	13.1	47.1	68.7	38.8	6.4
Legumes						
9. *Neonotonia wightii*	13.5	9.9	69.2	41.3	33.4	6.9
10. *Rhynchosia malacophylla*	16.5	7.7	50.8	42.0	41.7	5.4

CP = Crude Protein; IVDMD = *In-vitro* Dry Matter Digestibility; NDF = Neutral Detergent Fibre; ADF = Acid Detergent Fibre; ADL = Acid Detergent Lignin

Grasses and legumes had comparable ash content even though *D. insculpta, C. ciliaris* and *P. mezianum* had contents above 10%. These results are in conformity with those of Berhane *et al.* (2006) who reported ash contents of six grasses sampled from central Tigray, Ethiopia ranging between 6.1 to 10.5%. Legumes generally contain higher amounts of nitrogen, calcium, phosphorus, potassium and magnesium and lower amounts of sodium and chloride when compared with grasses (Meissner *et al.*, 2000). However, the mineral content of herbage is variable, and for some minerals, the contents vary within same species and between species. For example, the crude protein and ash contents of Silverleaf Desmodium were significantly ($P \leq 0.01$) higher in the leaves than the stem (Baloyi *et al.*, 2008).

Digestibility of forage is an estimate of the difference between amount of feed ingested by an animal and the amount excreted, expressed as percentage of feed eaten (Crowder and Chheda, 1982). Percent digestibility was highest for *N. wightii* at 69.2% while *D. insculpta* had least digestibility of 42.4%. These results are in conformity with those of Bekure *et al.* (1991) who reported that pastures in southern Kenya had an average digestibility of 54% for mature but green herbage during the growing season but with short-lived peaks of up to 65% in very young growth. Late in the dry season, digestibility fell to 46%. The study added that *in vitro* digestibility was closely correlated ($r = 0.86$) with the crude protein content and that the two factors were the main determinants of the nutritive value of range forage. Studies conducted by Muinga *et al.* (2006) showed that N was the major limitation to intake and digestibility of feeds in ruminants fed on poor quality basal diets.

4.3 Land use and farming systems of Kajiado District

Most of Kajiado District (about 93%) lies in semi-arid and arid zones (agro-climatic zones V and VI) and only 7% of the district's land which lies in agro-climatic zone IV has some potential for rain fed cropping (Ojwang' *et al.*, 2006). Approximately 95% of the people living in the district are semi-nomadic pastoralists who keep large herds of livestock as their main source of livelihood (Plate 9). The dominant cattle are the indigenous Zebu, but the number of exotic and improved breeds mainly Sahiwal, Boran and their crosses are on the increase (ASAL, 1998). The major sheep breeds are Red Maasai, black headed Persian and Dorper while major goat breeds are Galla and the Small East African goat. Donkeys are many and are mainly used as pack animals to ferry firewood, goods and water. Bee-keeping and poultry production are also undertaken. Camels were introduced into the district in 1998 from the northern districts of Kenya on an experimentation basis but their population had declined from 1,290 to 660 within two years (Ojwang' *et al.*, 2006). Unfamiliar habitats, deaths and sale of the camels may have contributed to this rapid decline.

The dominant livestock production units in the district have been individual and group ranches. The group ranch boundaries were demarcated in the 1960's with help from Kenya Livestock Development Programme (KLDP) which was a project of the World Bank (ASAL, 1990). The first group ranch was registered in 1968 but the programme collapsed in 1982 due to non-fulfillment of set objectives, continued registration of members, envy of the success of individual ranchers and change in government land policies. Up to 1990, the group ranches had been sub-divided into individual parcels of land, and depending on membership numbers, 37.3% of

Plate 9: A herd of cattle on the way to a watering point in Kajiado District

farmers got land measuring between 50 and 99 ha each, 23.5% got 49 ha each, 21.6% got 100-149 ha each, 13.7% got between 150 and 199 ha each and lastly, 3.9% got more than 200 ha of land each (Rutten, 1992).

Although land has been sub-divided, livestock are still herded on the natural free range even across individual land. The bimodal and unreliable distribution of rainfall received in the area does not guarantee year round pasture availability, and therefore farmers try to maximize utilization of pastures during the short and long rainfall seasons when there is abundant herbage. This high grazing pressure exerted on natural pastures results in overgrazing in some areas, and when dry seasons set in, livestock are moved (save for calves, sick and lactating cows) to other areas in search of pasture and water, sometimes to very far away places like in coastal lowlands, Nairobi, Mt. Kilimanjaro, Chyulu hills and swamp margins of Amboseli (Campbell, 2003). During the wet seasons, livestock disperse as the resources are ample and widespread. This practice usually encounters problems (sometimes serious conflicts) because of individualization of land and changes in land use, specifically the growing of maize and beans by some farmers on acreages between 2 and 10 ha (ASAL, 1998).

The Maasai community used to reserve areas for dry season grazing before sub-division of communal lands into individual land parcels (Ojwang' *et al.,* 2006). With advent of ranch sub-division, allocation of land to individuals and development of private water pans, reserved dry season grazing areas have become almost non-existent. Currently, preserved pasture areas (about 3-5 ha) are only limited to enclosed portions of preserved pasture known as *Olopololi* in Maasai language which are located near homesteads (Plate10). These enclosures are controlled by

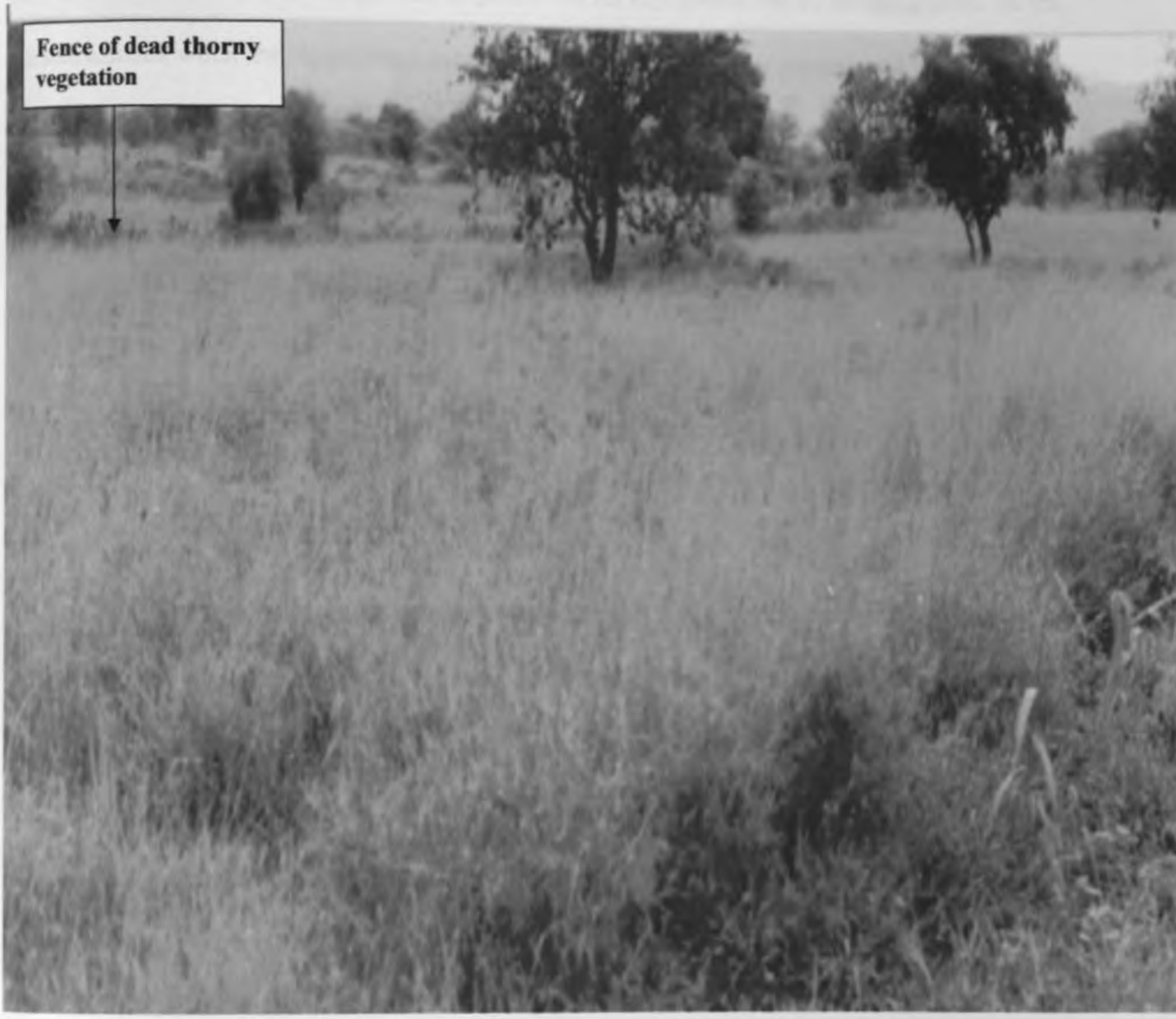


Plate 10: Pasture preserved in *Olopololi* for utilization during the dry season

individual households where the pasture is preserved for dry season use by lactating cows, calves and sick animals when the bigger herd moves away in search of better pasture and water. The preserved pasture in *Olopololi* is usually not enough and by the time it is to be utilized, it is mature and dry, hence of low quality. The district was therefore an ideal area to conduct the study with a view of improving the livestock feed through introduction of forage legumes into natural pastures.

4.4 Legume screening

4.4.1 Seed germination

Seeds of Dolichos and Velvet bean (large seeded legumes) had a better germination than seeds of Glycine, Siratro, Stylo and Rhynchosia (small seeded legumes) (Table 6). In addition, over 50 % of legume seeds germinated by the third day while grass seeds were slow because by the fifth day, only 40 % had germinated. Even though Glycine and Siratro had comparable size of seeds and similar growth habit, Siratro had a better percent germination (more than double) than Glycine, results which could be attributed to amount of hard seeds in each legume type. Skerman *et al.* (1988) reported that Siratro and Glycine have a minimum of 40 and 70 % hard seeds, respectively, which required pre-treatment such as mechanical scarification to break dormancy if uniform germination was required during pasture establishment.

Table 6: Percent seed germination of experimental legumes, dominant grasses and a locally growing herbaceous legume

Species	Seed germination (%)
Legumes	
1. Glycine	25
2. Siratro	60
3. Stylo	70
4. Dolichos	95
5. Velvet bean	85
Grasses	
6. Horsetail grass	16
7. African Foxtail grass	19
8. Maasai Love grass	10
Local legume	
9. Rhynchosia	10

The locally growing herbaceous legume (Rhynchosia) had least germination of 10% as compared to the introduced legumes. It should be noted that the seeds of this legume were harvested from the natural pasture at the study site. The legume's low percentage germination was in agreement with Crowder and Chheda (1982) who reported that seeds harvested from local species may have low germination rates.

4.4.2 *Nodulation and growth characteristics in potted experiment*

All legume species, except Dolichos, had nodules which contained a distinctive pink coloration: an indicator that they were fixing atmospheric nitrogen (Table 7). Skerman *et al*. (1988) reported that a distinctive pink colour in legume nodules provided a quick indication of fixation of atmospheric nitrogen by the legumes. The authors further stated that in a few instances, an old nodule may have a green area indicating previous hemoglobin and thus effective nodulation as was the case with Dolichos in the current study. It can thus be concluded that Dolichos may also have been fixing nitrogen as witnessed from the dark-green coloration that was observed. The interiors of active nodules (those fixing N) are pink to deep red in colour, changing to green as the nodules decay (Wassermann *et al*., 2000). Ineffective nodules appeared translucent or white inside, as was the case with some Siratro and Velvet bean nodules that were observed in the current study.

The average number of nodules between legume plants was significantly ($P \leq 0.05$) different with the highest number in Siratro and the least in Velvet bean. The dry matter of nodules was also significantly ($P \leq 0.05$) different between species, where the nodules of Velvet bean (due to their large size) had the highest dry matter followed by those of Dolichos and Siratro. In Chuka, Meru

South District, Mugwe *et al.* (2007) reported that Velvet bean had a mean of 6 nodules with size close to a maize seed. However, in the cool highlands of Timboroa in Uasin Gishu District, Dolichos and Velvet bean did not nodulate 75 days after planting (Mureithi *et al.*, 2006). The study attributed lack of nodulation and hence lack of N fixation to the acidic soils (pH 4.3) which may have resulted in P fixation. The study recommended that the only way to improve soil N in those cool highlands was to use the legumes as green manure. The study by Mugwe *et al.* (2007) concluded that poor nodulation could be due to soil acidity, low soil pH levels and possibly lack of adequate indigenous rhizobia.

In the current study, even though Glycine and Stylo had an average number of 16 and 13 nodules per plant, respectively, their dry matter was very small because the nodules were very minute. The results further indicated that the annual legumes (Velvet bean and Dolichos) had significantly ($P \leq 0.05$) higher root dry matter than the perennial legumes (Glycine, Siratro and Stylo). It was also noted that Velvet bean and Dolichos possessed shorter tap roots but more lateral roots (hence more root mass) than Glycine, Siratro and Stylo which possessed longer tap roots but less root mass.

Table 7: Nodulation and growth characteristics of experimental legumes grown in pots

Legume	Nodule colour	Nodule number	Nodule DM (g)	Roots DM (g)	Shoots DM (g)	Tap root length (cm)	Lateral roots length (cm)	Shoot length (cm)
Glycine	Pink	16±1	0.02± 0.10	1.07± 0.40	1.85± 0.62	37.00± 9.06	24.90± 2.18	24.23± 7.89
Siratro	Pink, black, white	38± 2	0.26± 0.06	2.30± 0.59	2.52± 0.66	28.00± 3.72	25.33± 1.36	6.67± 0.49
Stylo	Pink	13± 7	0.01± 0.01	0.46± 0.18	0.86± 0.31	44.10± 4.54	30.33± 1.93	12.20± 2.97
Dolichos	Dark green	14±2	0.48± 0.18	3.14± 0.38	6.34± 0.78	29.80± 2.63	29.00± 2.18	11.20± 0.95
Velvet bean	Pink, white, brown	4±1	0.66± 0.23	4.32± 0.88	11.48± 1.39	28.57± 0.59	22.43± 0.87	41.43± 4.08
CV (%)		40.0	86.01	39.63	32.21	28.27	13.89	36.30

DM = dry matter

4.4.3 Rooting characteristics of experimental legumes under field conditions

Five months after planting, Glycine, Siratro and Stylo (the perennial legumes) had developed tap roots and some lateral roots up to depths of 80, 95 and 85 cm, respectively (Table 8). On the other hand, Dolichos and Velvet bean (the annual legumes) possessed tap roots of 30 and 60 cm, respectively. Most lateral roots of the annual legumes were located between 0 and 15 cm depth. The indigenous legume *Rhynchosia* which was excavated from the natural pasture had a relatively thicker tap root of 100 cm length as compared to the other legumes that had thin tap roots. However, it was not possible to determine how long the legume had grown in the natural pasture. *Chloris roxburghiana* and *Themeda triandra* grasses which were also excavated from the natural pasture had a fibrous root system with most roots (about 75 %) concentrated between 0-30 cm depth. A few roots (about 15 %) were located between 70 and 80 cm depths.

These results indicate that annual legumes and grasses possessed the bulk of their lateral and fibrous roots, respectively, near the soil surface where they could maximally utilize soil moisture after a light shower of rainfall. Even though the perennial legumes possessed little root mass (as shown in section 4.4.2), they were capable of sourcing soil moisture located in deep soil horizons. There is evidence that the deep penetrating roots are more efficient per unit weight of root than are the surface roots in accessing soil water (Snyman, 2005).

Table 8: Rooting characteristics of experimental legumes, some common grasses and a naturally growing (indigenous) legume at the study site

Species	Growth habit	Rooting pattern	Rooting depth (cm)
Legumes			
Glycine	Herbaceous perennial legume	Tap root with few lateral roots located up to 60 cm	80
Siratro	Herbaceous perennial legume	Tap root with few lateral roots located in the 0-15 cm soil depth	95
Stylo	Erect shrubby perennial legume	Tap root with lateral roots spread evenly along the tap root	85
Dolichos	Twining herbaceous annual legume	Tap root with lateral roots located in the 0-15 cm soil depth	30
Velvet bean	Long-lived annual legume	Thick tap root with lateral roots located in the 0-15 cm soil depth	60
Rhynchosia	Herbaceous perennial legume	Thick tap root with 2 lateral roots located in the 15-20 cm soil depth	100
Grasses			
Horsetail grass	Tufted perennial grass	Fibrous roots which about 75 % are concentrated in the 0-30 cm soil depth	70
Red Oat grass	Tufted perennial grass	Fibrous roots which about 75 % are concentrated in the 0-30 cm soil depth	80

The deep rooting characteristics of the perennial legumes implied that they had a better ability than the annual plants to source soil moisture and nutrients from deep soil horizons. Legumes are dicotyledonous plants with a typical tap-root system which branches into lateral roots to a greater or lesser extent depending on species (Wassermann *et al.*, 2000). The authors indicated that in some species like Lucerne, the tap root can be several meters long, while in others like White Clover, the tap root may be no longer than 40 cm while most annual legumes developed a shallow branching tap root system. A shallow rooted species such as White Clover is intolerant to drought and cannot effectively control transpiration which leads to early leaf wilting and senescence (Skinner *et al.* 2004). However, the Kentucky bluegrass survives severe drought by becoming dormant during the dry period. In addition, unlike the perennial Clover species, the prostrate to semi-upright stems produced from primary stems do not root from the nodes to develop a secondary root system and therefore, the plants die when the primary root system dies at onset of the dry season (Wassermann *et al.*, 2000).

These results are in agreement with Wolfson and Tainton (2000) who reported that more than 85% of the root mass in grasses was found in the top 15 cm of the soil. At Kedong, Kajiado District, more than half of the total root volume of grasses was located at the top 20 cm of the soil (Boonman, 1993). However, the proportions were found to change considerably during the season. The study by Boonman (1993) further reported that the drought tolerant *Themeda triandra* had 73 and 15 % of its root dry matter located at 0-20 and 20-40 cm depth, respectively, while *Eragrostis superba* had 74 and 18 % of its root dry matter located at 0-20 and 20-40 cm depths, respectively. The study noted that a heavy concentration of roots at the soil surface enabled grass species to make fullest use of light showers of rain while they easily desiccated at onset of the dry season. Both *T. triandra* and *E. superba* grass species were also dominant species at the current study site and their root distribution was almost similar with that obtained at Kedong. Prasad (1995) on root development of *Andropogon gayanus* Kunth, *A. pumilus* Roxb and *Pennisetum pedicellatum* Trin perennial grasses in Kanke, India , found that majority of the roots (67-79%) were located within 0-10 cm soil depth, while 20-22% were located within 10-20 cm and very few (1-11%) were located below 20 cm soil depth. These results were closely similar with results of root distribution of grasses at the current study site where majority (about 75%) of grass roots were located in the 0-30 cm soil depth.

4.4.4 Dry matter production of experimental legumes

The effect of harvesting legumes at two intervals and two heights produced significantly ($P \leq 0.05$) different dry matter amounts (Table 9). Further, dry matter production of Glycine, Siratro and Stylo was significantly ($P \leq 0.05$) higher than that of Dolichos and Velvet bean. Glycine and Siratro produced highest dry matter rate of 10.31 and 7.81 t ha^{-1} yr^{-1}, respectively, when harvested after two months at ground level while Stylo produced highest dry matter rate (3.52 t ha^{-1} yr^{-1}) when harvested after four months at 15 cm height.

After harvesting, Glycine, Siratro and Stylo had vegetative regrowth from crown buds located below the soil surface and from other buds located on aerial stems. Once the primary stem was clipped at first harvest, more stems developed which later ramified into more stems and branches. This phenomenon was responsible for the high dry matter production from the three legumes. Wassermann *et al.* (2000) reported that as stems of upright perennial legumes mature, their bases become thickened and woody, thereby forming a crown which is comprised of thick and short lengths of basal stem material.

Dolichos and Velvet bean produced very low dry matter because after their clipping at ground level, they were unable to regenerate because they did not possess crown and aerial growth buds for production of secondary stems. When clipped at 15 cm height, very little regrowth occurred from the terminal growing points of Dolichos and Velvet bean. Even though Glycine and Siratro had the same prostrate growth habit, Glycine had a slower establishment after germination, but the species eventually produced more ($P \leq 0.05$) dry matter than Siratro at ground level. This was attributed to Glycine producing 14 stems per plant with the longest stem reaching 2.55 m length after only two seasons of growth while Siratro produced three stems per plant with the longest stem reaching 1.85 m in length.

Glycine harvested after two months at ground level, produced 10.31 t ha^{-1} yr^{-1}, but this declined significantly ($P \leq 0.05$) to 7.53 t ha^{-1} yr^{-1} when harvested after four months. Siratro had significantly ($P \leq 0.05$) higher dry matter rate of 7.81 t ha^{-1} yr^{-1} at the two months harvest interval but this significantly ($P \leq 0.05$) decreased to 3.58 t ha^{-1} yr^{-1} at the four months harvest interval. Dry matter production for Stylo at the two and four months harvest intervals was not significantly ($P \geq 0.05$) different. The dry matter produced at the four months interval (3.52 t ha^{-1} yr^{-1}) was slightly higher than that of two months interval (3.27 t ha^{-1} yr^{-1}).

Table 9: Effect of harvesting interval and height on legume dry matter production rate (t ha^{-1} yr^{-1}) during screening phase

Forage legumes	Harvesting interval	Harvesting height	
		Ground level	15 cm above ground
Glycine	2	10.31± 1.02	8.07± 1.00
Glycine	4	7.53± 1.14	8.52± 1.34
Siratro	2	7.81± 1.34	4.01± 0.42
Siratro	4	3.58± 0.49	3.31± 0.64
Stylo	2	1.57± 0.63	3.27± 0.45
Stylo	4	2.38± 0.53	3.52± 0.32
Dolichos	2	0.0± 0.00	2.48± 0.55
Dolichos	4	0.0± 0.00	0.90± 0.23
Velvet bean	2	0.0± 0.00	1.91± 0.36
Velvet bean	4	0.0± 0.00	0.68± 0.19

Frequently harvested legumes resulted in higher dry matter production due to production of more secondary stems after the primary stems were clipped. Njunie *et al*. (1996) evaluated the effect of harvesting frequencies on herbaceous legumes at Mtwapa in the coastal lowlands of Kenya and found that plots harvested four times per year gave the highest cumulative dry matter production while the least was when the legumes were clipped once per year. Studies conducted by Gachene and Makau (1997) found that a three months harvesting interval produced the highest biomass for most species during the long rainy season. Only Velvet bean, Dolichos, Jack bean, and Siratro persisted into the 6 months harvesting interval. These results showed that a harvesting interval of between two and three months was likely to produce higher dry matter from forage legumes in a 'cut and carry' livestock feeding system than from a longer harvesting interval.

Other studies in Kenya and Ghana showed a lower dry matter production by legumes used in the current study as shown in Table 10. These variances in dry matter production from site to site are attributed to amount of rainfall received at a particular site (Barnes and Addo-Kwafo, 1996; Gachene and Makau, 1997), presence or absence of native *Rhizobia* (Mureithi *et al*., 1998; Mugwe *et al.* (2007)) and levels of soil fertility (Miles and Manson, 2000).

Table 10: Comparative dry matter production rate (t ha^{-1} yr^{-1}) of experimental legumes harvested bimonthly at 15 cm height from different sites in Kenya and Ghana

Experimental site	Elevation (m a.s.l.)	Rainfall (mm)	Experimental legumes					Source
			Glycine	Siratro	Stylo	Dolichos	Velvet bean	
Sultan Hamud	1,280	670	8.1	4.0	3.3	2.5	1.9	Current study
Matanya	1,842	600	5.7	Np	Np	1.3	0.7	Mureithi *et al.* (1998)
Katumani	1,600	717	Np	2.4	1.2	Np	Np	Njarui and Wandera (1997)
Mtwapa	15	1,200	Np	2.5	Np	2.1	0.7	Mureithi *et al.* (1998)
Gachoka	1,070	950	0.5	Np	0.4	0.8	0.8	Gitari *et al.* (1997)
Pokoase (Ghana)	152	1,050	2.2	2.3	3.1	2.9	Np	Barnes and Addo-Kwafo, 1996

Np = Not planted

4.4.5 *Litter production*

The litter production of perennial legumes, namely Stylo, Siratro and Glycine were 141, 140 and 106 g m^2, respectively, and were not significantly ($P \geq 0.05$) different (Figure 7). On the other hand, the litter production of annual legumes, namely Velvet bean and Dolichos were 39 and 30 g m^2, respectively, and were not significantly ($P \geq 0.05$) different. However, the litter produced by the perennials was significantly ($P \leq 0.05$) different from that of the annuals, except that for Glycine. These results indicate that, even though Stylo is small-leaved in comparison to Siratro and Glycine, it was capable of shedding large quantities of leaves and other materials and still survive the dry season in a deciduous state.

Njunie *et al.* (1996) conducted a litter drop study at coastal KARI-Mtwapa Research Station for 18 herbaceous legumes and obsérved that half of the legumes started to drop litter three months after planting and obtained significant ($P \leq 0.05$) litter fall differences. It was noted that Dolichos dropped more litter than Siratro, and their results were different from those obtained in the current study, where Siratro had significantly ($P \leq 0.05$) higher litter drop than Dolichos five months after planting. The difference in results obtained at Mtwapa and the current study site could be explained by the fact that at the end of three months, Dolichos being an annual shedded its leaves before the perennial Siratro which had a longer growing period. Njunie *et al.* (1996) found that *M. lathyroides* (L.) Urb, *L. purpureus* and *M. atropurpureum* had the potential to improve soil fertility through litter fall. The study concluded that though the trait of litter shedding was undesirable for farmers growing forages for feeding livestock, the legumes were capable of improving soil organic matter content by providing litter mulch *in situ* and hence improving soil fertility

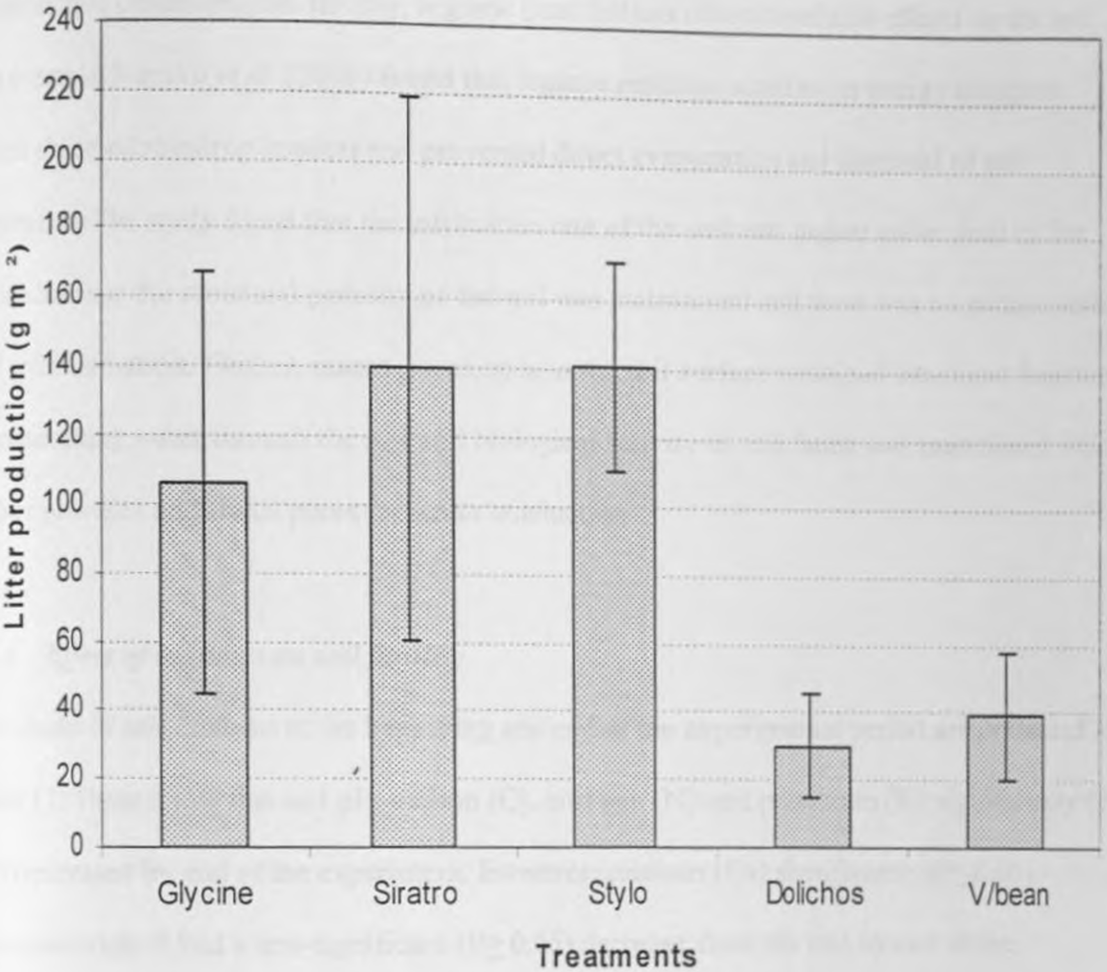


Figure 7: Litter production (g m^2) of experimental legumes at peak of the long dry season

In addition to enhancing soil fertility, legume litter fall has other beneficial effects on the soil. For example, Karuku *et al.* (2006) found that legume residues acted as an energy dissipater which absorbed raindrop impacts and prevented direct evaporation and dispersal of soil aggregates. The study found that the infiltration rate of the soil was higher under dead or live mulch because the structural porosity of the soil was maintained and there was no surface sealing and crust formation. Further, macro-pores open to the soil surface remained intact and functional in transmitting water through the soil and biological activity of soil fauna was maintained which further provided additional pores for water conduction.

4.4.6 Effect of legumes on soil fertility

The results of soil analysis at the beginning and end of the experimental period are presented in Table 11. These show that soil pH, carbon (C), nitrogen (N) and potassium (K) significantly ($P \leq 0.05$) increased by end of the experiment. However, calcium (Ca) significantly ($P \leq 0.05$) decreased while P had a non-significant ($P \geq 0.05$) decrease from the soil by end of the experiment.

A similar trend was observed by Nzabi *et al.* (2000) after addition of maize + soybean residues at Nyamonyo, Kisii District. The study found that in plots where maize and soybean residues were added to the soil, the pH increased from 4.6 to 5.2 while organic C increased from 2.02 to 2.49%, N from 0.19 to 0.23% and K from 0.72 to 0.78%. Mureithi *et al.* (2000) also found that, addition of mulch from legume residues to the soil increased P and K by 32 and 48%, respectively, in Gatanga area in central Kenya.

Table 11: Effect of legumes on soil fertility during legume screening phase

Period	pH (H_2O)	C (%)	N (%)	P (ppm)	K (me %)	Ca (me %)
Beginning	4.92± 0.08	1.17± 0.04	0.17± 0.01	178.8± 3.81	1.23± 0.04	7.97± 0.67
End	5.36± 0.03	2.57± 0.09	0.22± 0.01	177.0± 3.03	1.68± 0.34	4.50± 0.15
Cv (%)	3.92	15.65	18.00	7.59	9.24	30.74

The pH increase in the soil at end of the experiment was attributed to addition of organic residues from legume plants. A study by Bationo (2008) in Sadore, Niger reported that in unmulched control plots the pH level was 4.3, but in plots where crop residues were added, the pH increased to 4.7 over 14 years. Even though the soil pH in the current study increased to 5.36 by end of the current experiment, the values still fell under soils classified as acid soils (pH<5.5) (Landon, 1984). For majority of crops, the most suitable soil pH is in the range of 5.5 to 7.0 with certain tolerance to more acid or slightly alkaline conditions (Muriuki and Qureshi, 2001). For example, maize has a pH tolerance of 5.0 to 8.0 and paddy rice 4.0 to 8.0 (Landon, 1984). In acid soils, availability of Mg, Ca, P and Mo limits plant growth, but as pH level is raised, these nutrients become available for plant uptake (Muriuki and Qureshi, 2001). This may have been the reason why P and Ca decreased from the soil by end of the experiment after being taken up by legume plants. In addition, as organic residues decomposed and mineralization occurred, major elements like N, P and C are released due to increased soil microbial activities which are activated by more favourable pH conditions after an initial N immobilization by soil microorganisms (Giller and Wilson, 1991).

The increase of soil organic C by end of the current study was also attributed to addition of organic residues by the legumes in form of litter drops and from the decay of below ground biomass. Several studies have made similar observations (Bationo *et al.*, 1995; Mureithi *et al.*, 2000; Nzabi *et al.*, 2000). Rutunga *et al.* (2001) also reported that only 30% of leaves, stems and roots of *Tephrosia vogelii* Hook F. and *Tithonia diversifolia* (Hemsley) A. Gray remained undecomposed after eight months of incubation, thereby releasing nutrients. The study concluded that decomposition and nutrient release patterns were influenced by quality of the material, in particular the N content, lignin and polyphenols. Crespo *et al.* (2005) also reported that litter from *Desmodium ovalifolium* and *Stylosanthes guianensis* legumes decomposed after six months whereas *Pueraria phaseoloides*, *Neonotonia wightii* and *Macroptilium atropurpureum* decomposed after seven months. However, litter decomposition was slow in *Cynodon nlemfuensis*, *Panicum maximum* and *Brachiaria decumbens* grasses because after one year, there was still 30, 15 and 10 %, respectively, of the original litter material which remained undecomposed. This was attributed to the high lignin content in grasses as compared to legumes (Crespo *et al.*, 2005).

Legumes contain large amounts of N (Lascano and Peters, 2007) which upon decomposition may have become available, resulting in a significant ($P \leq 0.05$) increase in the soil by end of the experiment. The main source of available N in natural pastures was from soil organic matter (after mineralization) for growth of unimproved grasslands (Giller and Wilson, 1991). However, in improved pastures containing nodulated legumes, soil N was supplemented by N fixed by the legume-*Rhizobium* symbiosis. The authors reported that fixed N was first utilized for growth of legume plants and later contributed to growth of other plants in the pasture, after decomposition and mineralization of legume residues. Njarui and Mureithi (2006) reported that after incorporation of Lablab and Mucuna legume residues into the soil, the maize stover yield was 4.44 and 5.17 t ha^{-1}, respectively. In plots where incorporation was not done, the stover yield was 3.74 and 3.5 t ha^{-1}. The study concluded that N derived from legume residues was as effective as the inorganic N fertilizer in enhancing stover production.

The decrease in soil P by end of the experiment was attributed to P uptake by legumes. Phosphorus is required for growth and development of leguminous cover crops as it is critical for both nodulation (number and density of nodules) and nitrogen fixation in some legumes (Chemining'wa *et al.*, 2006). Bationo (2008) citing Hafner *et al.* (1992) reported that root length density and total P uptake increased from 3.4 kg ha^{-1} with no crop residue application to 10.6 kg P ha^{-1} after application of crop residues. However, once P contained in organic matter was released through mineralization into the soil, it can either be immobilized by soil micro-organisms and plants or become fixed in the soil (Rowell, 1994).

By end of the experiment, K significantly ($P \leq 0.05$) increased in the soil, an increase that may be attributed to the release of nutrients after decomposition and mineralization of the legume's organic residues. K was the next mineral element with a high concentration in plant parts after N and hence, large amounts are added to the soil after organic residues decompose (Rowell, 1994; Marschner, 1995). During mineralization of organic matter, there occurs a rapid release of K followed by slower releases of N, P and Ca (Thomas and Lascano, 1995). However, the release of N, K and Ca is usually greater in legume litter due to tenderness of legume leaves compared to the slow release from grasses due to their higher lignification (Thonnissen *et al.*, 2000).

Calcium content in the soil decreased significantly ($P \leq 0.05$) from 7.97% at the beginning to 4.50% by end of the experiment, a decrease of 44 %. A high demand of Ca for the growth of legume meristematic tissue and nodules may have led to a decrease of Ca from the soil. Muriuki and Qureshi (2001) reported that as soil pH is raised, Ca becomes more available for plant uptake. Ca is also among nutrients that are released during the initial period of litter decomposition (from 0 to 56 days) and may either be taken up by plants, immobilized in soil minerals or micro-organisms or lost by leaching (Rutunga *et al*., 2001).

4.4.7 Criteria for selection of legumes for integration into natural pastures

The legume screening study showed that Glycine, Siratro and Stylo performed well under the prevailing climatic and edaphic conditions of the semi-arid study site. Therefore, these species, qualified as potential forage legumes for integration into natural pastures of semi-arid rangelands for enhancement of livestock feed and soil fertility. The following were the criteria used for selection of the three forage legumes for integration into natural pastures.

i) Perennial growth habit

Glycine, Siratro and Stylo were able to survive the short and long dry seasons which occurred at the site and therefore were not planted every season as happened with the annuals (Dolichos and Velvet bean). The three legumes survived the dry seasons by becoming deciduous and regenerated well after onset of the rains. In this regard, the perennial growth habit of these forage legumes is an important attribute to farmers, since more often than not they will not prefer legumes which they have to plant every season.

ii) Possession of deep penetrating tap roots

The deep penetrating tap roots of Glycine, Siratro and Stylo were beneficial to the legumes in sourcing soil moisture and nutrients from deep soil horizons thus enabling the legumes to survive the dry seasons. This aspect may have enabled the legumes to remain green long into the dry season after grasses in the surrounding area became dry after their shallow rooted fibrous root system could not withstand the dry conditions which caused them to desiccate at onset of dry conditions. In semi-arid rangelands, plants with a deep rooting system were likely to survive the dry seasons better than shallow rooted plants.

iii) Potential to withstand heavy grazing

The ability of a forage legume to withstand heavy grazing was a desirable attribute to consider when introducing forage legumes into natural pastures. Glycine, Siratro and Stylo showed this potential after they were clipped to ground level and again after cattle accidentally grazed on part of the experimental plots. The cattle grazed Glycine and Siratro to ground level, whereas they left about 5 cm stubs of Stylo plants due to their tough and woody nature. The cattle were unable to uproot the three legumes due to their firm rooting characteristics. At the onset of the rains, the three legumes were able to regenerate into many stems and branches from crown buds located just below the soil surface and from buds located on aerial stems (as was the case with Stylo).

iv) Ability to produce high dry matter

Glycine, Siratro and Stylo yielded dry matter which was significantly ($P \leq 0.05$) higher than that of the annual legumes (Dolichos and Velvet bean). The high dry matter yield produced by the three legumes was attributed to the perennial and multi-stemmed growth habit of the legumes. The multi-stemmed growth habit resulted into even more stem and branch ramification after the legumes were harvested which led to production of more dry matter.

v) Ability to add organic matter to the soil

Glycine, Siratro and Stylo dropped litter during the dry seasons, amounts which were significantly higher than those of Dolichos and Velvet bean. Thus, the legume's ability to add organic matter to the soil was an important pathway for enhancement of soil fertility and by implication the water holding capacity of the soils. Litter drop may also have been beneficial in reducing rain drop impacts in regard to soil aggregation and runoff.

vi) Ability to self-seed

Field observations showed that Glycine, Siratro and Stylo were self-seeding as new seedlings germinated on their own after onset of the rains. This was a desirable characteristic with respect to self-propagation within pastures which meant growth of more seedlings in the natural pasture. Siratro even produced flowers and pods two months after planting, an aspect that continued during the lifespan of the plants except when plants were in a deciduous condition.

4.5 Legume integration into natural pastures

4.5.1 Legume germination and establishment

Monocultures of Glycine, Siratro and Stylo legumes had a better germination and were quicker to establish than the same legumes sown mixed with natural pastures. In addition, monoculture seedlings were able to withstand the June to October long dry season. Legumes sown in the natural pasture had slow growth (particularly Stylo) and some seedlings died after onset of the dry season, implying that the seedlings may not have established well. Skerman *et al.* (1988) reported that legumes require a well prepared seed bed for good establishment. However, in undisturbed grassland, sowing of Siratro and Glycine seeds along narrow strips had achieved more successful establishment than when legume seeds were broadcasted (Boonman, 1993).

The present study observed that Siratro and Stylo had a better germination and quicker establishment than Glycine whether sown as monoculture or mixed with natural pasture. This observation is in conformity with the results of seed germination tests described in Section 4.4.1, results which showed that Siratro and Stylo had 60 and 70% seed germination, respectively, while only 25 % of Glycine seeds germinated. In addition, Glycine establishment from seed was slow and failure to germinate was high (Boonman, 1993). Skerman *et al.* (1988) attributed these failures to the high percentage of hard seeds that was common in seeds of Glycine. Regarding Stylo, even though germination was good, establishment was slow for young plants, especially when mixed with natural pasture. The germination and establishment results for Siratro and Stylo are in conformity with those of Njarui *et al.* (2007) who reported that Siratro had an establishment of 15 plants m^{-2} while the plant population of Stylo was 25 plants m^{-2}.

After a slow start in establishing, Glycine developed many stems from crown buds located just below the soil surface while Siratro developed only a few stems, results similar to those described in Section 4.4.4. The superior ability of Glycine to produce many stems and branches is in conformity with results obtained by Pamo and Mubeteneh (1995) who studied the ramification ability of five forage legumes. The study reported that after three months of growth, *Neonotonia wightii* ramified into five branches while *Macrotyloma axillare* had four, *Dolichos axilaris* had three, *Macroptilium atropurpureum* had two and *Desmodium intortum* ramified into one branch only. In the present study Glycine, Siratro and Stylo were self-seeding, with new seedlings (especially Stylo) spontaneously germinating at onset of the rainy season. Njarui *et al.* (2007) observed a similar increase of volunteer Stylo seedlings that emerged after the rains. However, these seedlings quickly died after onset of dry conditions as they were still young and their rooting system may not have developed well. It was also observed that old plants of Siratro were prone to leaf rust attack while in Stylo, the roots and stems were attacked by termites, especially during the dry season, eventually killing some plants.

4.5.2 Dry matter production of grass/legume mixed pastures

4.5.2.1 Effect of slashing and burning herbage on dry matter production

Treatment effects of slashing and burning on total dry matter production were not significant ($P \geq 0.05$), although the dry matter production in burned plots was higher by 18% (Figure 8). Fire causes the release of nutrients previously immobilized in foliage (O'Connor *et al.*, 2004), hence some nutrients may have become available for plant uptake in the burned plots resulting in higher dry matter production. In addition, fire may have stimulated the growth of some grass species in burned plots resulting in higher dry matter production.

Mnene (1995) found that the relative abundance of *Dichanthium insculpta* and *Themeda triandra* was greater after burning than in un-burned paddocks at Kiboko Range Research Station. Snyman (2006) also reported that the species *Digitaria eriantha*, *Eragrostis superba* and *E. chloromelas* were stimulated to grow and produce seeds more rapidly after burning, hence more dry matter production.

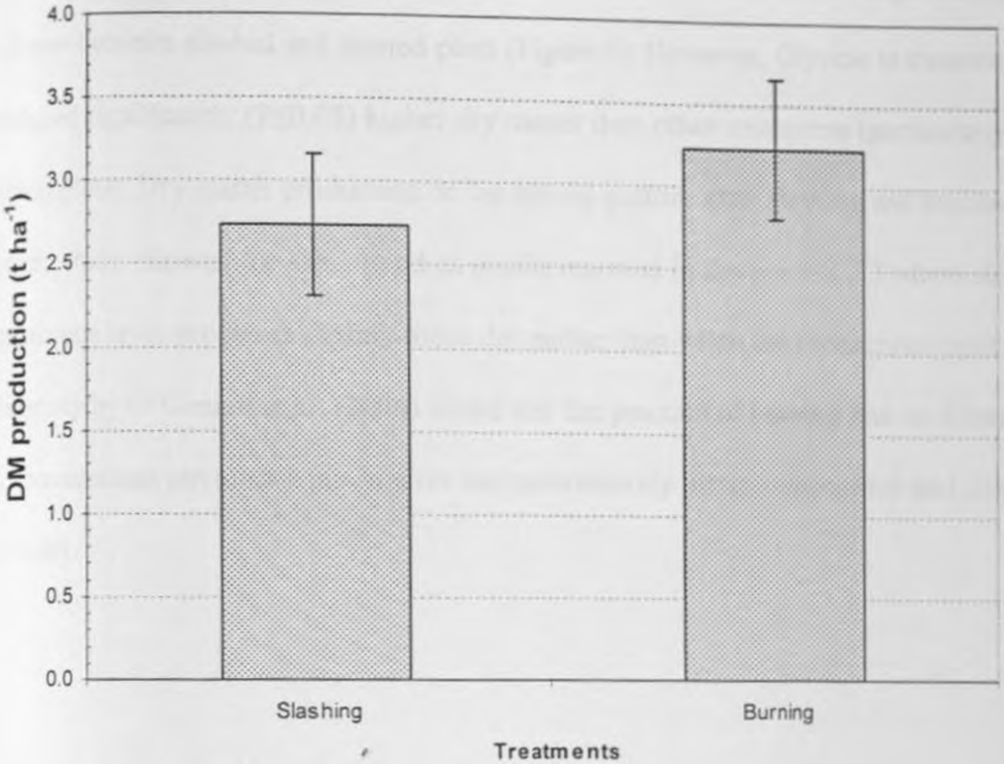


Figure 8: Total dry matter production (t ha^{-1}) after slashing and burning herbage

Results further showed that dry matter production per treatment was not significantly ($P \geq 0.05$) different between slashed and burned plots (Figure 9). However, Glycine in monoculture produced significantly ($P \leq 0.05$) higher dry matter than other treatments (particularly in the burned plots). Dry matter production of the natural pasture after slashing and burning in the present study showed the same trend as results reported in Section 4.2.2.3 where slashing the herbaceous layer produced slightly more dry matter than when the herbaceous layer was burned. The study by O'Connor *et al.* (2004) found that the practice of burning had no discernible effect on aboveground phytomass production but quantitatively alters composition and slightly effects diversity.

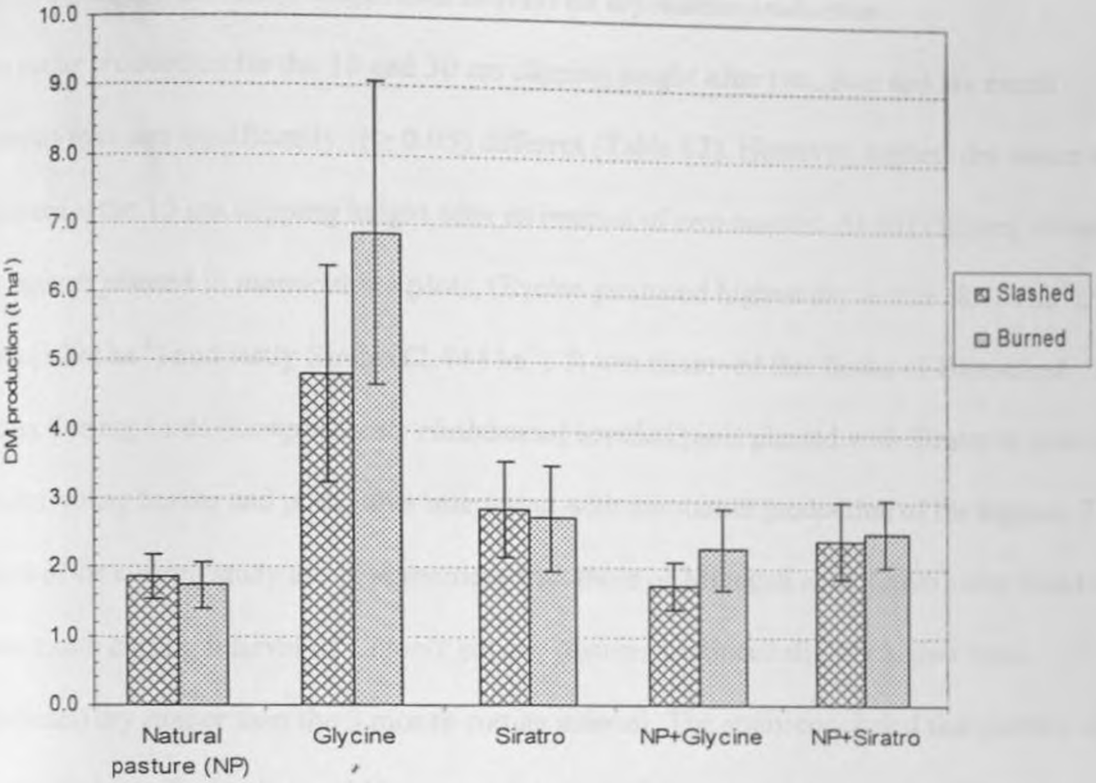


Figure 9: Dry matter production (t ha^{-1}) of treatments in slashed and burned plots

4.5.2.2 *Effect of harvesting height and interval on dry matter production*

Dry matter production for the 15 and 30 cm clipping height after two, four and six month intervals were not significantly ($P \geq 0.05$) different (Table 12). However, highest dry matter was produced at the 15 cm clipping height after an interval of two months. At this clipping intensity for legumes planted in monoculture plots, Glycine produced highest dry matter (8.43 t ha^{-1}), then Stylo (3.29 t ha^{-1}) and lastly Siratro (2.44 t ha^{-1}). It was observed that flocks of Blue-eared Glossy Starling birds (*Lamprotornis chalyboeus*) invaded plots planted with Siratro to feed on flowers, young leaves and pods, thus interfering with dry matter production of the legume. The results of the current study are in agreement with those of Mtengeti *et al.* (2006) who found that a two month cutting interval of *Chloris gayana* pastures produced slightly higher (non-significant) dry matter than the 3 month cutting interval. The study concluded that farmers of Njombe District, Tanzania would have no advantage of increased dry matter by increasing the cutting interval beyond two months.

The combined dry matter production of NP+Glycine mixed pastures harvested at 15 cm height after every two months was 40% more than of NP harvested at the same height and interval. Also, the combined dry matter production of NP+Siratro mixed pastures harvested at 15 cm height at two months interval was 42 % more than of NP. However, the dry matter production of NP+Stylo was less than that of NP, which was attributed to the slow growth of Stylo when intercropped with natural pasture. This slow growth of Stylo implied that it needed to grow for more than four seasons before it to could exceed the dry matter from the natural pasture. Kitabe and Tamir (2005) also reported a late emergence and slow growth of *Trifolium pretense* legume intercropped with grasses in central highlands of Ethiopia.

Table 12: Dry matter production (t ha^{-1}) of pastures harvested at two heights and three intervals

Treatments	Harvesting height (cm)	Harvesting interval (months)		
		Two	Four	Six
Natural pasture (NP)	15	2.71$\pm$ 0.49	2.24$\pm$ 0.49	1.89$\pm$ 0.31
Natural pasture (NP)	30	1.88$\pm$ 0.33	1.21$\pm$ 0.29	1.20$\pm$ 0.26
Glycine	15	8.43$\pm$ 2.55	3.00$\pm$ 1.09	5.53$\pm$ 3.05
Glycine	30	4.01$\pm$ 1.50	3.74$\pm$ 1.39	4.13$\pm$ 1.03
Siratro	15	2.44$\pm$ 0.65	3.46$\pm$ 1.01	1.93$\pm$ 0.82
Siratro	30	3.28$\pm$ 0.97	1.78$\pm$ 0.45	4.18$\pm$ 1.10
Stylo	15	3.29$\pm$ 0.43	2.66$\pm$ 0.20	3.07$\pm$ 0.25
Stylo	30	2.23$\pm$ 0.37	1.37$\pm$ 0.23	1.48$\pm$ 0.23
NP+Glycine	15	3.79$\pm$ 0.51	1.84$\pm$ 0.38	1.27$\pm$ 0.16
NP+Glycine	30	1.47$\pm$ 0.12	1.16$\pm$ 0.19	0.93$\pm$ 0.16
NP+Siratro	15	3.84$\pm$ 1.03	2.67$\pm$ 0.69	2.36$\pm$ 0.57
NP+Siratro	30	1.32$\pm$ 0.22	2.69$\pm$ 0.87	1.72$\pm$ 0.38
NP+Stylo	15	2.59$\pm$ 0.32	1.12$\pm$ 0.12	2.20$\pm$ 0.36
NP+Stylo	30	1.34$\pm$ 0.15	0.68$\pm$ 0.10	0.94$\pm$ 0.08

The high dry matter production obtained at 15 cm height at an interval of two months was attributed to three possible factors. Firstly, when grasses and legumes were defoliated, they tended to produce more tillers. Grasses harvested at 30 cm height were less stimulated to produce other stems than plants harvested at 15 cm height. This is in agreement with Wolfson (2000) and Snyman (2003) who found that plant parts that remained un-defoliated for long became moribund and may cease to produce other stems. In legumes, clipping stimulated further development of secondary stems from crown buds situated below the soil surface or from aerial nodes located on the stems. This implied that legume stems clipped at 15 cm height were stimulated to produce more secondary stems (hence production of more dry matter) than those clipped at 30 cm height. Secondly, harvesting grasses and legumes at 15 cm height may have increased penetration of incident light to lower levels of the pasture sward than in pastures harvested at 30 cm. The increased light intensity and quality may also have stimulated germination and spontaneous growth of other seedlings which later contributed additional dry matter. Various authors (Wassermann *et al.*, 2000; Wolfson, 2000) showed that increased light intensity after plant canopy thinning stimulated growth of grass stems below the canopy. Ghebrehiwot *et al.* (2006) found that in the high producing mesic regions of South Africa, regular fire or mowing was critical in maintaining dominance by *T. triandra* because fire and mowing removed accumulated litter which allowed sufficient light penetration to the growing points of the grass. However, grasses such as *Eragrostis curvula* and *Aristida junciformis* were able to grow new tillers in light limited environments and were able to persist and dominate the pasture.

Boonman (1993) also reported that in Serere, Uganda, shading prevented new grass tillers from emerging from pasture swards harvested at 30 cm height. The study found that in grazing paddocks that were clipped to near ground level prior to a new grazing cycle, the grass regrowth was more vigorous than in paddocks clipped at 30 cm height. Thirdly, clipping plants at 15 cm height after every two months may have suppressed flower shoots formation, thereby encouraging growth of more leafy material and hence production of more dry matter. Gettle *et al.* (1996) reported that when grass plants were about to shift from vegetative to reproductive development, close cutting can prevent formation of flowering shoots, promoting further growth of leaves and production of more secondary branches.

Other studies have shown integration of grasses with legumes to be effective in improving dry matter production from such pastures. For example, Hassen *et al.* (2007) from an on-station study reported a more than double dry matter production from grass/legume pastures compared to that from traditional grass fallows in western Ethiopia. *Chloris gayana* grass mixed with *Stylosanthes hamata* legume produced dry matter of 12.5 t ha^{-1} yr^{-1} by second year as compared to 5.1 t ha^{-1} yr^{-1} produced from traditional fallows. When *C. gayana* was mixed with *Macrotyloma axillare* and *Desmodium intortum*, the production rate was 14.5 and 11.2 t ha^{-1} yr^{-1}. The dry matter from mixed pastures exceeded that from pure legume stands. However, the herbage production fell sharply by the third year. At Machakos, Kenya, Njarui *et al.* (2006) reported similar results where Napier grass intercropped with Stylo and Siratro produced highest dry matter in year two and thereafter, herbage production declined.

4.5.3 Nutritive content of grass/legume mixed pastures

4.5.3.1 Crude protein content

Grass-legume intercrop contained significantly ($P \leq 0.05$) higher crude protein content than sole grass sward at all stages of growth (Table 13). It appears that grasses mixed with legumes may have benefited from N fixed by the legumes and/or from soil N after decomposition and mineralization of legume residues. Crude protein content of plants declined significantly ($P \leq 0.05$) with plant maturity among treatments. It was also noted that there were decreased amounts of crude protein in some legume plants after they were mixed with grasses.

These results are comparable to those of Zemenchick *et al*. (2002) who reported significant increases in crude protein content of Brome grass (*Bromus inermis* Leyss.) after being mixed with either Kura Clover (*Trifolium ambiguum*) or Birdsfoot trefoil (*Lotus corniculatus* L.) legumes. By the third year, the crude protein of the grass in monocultures increased from 127 g kg^{-1} to 189 and 197 g kg^{-1} after mixing with Kura Clover and Birdsfoot trefoil legumes, respectively. The study recommended combining the legumes with the grasses to reduce reliance on fertilizer N in North-Central USA. Njarui *et al.* (2006) also reported a significant increase of crude protein content of Napier grass after it was mixed with either Siratro or Stylo in an on-station study. The study reported that after two years, sole Napier had crude protein content of 8.14% while the crude protein content of Napier mixed with Siratro and Stylo was 9.64 and 9.96%, respectively.

Table 13: Crude protein content (%) of monoculture and grass/legume mixed pastures at three stages of growth

Treatments	Vegetative		Flowering		Senescent	
	Grass	Legume	Grass	Legume	Grass	Legume
Natural pasture (NP)	7.1± 1.11	-	5.9± 0.79	-	2.8± 0.03	-
Glycine	-	25.3± 0.95	-	17.6± 1.28	-	6.6± 0.36
Siratro	-	28.3± 0.48	-	21.9± 1.08	-	7.7± 0.60
Stylo	-	14.5± 0.16	-	14.0± 1.25	-	10.4± 1.15
NP+Glycine	14.3± 1.83	19.0± 1.68	7.5± 0.54	21.0± 3.20	4.0± 0.21	7.6± 0.07
NP+Siratro	11.9± 1.18	21.5± 3.09	8.5± 2.04	20.0± 1.40	3.1± 0.05	9.8± 0.42
NP+Stylo	10.2± 2.37	15.6± 0.47	6.1± 0.56	12.6± 0.47	3.1± 0.26	11.1± 0.59

The plant litter which is annually shed by legumes must have decomposed thus providing a source of soil N for grasses, resulting in increased crude protein content of grasses mixed with legumes. A number of authors (Crowder and Chheda, 1982; Steele and Vallis, 1988; Miles and Manson, 2000) also reported that some of the mechanisms of N transfer from legumes to grasses revolved around direct transfer of N between legume plants and grass roots or after a phase of nodule and litter decomposition in the soil. Moreover, Miles and Manson (2000) noted that nodule senescence was stimulated by defoliation and adverse environmental conditions and was characteristically more rapid than that of the remaining root material. After mineralization of plant litter, between 10 and 30% N becomes available to pasture plants within the first year after deposition (Steele and Vallis, 1988). Further, as reported by Crowder and Chheda (1982), underground N transfers during growth of perennial legumes may not exceed 1 or 2% in the short term, but over a longer period (more than two years), the amounts may vary from less than 5% to more than 30%. The processes quoted above may explain the increased crude protein content of grasses in mixed pastures especially during the vegetative stage and the decreased crude protein content in some legume plants when mixed with grasses.

Crude protein content decreased as the plants shifted from vegetative to flowering and finally to the senescent stage in all treatments. However, Glycine and Siratro legumes (monoculture stands and intercrops with grasses) had over 50% decrease in crude protein content as they shifted from flowering to senescent stage. From vegetative to flowering stages, the crude protein decrease in the same legumes was levels less than 30%. Baloyi *et al.* (2008) found that the crude protein of Cowpea and Silverleaf Desmodium forages increased up to flowering and then declined with maturation. For example, the crude protein content of the Desmodium leaves was 150, 237 and

246 g kg DM at pre-anthesis, anthesis and post-anthesis stages of growth, respectively. The most important factor that controls forage quality is the age of the plant or growth stage (Ngugi *et al.*, 2004; Nsinamwa *et al.*, 2005). As plant growth progressed towards maturity, the stems form the larger proportion of the total dry matter after the proportion of leaves decreases. In addition, the stems become fibrous and rather indigestible compared to the leaves which are usually low in fibre and high in protein. However, as the leaf: stem ratio decreased with advancing maturity, the plants contained less crude protein and more fibre. Wolfson and Tainton (2000) reported that the economy of plants could be considered as a balance between the need to produce vegetative and reproductive growth. Leaf senescence was often associated with N deficiency as a consequence of remobilization of the N they contained for reproductive growth, the report noted.

Results obtained in the current study showed that whether legumes grew in monoculture stands or were intercropped with grasses, they contained a crude protein content that was higher than the minimum required for maintenance of ruminant animals. According to Meissner *et al.* (2000), a minimum of 7 to 8 % crude protein content is required by ruminant animals to meet their dietary needs, but high producing animals (e.g. lactating cows) required levels approaching 13 to 14% of crude protein content for optimal performance. In contrast, beef animals required a crude protein content of 10% in their feed. In the current study, therefore, grasses at vegetative stage contained enough crude protein to maintain ruminant animals. However, at flowering and senescent stages of growth, the crude protein content fell below the minimum needed for maintenance. Addition of legumes into the natural pasture raised the crude protein content of grasses to adequate levels for animal maintenance.

4.5.3.2 Ash content

Treatment effects and stages of growth resulted in significantly ($P \leq 0.05$) different levels of ash content (Table 14). The content decreased as the plant's growth progressed from vegetative to flowering and finally to the senescent stage. At vegetative stage, ash content of monoculture stands of Glycine and Siratro was significantly ($P \leq 0.05$) higher than that of Stylo and grasses in natural pasture. In mixed pastures of NP+Glycine and NP+Siratro, ash content of the grass and legume components were not significantly ($P \geq 0.05$) different. However, ash content of legume components in NP+Stylo was significantly higher by 35% than that of grass components.

At flowering stage, grasses in natural pasture and Glycine, Siratro and Stylo in monoculture stands had no significant ($P \geq 0.05$) differences in ash content. In mixed pastures, ash content of grass and legume components was similar but not significant ($P \geq 0.05$). However, ash content in legume components was lower than of grass components. At senescent stage, the legume plants in monoculture stands and those intercropped with grasses contained significantly ($P \leq 0.05$) lower ash content than grasses mixed with legumes or those in natural pastures.

It was observed that ash content of grasses in natural pasture did not fluctuate much with age. Similar observations were reported by Ngugi *et al.* (2004) who studied the ash content of sheep diets in Kibwezi, Kenya. The ash content in the diets did not significantly change between January and July (from 13.6 to 13.1%) unlike crude protein content which significantly changed from 15.4% in January to 8.9% in July. The study concluded that seasonal variations in diet quality are attributed to corresponding variations in chemical composition of forages.

Table 14: Percent ash content of monoculture and grass/legume mixed pastures at three stages of growth

Treatments	Vegetative		Flowering		Senescent	
	Grass	Legume	Grass	Legume	Grass	Legume
Natural pasture (NP)	11.5± 0.58	-	10.8± 0.51	-	10.8± 0.83	-
Glycine	-	13.1± 0.57	-	10.8± 0.29	-	8.5± 0.31
Siratro	-	14.1± 0.25	-	8.9± 0.39	-	7.4± 0.44
Stylo	-	9.4± 0.12	-	7.9± 0.17	-	7.1± 0.51
NP+Glycine	13.4± 1.00	12.8± 0.47	11.3± 0.50	10.5± 0.27	11.3± 0.39	9.0± 0.17
NP+Siratro	11.6± 0.24	11.1± 0.24	10.7± 0.55	8.8± 0.23	8.0± 0.20	7.3± 0.33
NP+Stylo	10.1± 0.35	13.6± 0.35	10.8± 0.10	10.1± 0.48	8.1± 0.50	7.9± 0.26

The overall results of the current study showed that in majority of the treatments, grasses intercropped with Glycine, Siratro and Stylo contained more ash contents (hence minerals) than grasses in natural pasture. After decomposition of legume litter, the released nutrients became available for uptake by grasses which improved their productivity and crude protein (see Section 4.5.3.1) which is an important measure of nutritive value of forages. Crowder and Chheda (1982) stated that Ash left after heating a forage sample at 600°C provided an approximation of total minerals present after moisture, carbon, oxygen, and nitrogen are lost during combustion. Meissner *et al*. (2000) reported that legumes contained higher amounts of N, Ca, P, K and Mg, nutrients that became available for uptake by associated grasses after decomposition of legume litter, thereby improving the digestibility of the forage.

Concentration of minerals in forages is determined to a large extent by maturity of the material as the concentrations declined with age of the plants (Meissner *et al*., 2000; Muinga *et al*., 2006). Other factors that determine mineral concentrations in forages are; season of the year, temperatures, soil fertility and moisture availability, factors that explain the differences among similar legumes grown in different agro-ecological zones and harvested at similar stages of growth (Muinga *et al*., 2006). In addition legumes contain higher amounts of nitrogen, calcium, phosphorus, potassium and magnesium, but lower amounts of sodium when compared with grass species (Crowder and Chheda, 1982). For example, Muinga *et al*. (2006) reported an N content of 0.5% in natural pastures while Glycine and Siratro legumes contained 2.2 and 2.4% N, respectively. Zyl and Dannhauser (2005) also reported that *Avena sativa* (Oats) contained a calcium and phosphorus content of 0.25 and 0.16%, respectively. In *Vicia dasycarpa* (Grazing vetch), the legume contained 0.91 and 0.34% calcium and phosphorus content, respectively.

Results of the current study indicate that Glycine, Siratro and Stylo contained more ash than that from *Leucaena leucocephala* and *Acacia brevispica* analyzed by Nyambati *et al*. (1996). Their results showed that seeds of *L. leucocephala* and *A. brevispica* contained 4.2 and 3.3% ash, respectively. Whole pods contained 5.7 and 4.1% ash, respectively, while empty pods contained 7.8 and 5.1% ash, respectively. Therefore it appears that feeding livestock with forage from Glycine, Siratro and Stylo may be a better source of minerals than feed from seeds, whole and empty pods of *L. leucocephala* and *A. brevispica*.

4.5.3.3 In-vitro dry matter digestibility

In-vitro dry matter digestibility (IVDMD) for all treatments showed significant ($P \leq 0.05$) differences (Table 15). In addition, digestibility of the legumes in monoculture or mixed stands were significantly ($P \leq 0.05$) higher than that of grasses at all stages of growth. Tainton (2000) described digestibility as the proportion of a feed that had the potential to be ingested by animals and is usually expressed as percentage of the feed eaten.

Results of this study showed that the digestibility of grasses and legumes decreased as the plants matured from vegetative to flowering and finally to the senescent stage of growth. Williams *et al*. (2004) attributed this decrease to changes in the leaf/stem ratio. This decrease was in agreement with results from various authors (Kinyamario and Macharia, 1992; Kevelenge *et al*., 1996; Nyambati *et al*., 1996; Ngugi *et al*., 2004; Kuria *et al*., 2005) who reported a decrease of digestibility of forages as the plants advanced with age. Ngugi *et al*. (2004) further reported that the digestibility of goats and sheep diets was significantly higher during wet season than during the dry season. However, the drop in digestibility of sheep diets was more drastic (22.1%) than

Table 15: Percent *in-vitro* dry matter digestibility of monoculture and grass/legume mixed pastures at three stages of growth

Treatments	Vegetative		Flowering		Senescent	
	Grass	Legume	Grass	Legume	Grass	Legume
Natural pasture (NP)	54.6± 0.58	-	49.7± 2.10	-	49.5± 2.07	-
Glycine	-	59.7± 3.83	-	70.0± 0.30	-	51.2± 1.58
Siratro	-	71.4± 1.21	-	65.5± 0.20	-	52.4± 0.41
Stylo	-	65.7± 0.01	-	66.3± 0.61	-	58.1± 1.08
NP+Glycine	43.5± 4.99	56.2± 1.14	58.8± 0.91	68.4± 0.75	53.7± 2.70	59.5± 0.78
NP+Siratro	59.3± 2.45	65.4± 1.36	62.9± 2.14	64.5± 0.89	51.1± 2.52	55.7± 2.07
NP+Stylo	59.7± 0.82	68.8± 7.14	50.1± 5.09	67.8± 0.49	53.7± 2.11	59.1± 0.90

in goat's diets (14.9%) because as the dry seasons set in, goats changed their diets more to browse species which exhibited a slower rate of quality deterioration with advancing maturity than grass species.

These results showed that Glycine, Siratro and Stylo grown in monoculture stands were more digestible than grasses in the natural pasture at all stages of growth. Meissner *et al.* (2000) attributed the lower digestibility of grasses to structural characteristics particularly lignification. The results of current study also showed that grasses mixed with legumes were more digestible than grasses in the natural pasture, indicating that incorporation of legumes into natural pastures improved digestibility of the associated grasses. This can be attributed to increased crude protein and ash contents of the grasses intercropped with legumes which contributed to the improved digestibility. Results in Section 4.5.3.1 showed that intercropping grasses with Glycine, Siratro and Stylo raised the crude protein content of grasses from 7.1% to 14.3, 11.9 and 10.2%, respectively, during the vegetative stage. Effect of crude protein content on digestibility of forages is important for maintenance of rumen microbial activities (Crowder and Chheda, 1982). This is because, if crude protein content in the forage fell below 7%, the microbial activity in the rumen is depressed by lack of nitrogen, thus significantly reducing forage digestibility. The end result is that nitrogen excretion may exceed nitrogen intake (Kinyamario and Macharia, 1992).

The high ash contents (hence minerals) reported in Section 4.5.3.2 may have translated to higher digestibility of the grasses mixed with legumes at all stages of growth. This is because after litter from legumes decomposed, nutrients were released into the soil, which became available for uptake by grasses intercropped with legumes. After uptake by grasses, they improved their ash (mineral) contents and hence attained higher digestibility as attested by the results.

4.5.3.4 Fibre content

Fibre content fractions indicate the fibrosity of forage and the extent to which fibre could be degraded by rumen micro-organisms (Topps, 1996). Percent neutral detergent fibre (NDF) is an indication of cell wall contents; percent acid detergent fibre (ADF) indicates cellulose plus lignin content; while percent acid detergent lignin (ADL) indicates amount of lignin content. Forages containing high amounts of these fibre fractions have low digestibility (Topps, 1996). The results of individual fibre fractions are discussed here below.

Neutral Detergent Fibre

Neutral Detergent Fibre (NDF) content differed significantly ($P \leq 0.05$) among all treatments as well as for different stages of growth (Table 16). NDF content increased as grass and legume plants matured from vegetative to flowering and finally to senescent stage of growth. Legumes, in monocultures or mixed with natural pasture maintained significantly ($P \leq 0.05$) lower NDF contents than grasses at all stages of growth. At senescent stage, legumes in monocultures had more NDF than those intercropped with natural pasture. This phenomenon may be attributed to the delayed maturity of legumes intercropped with natural pasture as explained in Section 4.5.1.

Table 16: Percent neutral detergent fibre content of monoculture and grass/legume mixed pastures at three stages of growth

Treatments	Vegetative		Flowering		Senescent	
	Grass	Legume	Grass	Legume	Grass	Legume
Natural pasture(NP)	57.9± 1.96	-	67.4± 1.32	-	63.6± 0.64	-
Glycine	-	32.7± 1.80	-	43.9± 2.32	-	57.0± 0.74
Siratro	-	33.1± 2.13	-	44.1± 0.81	-	62.1± 1.74
Stylo	-	41.7± 0.85	-	48.0± 1.75	-	53.3± 1.71
NP+Glycine	55.8± 2.10	34.9± 1.91	67.0± 0.87	43.3± 1.23	71.1± 1.07	49.5± 0.43
NP+Siratro	58.8± 1.57	40.5± 4.65	55.3± 0.90	44.1± 0.32	79.3± 3.89	59.2± 1.56
NP+Stylo	54.1± 10.36	44.0± 1.92	68.4± 0.56	47.7± 4.94	78.9± 1.46	48.5± 0.17

The current study shows that legumes contained lower NDF than grasses, results which are in agreement with those of Fleischer and Tackie (1996) and Kuria *et al*. (2005). Fleischer and Tackie (1996) reported an NDF content of 77.7 and 33.7% for *Sorghum arundinaceum* (wild sorghum) and *Leucaena leucocephala* (Lam) De Wit, respectively. These differences were also an indication of digestibility of the species which made *Leucaena* leaves more digestible (66.2%) compared to the wild sorghum (47.2%). Kuria *et al.* (2005) also found that shrubs that formed forage feed of camels in Marsabit area contained lower fibre and higher crude protein and ash contents than the grasses. Shrubs had a mean NDF content of 51.0% compared to 60.4% for grasses. These attributes made the shrubs more palatable than grasses and were thus preferred by the camels. Ngugi *et al*. (2004) also reported that the NDF content of goat's diets (which was mainly from browse species) was lower (37.6-50.3%) than that of sheep (which fed mainly on grasses) diets (46.4-56.9%).

NDF content in forages vary with plant species and their development, chemical composition and structural complexity (Topps, 1996; Theron and Snyman, 2004; Nsinamwa *et al*., 2005). In addition, NDF is the major determinant of overall forage quality and digestibility, and has a direct effect on animal performance (Linn, 2004). High NDF in forages lowers the voluntary dry matter intake of grazing animals and that of neutral detergent solubles like starches, sugars, fats, minerals and crude protein (Kandil and El Shaer, 1990). According to El Shaer and Gihad (1994), nutritious fodders should contain a normal range of 35-40% NDF content for grazing animals. However, Theron and Snyman (2004) pegged the minimum requirement of NDF content in forages for lactating dairy cows to be in the range of 25-28%. Thus, results from the current study show that only legumes in monoculture stands at their vegetative stage met the normal range of NDF content recommended for grazing animals. However, the values were higher than the recommended range of NDF content in the feed of lactating dairy cows, implying that fodder at the study site was low in quality for the maintenance of lactating dairy cows.

Acid Detergent Fibre

Acid Detergent Fibre (ADF) content differed significantly ($P \leq 0.05$) among all treatments as well as for different stages of growth (Table 17). These results show that the percent ADF content generally increased as the grasses and legumes (monocultures and mixed stands) advanced into maturity from vegetative to flowering and finally to senescent stage. The results also indicate that grasses generally contained higher ADF content than legumes at all stages of growth. Hence grasses had lower digestibility than legumes. These results are in agreement with those of Zemenchik *et al.* (2002) who reported that the Kentucky bluegrass in monocultures contained 304 g kg^{-1} ADF content, but when mixed with either Kura Clover or Birdsfoot trefoil, the ADF content was lowered to 253 and 274 g kg^{-1}, respectively. Fleischer and Tackie (1996) also reported an ADF content of 47.4 and 22.1% for wild sorghum grass and *Leucaena* leguminous shrub, respectively. Increases in ADF content of forage plants result in lowered digestibility of forages due to increased cellulose and lignin content (Topps, 1996).

ADF content of forages provides an indication of the lignocellulose content of the plant material (Theron and Snyman, 2004). The study noted that ADF content was NDF value minus hemicellulose and protein in cell walls. Cellulose, lignin, cutin, silica and other acid insoluble minerals were part of the ADF content which increased as forage plants matured. Further, increased cell wall content in forages is associated with slower passage rates in the digestive

Table 17: Percent acid detergent fibre content of monoculture and grass/legume mixed pastures at three stages of growth

Treatments	Vegetative		Flowering		Senescent	
	Grass	Legume	Grass	Legume	Grass	Legume
Natural pasture(NP)	37.1± 2.51	-	39.6± 0.96	-	43.0± 0.78	-
Glycine	-	29.4± 1.39	-	28.0± 0.46	-	43.5± 1.16
Siratro	-	31.9± 2.01	-	30.8± 1.44	-	48.6± 2.20
Stylo	-	32.8± 0.47	-	37.7± 0.41	-	40.8± 1.82
NP+Glycine	33.5± 2.04	34.4± 0.53	43.3± 0.69	33.0± 0.84	41.5± 1.50	36.4± 0.62
NP+Siratro	36.4± 0.94	31.4± 1.24	41.1± 1.32	35.2± 0.84	45.3± 0.70	41.5± 1.48
NP+Stylo	39.4± 0.50	32.2± 1.64	40.4± 0.47	36.8± 1.07	43.7± 1.36	35.4± 0.12

system of ruminant animals, with consequent decreases in animal performance. The minimum requirements of ADF in forages for lactating cows should be in the range of 19-25% (Theron and Snyman, 2004), while heifers needed a diet with 19% ADF content (Meissner *et al.*, 2000). Results from the current study show that the grass and legume forages contained high ADF content and were therefore less suited to sustain heifers and lactating dairy cows.

Acid Detergent Lignin

Acid Detergent Lignin (ADL) content differed significantly ($P \leq 0.05$) among all treatments as well as for different stages of growth (Table 18). These results show that lignin content increased as grasses and legumes advanced into maturity from vegetative to flowering and finally to senescent stage. By the time grasses became senescent, the ADL content of grasses in natural pasture had significantly ($P \leq 0.05$) increased by 103%. By the time Glycine and Siratro in monoculture stands reached senescent stage, their lignin content had significantly ($P \leq 0.05$) increased by 128 and 77%, respectively. However, the increase in lignin content in Stylo by 4% was not significant ($P \geq 0.05$). These results further showed that grasses intercropped with legumes contained lower lignin content than grasses in natural pasture at all stages of growth, resulting in increased digestibility. Thus livestock fed on fodder from such grass/legume mixed pastures will have a higher quality fodder than livestock fed on natural pasture alone.

Levels of lignin content in legume plants in monocultures and mixed pastures were not significantly ($P \geq 0.05$) different. However, at senescent stage, grasses in natural pasture contained highest lignin content of 12.4% which was significantly ($P \leq 0.05$) different from that of grasses (7.4%) intercropped with Siratro (NP+Siratro). Nsinamwa *et al.* (2005) also reported a doubling

Table 18: Percent acid detergent lignin content of monoculture and grass/legume mixed pastures at three stages of growth

Treatments	Vegetative		Flowering		Senescent	
	Grass	Legume	Grass	Legume	Grass	Legume
Natural pasture(NP)	6.1± 0.41	-	8.5± 0.60	-	12.4± 0.84	-
Glycine	-	4.6± 0.19	-	10.4± 0.06	-	10.5± 0.65
Siratro	-	6.5± 0.31	-	10.0± 0.15	-	11.5± 0.33
Stylo	-	8.4± 0.09	-	8.6± 0.15	-	8.7± 0.12
NP+Glycine	4.6± 0.24	5.8± 0.47	6.1± 0.26	8.8± 0.07	8.6± 0.22	10.2± 0.64
NP+Siratro	5.0± 0.12	6.9± 0.23	5.0± 0.33	7.2± 0.15	7.4± 0.06	10.1± 0.46
NP+Stylo	4.8± 0.25	7.1± 0.62	5.0± 0.62	8.3± 0.74	9.0± 0.78	8.9± 0.12

of lignin content from 6 to 12 % upon maturity of grasses from communal natural pastures in Botswana. The high lignin content of grasses in natural pasture can be attributed to the old grass stems which had persisted since the beginning of the experiment. Grasses mixed with legumes contained lower lignin content, implying that they had a higher digestibility than grasses in natural pasture. This may be attributed to enhanced quality of mixed pastures and also the growth of young stems in mixed pastures which were less lignified than old stems in natural pasture.

Results from the current study show that at vegetative and flowering stages of growth, legumes in monocultures or mixed with grasses in most cases contained higher ADL content than the grasses. These results are similar to those of Kuria *et al.* (2005) who reported higher ADL content in shrubs (8.1-23.4%) fed by camels than in grasses (6.2-7.1%) during the dry season. Results by Ngugi *et al.* (2004) also showed higher ADL content in diets of goats (4.9-7.3%) which fed mainly on browse species than in diets of sheep (4.0-6.5%) which fed mainly on grass species. The slightly higher quality of the sheep diets than goat diets particularly during the last two months of the wet season were attributed to high availability of young grasses and forbs.

Lignin is a plant polymer that accumulates in plant tissues with advancing age and is highly resistant to chemical degradation (Okello *et al.*, 2005). However, lignin is an important component of the fibre as it stimulates rumination which in turn stimulates saliva flow that is necessary for optimal microbial digestion. Lignin is not only indigestible, but also reduces the digestibility of other feed components possibly because of their encrustation, thus rendering them inaccessible to enzymes that would normally digest them e.g. in mature hays and straws (Crowder and Chheda, 1982). The authors reported that lignin was untouched by rumen micro-organisms and a unit increase in lignin could result into a three to four units decrease in digestibility of forages.

4.5.4 *Soil fertility*

4.5.4.1 Effect of slashing and burning herbage on soil chemical properties

The results of soil analysis after slashing and burning of herbage are presented in Table 19. There were no significant ($P \geq 0.05$) differences in soil pH, K and Ca between slashed and burned plots. Soil organic C and N decreased significantly ($P \leq 0.05$) after burning. Burning also significantly ($P \leq 0.05$) increased levels of P. Kleinman *et al.* (1996) while working in Kembera Village, Indonesia, also reported increased soil pH and P levels after burning. The increase in soil pH was attributed to the liming effect by oxides of basic cations (potassium, magnesium and calcium) contained in the ash while increase in soil P in burned plots was attributed to the decreased extractable aluminum. Kleinman *et al.* (1996) also recorded decreased levels of organic C after burning which was attributed to the oxidation of organic matter after burning.

Even though levels of pH, K and Ca were not significantly different between slashed and burned plots, the contents were slightly higher in burned plots. These results are in agreement with those of Grace *et al.* (2006) who found that heavier elements such as phosphorus, potassium and calcium formed ash, much of which was deposited on the soil surface resulting in higher soil mineral contents. The flash of nutrients released after burning stimulated physiological activity and resulted in rapid growth of pasture plants with relatively high nutritional value to livestock. However, this was followed by a gradual decrease in soil nutrients during the cropping period due to leaching and crop uptake, thus making the increase to be short-lived.

Table 19: Effect of slashing and burning herbage on soil chemical changes

Treatments	Soil parameters					
	pH (H_2O)	C (%)	N (%)	P (ppm)	K (me %)	Ca (me %)
Slashed	5.06± 0.02	1.34± 0.02	0.17± 0.01	166.8± 2.17	1.20± 0.03	5.12± 0.40
Burned	5.25± 0.02	1.29± 0.01	0.15± 0.01	177.9± 1.93	1.25± 0.02	5.34± 0.44
CV%	1.71	4.58	11.58	6.12	7.99	21.19

In the current study, burning pasture herbage resulted in a significant ($P \leq 0.05$) decrease in organic carbon from 1.34 to 1.24%. In a cultivation system where vegetation and organic residues are burnt, levels of organic carbon in the soil are likely to decrease. Manson *et al.* (2007) found that burning effects were greatest at the 0-50 mm soil depth. In the study, contents of basic cations (K, Ca, Mg) were lower in treatments burnt infrequently (five-year and no-burn) than in those burnt frequently (annual and biennial). Soil pH was also lower in treatments burnt infrequently than in those burnt frequently. Msaky *et al.* (1996), Zake *et al.* (1998) and Tenywa *et al.* (1999) discouraged the practice of burning as it leads to loss of valuable nutrients that are necessary for plant growth.

4.5.4.2 Effect of forage legumes on soil fertility

The results of soil fertility analysis of the integration experiment are presented in Table 20. These results show that except for soil pH, there was a decrease in all the other soil nutrients at end of the experiment. There was a significant ($P \leq 0.05$) increase in soil pH from 5.23 at beginning of the experiment to 5.31 by end of the experiment. A similar trend was observed in the screening experiment whereby the pH increased significantly ($P \leq 0.05$) from 4.92 to 5.36 (Section 4.4.6). As discussed in Section 4.4.6, the application of organic residues to the soil is one way of increasing soil pH, thereby alleviating aluminum toxicity which inhibits plant growth (Bationo *et al.*, 1995). Addition of organic residues may have been followed by decomposition and mineralization through action by soil micro-organisms resulting in increased soil pH. Miles and Manson (2000) and Muriuki and Qureshi (2001) reported that a change of soil pH to less acidic conditions caused the release of major nutrients namely C, N, P, K, Ca, Mg and S which thereafter became available for plant uptake leading to a gradual decrease from the soil.

Table 20: Effect of forage legumes on soil fertility at beginning and end of the grass/legume integration experiment

Time	pH (H_2O)	C (%)	N (%)	P (ppm)	K (me %)	Ca (me %)
Beginning	5.23$\pm$ 0.01	1.37$\pm$ 0.01	0.18$\pm$ 0.00	170.3$\pm$ 2.63	1.32$\pm$ 0.01	6.70$\pm$ 0.31
End	5.31$\pm$ 0.03	1.30$\pm$ 0.02	0.13$\pm$ 0.01	165.5$\pm$ 2.49	1.09$\pm$ 0.03	3.08$\pm$ 0.07
CV%	1.40	5.59	12.91	7.59	8.90	18.65

Results also indicated that levels of organic C, N, K and Ca decreased significantly ($P \leq 0.05$) while the decrease in P was not significant ($P \geq 0.05$). However, during the screening experiment, these nutrients significantly ($P \leq 0.05$) increased in the soil except P. These different results could be attributed to the high amounts of dry matter (hence organic residues in form of litter) produced by the legumes during the screening experiment. For example, the highest dry matter production was by Glycine, Siratro and Stylo during the screening experiment, 10.31, 7.81 and 3.52 t ha^{-1} respectively. However, during the grass/legume integration experiment, the experimental site received less rain with prolonged dry periods that resulted to lower dry matter of 8.43, 3.46 and 3.29 t ha^{-1}, respectively. Hence, there was low production of organic residues during the grass/legume integration experiment that may have resulted in decreased amounts of nutrients in the soil.

Competition for moisture and nutrients in mixed pastures may also have led to less dry matter production, hence less organic residues. Njarui *et al.* (2006) found that as increased levels of legume residues were incorporated into the soil, there was a corresponding increase in soil organic matter and N. Incorporation of 0, 50 and 100% of Lablab fallows, the soil organic matter content was 2.07, 2.17 and 2.29%, respectively. The N content was 0.100, 0.107 and 0.110%, respectively. A similar trend was observed after incorporation of Velvet bean residues. Buah (2008) recommended that large amounts of legume residues need to be applied for crop response since N recovery is much lower for organic residues than with mineral fertilizer. However, selection of legumes for soil fertility improvement should not be based on total dry matter production of the legume only but also on other parameters such as residue quality (e.g. lignin/N ratio), decomposition and mineralization rate.

The decrease in organic C, N, P and K from the soil is consistent with results reported by Mureithi *et al.* (1994) that after opening up virgin land for cultivation, all the major soil nutrients decreased up to the second year. However, this trend changed in the third year after application of *L. leucocephala* mulch. A study by Buah (2008) in Ghana, reported that after 6, 8 and 10 weeks of intercropping Velvet bean and maize, the total N was 0.043, 0.043 and 0.036%, respectively. Phosphorus declined to 11.96, 11.86 and 11.28 mg kg^{-1}, respectively. Potassium was 45.65, 44.25 and 46.16 mg kg^{-1}, respectively. However, the pH increased to 4.50, 4.58 and 4.62, respectively. The two studies by Mureithi *et al.* (1994) and Buah (2008) concluded that in the long term, improved soil nutrients will likely result not from direct addition of mulch from outside sources, but from large amounts of cover crop residues for soil fertility replenishment.

The significant ($P \leq 0.05$) decrease in Ca from the soil in the grass/legume integration experiment was similar to that obtained during the screening experiment. These results showed that as soil pH increased, soil calcium may have became more available for plant uptake and hence the noted decrease of its levels in the soil. These results are in contrast to those by Hassen *et al.* (2007) who reported an increase of soil Ca after on-station intercropping of *Chloris gayana* with *Stylosanthes hamata*, *Desmodium intortum* or *Macrotyloma axillare*. At the beginning of the fallows, soil Ca was 6.99 which increased to 8.48, 7.49 and 7.98 (meq 100 g^{-1}), respectively. However, Hassen *et al.* (2007) cautions on interpretations of the results since they are based on single composite samples per treatment and no statistical analysis was done. According to Marschner (1995), dicotyledons (such as legumes) require high levels of calcium than monocotyledons for optimum growth. In addition, the process of nodule formation in legumes is dependent on calcium which was required by the associated *Rhizobium* bacteria (Skerman *et al.*, 1988). Thus the high demand of calcium for the growth of grass and legume meristematic tissues and also uptake by the *Rhizobium* bacteria may have led to the 118 % significant ($P \leq 0.05$) decrease of calcium from the soil noted in the current study. Crowder and Chheda (1982) reported that tropical legumes are more efficient than their temperate counterparts in extracting Ca from the soil.

4.5.5 Soil moisture extraction by grasses and legumes

Soil moisture extraction at 15-30 cm soil depth was not significantly ($P \geq 0.05$) different between treatments (Figure 10). However, plots under NP+Glycine contained slightly higher soil moisture content than plots under other treatments, which was attributed to the poor establishment of Glycine in mixed pastures, hence less soil moisture extraction by legume plants.

Although soil moisture extraction at the 15-30 cm depth was not significantly ($P \geq 0.05$) different between treatments, plots with mixed pastures of NP+Siratro and NP+Stylo contained lower soil moisture content than those under natural pasture (NP). This may be an indication of soil moisture competition between grasses and legumes in this soil depth. Gachene *et al.* (1997) also reported soil moisture competition at 40 cm depth between maize and *Crotalaria ochroleuca* and *Mucuna pruriens* legumes when intercropped at Machakos and Kabete. Mburu and Gitari (2006) also reported that in an intercrop of maize and mucuna, over 80% of the roots were concentrated in the top 30 cm soil depth (see also Section 4.4.3) and maize had a relative advantage over Mucuna in water uptake as maize root mass was more than that of mucuna.

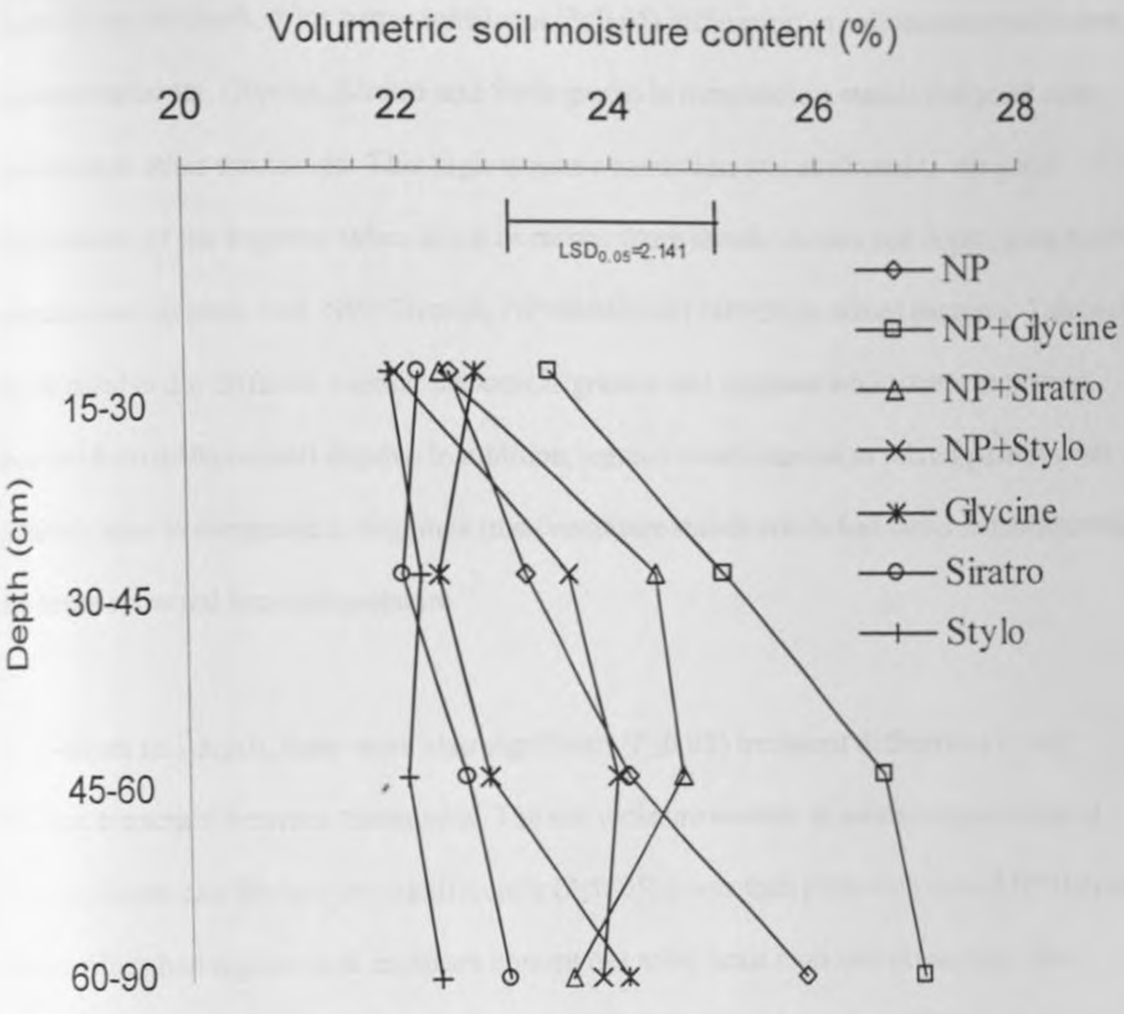


Figure 10: Soil moisture extraction in monoculture and grass/legume mixed pastures

At 30-45 cm soil depth, there were significant (P≤0.05) differences in soil moisture extraction between treatments. Glycine, Siratro and Stylo grown in monoculture stands extracted more moisture than other treatments. This high moisture extraction was attributed to the good establishment of the legumes when sown as monoculture stands. At this soil depth, least moisture extraction was in plots with NP+Glycine, NP+Siratro and NP+Stylo mixed pastures. This could be attributed to the different rooting patterns of grasses and legumes which were extracting moisture from different soil depths. In addition, legume establishment in mixed pastures was relatively poor as compared to legumes in monoculture stands which had better establishment, and hence extracted less soil moisture.

At 45-60 cm soil depth, there were also significant (P≤0.05) treatment differences in soil moisture extraction between treatments. The soil moisture content in monoculture stands of Glycine, Siratro and Stylo were significantly (P≤0.05) lower than plots with mixed NP+Glycine pasture which had highest soil moisture content (meaning least moisture extraction). Soil moisture content in plots with NP, NP+Glycine, NP+Siratro and NP+Stylo were not significantly (P≥0.05) different in this soil depth.

At 60-90 cm soil depth, plots with monoculture stands of Stylo had significantly (P≤ 0.05) the least soil moisture content (22.3%), implying that Stylo was extracting most soil moisture. This was attributed to the good establishment of the legume while sown in monoculture stands. This was followed by Siratro (22.9%), NP+Siratro (23.6%), NP+Stylo (23.8%), Glycine (24.1%) and NP (25.8%).

The differences in soil moisture extraction at different soil depths by grasses and legumes was attributed to their different rooting patterns as shown in Table 8 and described in Section 4.4.3. For instance, Figure 10 shows monoculture stands of Stylo extracted most soil moisture which was attributed to its lateral roots which were evenly spread along the tap root. Similarly, Siratro extracted more soil moisture than Glycine, although the two legumes have the same growth habit. This difference in soil moisture extraction can be attributed to the longer tap roots of Siratro (95 cm) compared to those of Glycine (80 cm) as shown in Table 8. In plots with natural pasture, soil moisture content increased with depth as the fibrous roots became fewer and fewer, implying less soil moisture extraction. This was because majority of grass roots were located within 0-30 cm soil depth.

Results of the current study are similar to those of Mburu and Gitari (2006) who reported that sole maize was extracting more soil water than an intercrop of maize and mucuna. This was attributed to reduced maize and mucuna root biomass, though maize had more root biomass than mucuna both in sole plots and in intercrops. Govindarajan *et al*. (1996) also reported that soil water content in the top 30-45 cm soil depth was similar in plots planted with sole maize and those intercropped with *L. leucocephala* plus maize or bean crops at Machakos, Kenya. The study reported that within intercrops, soil water content was higher close to the *Leucaena* hedgerow than further away. Other results by Aase *et al*. (1996) showed that most legume green manures sown as monoculture stands depleted more soil moisture up to 1.2 m soil depth for a longer period into the dry season more than in plots under fallow. An advantage with intercropping systems is that they are more effective in improving water use efficiency by using water that would otherwise be lost or underutilized when a monoculture is out of the growing season (Hook and Gascho, 1988). Such advantage was reported by Skinner *et al.* (2004) who found that intercropping five species in harsh environments utilized soil moisture more efficiently and produced more dry matter than where the intercrop was two species. The study further found that inclusion of drought-resistant species with deep rooting system allowed them to extract the bulk of soil water from deeper in the soil profile, leaving more water available near the surface for use by other species in the mixture.

4.5.6 Effect of four legume integration methods on dry matter production

Total dry matter production differed significantly (P≤0.05) between the four legume integration methods (Figure 11). The results showed that establishment of pastures through sowing on seedbeds produced the highest dry matter. This was followed by dry matter production from plots sown through furrows and bands which produced similar (P≤0.05) amounts of dry matter. Pastures established through furrows had 13% more dry matter than those established through bands. Pastures established through raking of soils produced least (P≤0.05) dry matter, which was attributed to poor establishment of the legumes.

These results are in agreement with those of Crowder and Chheda (1982) and Skerman *et al.* (1988) who reported that most successful pasture establishments were obtained from well prepared seed beds. The report recommended that the smaller the legume seed to be established, the finer the seedbed should be. Crowder and Chheda (1982) noted that sowing in rows facilitated weeding and cultivation especially during the early stages of pasture establishment. To minimize grass and legume competition in mixed pastures, legumes should be sown first, followed by grasses after a short time since grasses are generally more aggressive than legumes.

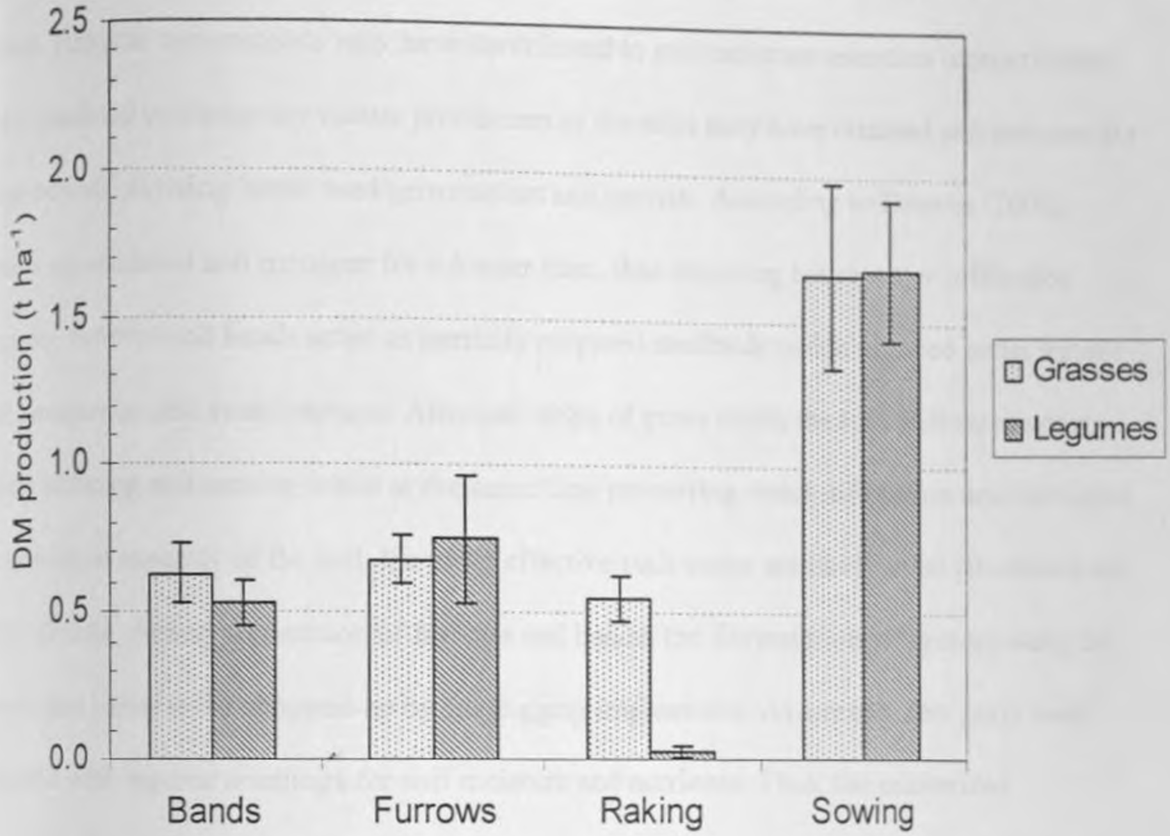


Figure 11: Effect of four legume integration methods on dry matter production (t ha^{-1}) of grass/legume mixed pastures

The similar levels of dry matter production from furrows and bands were attributed to three reasons. First, the two methods may have contributed to soil moisture retention (conservation) which translated to higher dry matter production as the soils may have retained soil moisture for longer periods allowing better seed germination and growth. According to Drewes (2000), furrows accumulated soil moisture for a longer time, thus allowing better water infiltration. Secondly, furrows and bands acted as partially prepared seedbeds which allowed better legume seed germination and establishment. Alternate strips of grass check the rate of flow of water thereby reducing soil erosion while at the same time promoting water infiltration and the higher the infiltration capacity of the soil, the more effective such strips are likely to be (Bartholomew, 2000). Thirdly, during preparation of furrows and bands, the fibrous roots of grasses along the furrows and bands were chopped-up by the digging implements. As a result, few grass roots competed with legume seedlings for soil moisture and nutrients. Thus, the minimized competition from grasses may have allowed the developing legume roots to penetrate the 0-30 cm soil layer where most fibrous roots of grasses were located. To minimize competition between grasses and legumes during the pasture establishment phase, Humphreys (1978) recommended use of economic techniques such as heavy grazing before seeding legumes to suppress grass growth.

Competition for space, soil moisture and nutrients between young legume seedlings and the already developed grasses resulted in low dry matter production from pastures established through raking of soils, due to germination failure and early death of legume seedlings. Seedlings that germinated took long to reach the 15 cm height (for clipping) due to competition from grasses. Once the dry conditions set in, the young seedlings died due to lack of proper establishment, and the few that survived got stunted and yielded low dry matter as shown in Figure 11. It is also possible that some of the legume seeds sown through this method may have been exposed to the surface and therefore could not germinate while others may have been washed away by runoff.

Results from the current study are in agreement with those of Mnene *et al.* (1998) who found that reseeding denuded rangelands in Kajiado District requires creation of micro-catchments (for seed and moisture retention). The study employed the pitting method to reseed with mixtures of *Cenchrus ciliaris, Chloris roxburghiana* and *Eragrostis superba* grasses and *Stylosanthes scabra* legume. There was no seed establishment in areas between the pits, which was attributed to the hard surface that inhibited penetration into the soil by roots of the germinating seeds. However, there was a 20-fold more herbage production in the pits than areas with no pits (controls) which was attributed to soil moisture retention that enabled better herbage production.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

Results obtained from this study have shown that Glycine, Siratro and Stylo are suitable forage legumes that can be integrated into natural pastures to improve the quantity and quality of livestock feed and also for enhancing the soil fertility of semi-arid rangelands of Kenya. This conclusion meets the aim of the main objective of this study which was concerned with introducing forage legumes into semi-arid rangelands with an aim of improving the productivity of the natural pastures. The specific objectives were met to a considerable extent as shown by the following specific conclusions and recommendations:

5.1 Conclusions

i) The first objective of the study was concerned with legume screening to understand the characteristics of five forage legumes with a view of identifying those that could be introduced into natural pastures of semi-arid rangelands to enhance dry matter production and nutritive quality of livestock feed. Results from the various experiments showed that Glycine, Siratro and Stylo are suitable for integration into natural pastures of semi-arid rangelands due to their ability to produce high dry matter of 10.31, 7.81 and 3.52 t ha^{-1}, respectively. The legumes are also characterized by a perennial growth habit and possession of deep tap roots to source soil moisture and nutrients from deep soil horizons. In addition, these legumes withstood heavy grazing, improved soil fertility and were self-seeding which meant they were capable of self-propagation within pastures.

ii) The second objective of the study involved determination of suitable defoliation intensities of natural pastures in semi-arid rangelands that could result in production of high dry matter. This study found that a defoliation intensity of 15 cm height after every two months contributed the highest dry matter yields possibly due to growth of more stems and branches by grasses and legumes. Glycine, Siratro and Stylo produced high dry matter because they possessed hidden crown buds just below the soil surface which was a desirable attribute as the legumes were capable of regeneration from the buds after intensive defoliation and grazing by livestock.

iii) Germination and establishment of legumes was generally better and quicker in monoculture stands than when the same legumes were sown mixed with natural pastures. Competition for soil moisture and nutrients between legume seedlings and the already established grasses may have contributed to the slow establishment of legumes intercropped with grasses. To overcome this, establishment of Glycine, Siratro and Stylo into natural pastures requires some form of partial seedbed preparation to sow the legume seeds and also to provide the seedlings a suitable environment for germination and establishment with minimal competition from the grasses.

iv) Studies conducted on effect of burning and slashing herbage on natural pasture regeneration and soil chemical properties showed that burning herbage resulted in better regeneration of the pasture by favouring the growth of grasses while suppressing the growth of dicotyledonous weeds. Moreover, burning pasture herbage improved the soil pH and increased phosphorus, potassium and calcium contents in the soil while having detrimental effects on the soil's organic matter and nitrogen content. However, the increased nutrients may be short-lived in the soil after being exposed to erosion, leaching and other agents of soil degradation. The practice of burning herbage of natural pastures may have provided short term desirable effects such as release of nutrients immobilized in foliage. However, the long term effect of the practice is to accelerate land degradation in the rangelands and it should be discouraged.

v) Results in support of objective two showed that inclusion of Glycine and Siratro into natural pastures resulted in higher dry matter production of 40 and 42%, respectively, as compared to that produced from natural pasture. Stylo produced low dry matter than the natural pasture since it was a slow grower. Even though Glycine established more slowly, it eventually surpassed Siratro in production of dry matter possibly due to better adaptation to the environmental conditions at the study site since it was growing naturally in the area. Siratro was a also a favourite feed of wild birds which made the legume produce lower dry matter, implying that livestock and wild birds may compete for its forage once established in natural pastures.

vi) Results addressing objective three indicated that livestock fed on fodder from grass/legume mixed pastures may benefit more than those fed on natural pastures alone. This is because Glycine, Siratro and Stylo sown into natural pastures improved the quality of grasses in terms of higher crude protein, digestibility and lower fibre content. This improvement was attributed to the uptake of nutrients contained in the legume residues after decomposition and mineralization and possibly from direct transfer of the nitrogen that may have been fixed by the legumes.

vii) Results towards objective four indicated that the amount of legume residues returned to the soil seemed to determine the level of soil fertility enhancement. The high amounts of legume litter produced during the legume screening experiment when legumes were grown in monoculture stands led to a significant increase of the soil pH, carbon, nitrogen and potassium by end of the experiment. However, due to production of less legume litter during the grass/legume integration experiment, only soil pH increased while all other soil nutrients decreased from the soil by end of the experiment. In both studies, calcium and phosphorus levels decreased in the soil possibly due to utilization by legumes for their nodulation and growth processes.

viii) Objective five of the study involved determination of soil moisture extraction by grasses and legumes in mixed pastures. The results showed that competition for soil moisture was least in mixed grass/legume pastures than in natural pasture and legumes in monoculture stands. This was because of the different rooting patterns of grasses and legumes which made them extract soil moisture at different soil depths. The highest soil moisture extraction between grasses and legumes occurred in the 0-30 cm soil depth where most roots of grasses were located. The competition between grasses and legumes for soil moisture and nutrients at 0-30 cm depth may have led to the poor germination, growth and death of legume seedlings in raked plots since the grasses had a well developed rooting system by the time the legumes were sown. Establishment of bands to integrate legumes into the natural pasture may have allowed better soil moisture infiltration into deeper soil layers

ix) Sowing legumes into existing natural pastures through furrows and bands resulted in better establishment and growth of legume seedlings after grass roots were broken-up during digging of furrows and bands. In addition, furrows and bands acted as partially prepared seedbeds and soil moisture conservation structures which may have conserved soil moisture for a longer period for young legume seedlings to utilize, thereby achieving better growth. Pastures established through raking of soils resulted in low dry matter production because of germination failure and death of legume seedlings due to competition for resources with the highly resilient grasses. Sowing and establishment of grass/legume pastures on well prepared seedbeds allowed better establishment of the pasture compared to other methods. This was because the grasses and legumes were sown at the same time, thereby minimizing soil moisture and nutrient competition between young grass and legume seedlings.

5.2 Recommendations

i) There is need to upscale results of this study particularly to smallholder livestock farmers in other areas of Kenya which have similar climatic and environmental conditions like in Kajiado District.

ii) The recommended niche to establish grass/legume mixed pastures are the preserved pastures (*Olopololi*) which are protected against direct grazing by livestock. Another niche is the establishment of 'legume fodder banks' on farm plots to source fodder and seeds.

iii) Utilization of the mixed grass/legume pastures would be better when harvested in a 'cut and carry' system instead of letting the animals to directly graze in the grass/legume mixed pastures to prevent trampling and selective grazing of the legumes by livestock.

iv) The best season for sowing legumes in similar ecosystems in Kenya would be during the short rainfall season since dry periods between the short and long rainfall seasons is usually short and therefore legume seedlings may not be adversely affected by the dry conditions.

v) After establishment of legumes in mixed pastures, a harvesting interval of two months at a stubble height of 15 cm is recommended during the growing season of the pasture. But during the dry period, the interval should be lengthened to four months for pastures with Glycine and Siratro, while pastures with Stylo should be given a six months rest period before the next harvest as the legume grows slowly when intercropped with grasses.

vi) Sowing of legumes into natural pastures would be better done on furrows and bands because the structures will conserve moisture and act as partially prepared seedbeds, thus allowing better seedling germination and establishment. In addition, the structures will check the flow of runoff thereby reducing soil erosion or washing away of sown seeds and those dropping from mature plants.

vii) During establishment of mixed pastures, there is need to accord the legume seedlings a growth advantage over grasses so as to allow legume tap roots penetrate the 0-30 cm soil layer where majority of fibrous roots of grasses are located. The aim would be to minimize competition for soil moisture and nutrients by grasses and legume seedlings. One way of doing this is to ensure that, during digging of furrows and bands in an already established grass pasture, the fibrous roots of grasses along the structures are chopped up by the digging implements. But when establishing new grass/legume pastures on well prepared farms, it would be better to sow legumes first and sow the grasses later as grasses have a faster growth rate and may overshadow legume seedlings if they are sown first.

viii) Further research is recommended on the:

a) The effect of intensive defoliation (two months interval at 15 cm height) on below ground root biomass of grass/legume mixed pastures in semi-arid rangelands to understand the sustainability of such pastures,

b) The reason why range burning before introduction of legumes caused Glycine to produce more dry matter under burned conditions while Siratro produced more dry matter under unburned conditions, and

c) The contribution of indigenous herbaceous legumes such as *Rhynchosia malacophylla* and *Neonotonia wightii* to productivity of natural pastures.

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APPENDICES

Appendix 1: Soil profile description of the study site

Location	:	Sultan Hamud
Altitude	:	1280 m a.s.l.
Soil classification	:	Haplic Lixisol (FAO, 1997)
Agro climatic zone	:	V (Sombroek *et al.*, 1982)
Geology	:	Undifferentiated gneisses (Waruru, 2000)
Physiographic unit	:	Erosional Plain
Relief and slope	:	Gently undulating, 3%

Horizon			Colour (moist)	Mottling	Texture	Cutans	Structure	Biopores	Consistence	Concretions	Brief soil description
Genetic	Depth (cm)	Boundary									
Ah	0-27	Clear smooth	2.5 YR 3/4 dark reddish brown	Nil	Clay	Patchy thin clay	Weak, very fine angular blocky and sub-angular blocky	Many very fine to coarse	Friable	Nil	Well drained, very deep, dark reddish brown, friable clay to clay loam
Bt_1	27-58	Gradual smooth	2.5 YR 3/4 dark reddish brown	Nil	Clay	Broken moderately thick clay	Moderate very fine to coarse angular and sub-angular blocky	Many very fine to coarse	Friable	Nil	
Bt_2	58-97	Gradual smooth	2.5 YR 3/4 dark reddish brown	Nil	Clay	Broken moderately thick clay	Moderate very fine to coarse angular and sub-angular blocky	Many very fine to coarse	Friable	Nil	
Bt_3	97-125		2.5 YR 3/4 dark reddish brown	Nil	Clay loam	Patchy thin clay	Weak, very fine to medium angular and sub-angular blocky	Many very fine to coarse	Friable	Nil	

Appendix 2: Plant species and their families found at the study site

A) Dicots (Trees, Shrubs and Herbs)

Anacardiaceae

Lannea schweinfurthii (Engl.) Engl.

Balanitaceae

Balanites glabra Mildbr. & Schlecht

Boraginaceae

Cordia monoica Roxb.

Burseraceae

Commiphora africana (A. Rich) Engl.

C. campestris Engl.

Commelinaceae

Commelina benghalensis L.

Convolvulaceae

Ipomoea kituiensis Vatke

Euphorbiaceae

Croton dichogamus Pax

Labiatae

Ocimum suave Willd

Liliaceae

Aloe secundiflora Engl.

Mimosaceae

Acacia mellifera (Vahl) Benth

A. brevispica Harms

A. drepanolobium Sjostedt

A. seyal Del.

A. tortilis (Forssk) Hayne

Papilionaceae

Indigofera spinosa Forsk

I. volkensii Taub

Neonotonia wightii (Wight & Arn.) Verdc.

Rhynchosia malacophylla (Spreng.) Boj.

Solanaceae

Solanum arundo Mattei

S. incanum L.

B) Gramineae (Grasses)

Aristida keniensis Henrard

Cenchrus ciliaris L.

Chloris roxburghiana Schult

Dichanthium insculpta (Hochst. *ex* A. Rich) A. Camus

Digitaria macroblephara (Hack) Stapf

Eragrostis superba Peyr

Harpachne schimperi Hochst. *ex* A. Rich

Heteropogon contortus (L) Beauv. *ex* R. & Sch.

Hyparrhenia filipendula (Hochst. *ex* Steud) Stapf

Pennisetum mezianum Leeke

Sporobolus pyramidalis Beauv.

Themeda triandra Forsk.