# MICRO ENVIRONMENTAL INFLUENCES OF *Acacia etbaica* AND *Acacia tortilis* ON HERBACEOUS LAYER PRODUCTION IN MUKOGODO RANGELAND, LAIKIPIA DISTRICT.





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## DECLARATION

This is my original work and has not been presented at any other University for the award of degree.

Signed ............................ Date 16/8/96

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

Signed ............................ Date 16/10/96

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Signed ............................ Date 3/10/96

**Dr. Hans Peter Liniger**

# DEDICATION

To my mother who, though lacking college education inspired my education steadfastly.

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## ABSTRACT

The influence of the canopy cover of mature *Acacia etbaica* and *A. tortilis*, on micro-environment was studied by measuring the ground layer Above ground Net Primary Productivity (ANPP), cover, species composition, soil water and fertility status in Mukogodo, Laikipia district. The study was done in the period of October 1992 up to July 1993 in an episodic stream catchment. Four sites were chosen in 3 different range sites, based on slope, initial ground cover, woody species density and depth of the soil. These areas were designated as **Riverine** (along the river) **Glade,** (a former cattle boma), **Bare open**, (characterised by bare open patches in between the woody species) and **Bare enclosed** (similar to the **Bare open**, but enclosed at the beginning of the study). Three zones - canopy (up to the edge of the tree crown), sub canopy (extending to 1 and 1/2 radius of the canopy) and open (extending up to 3 radii of the crown) - were marked out around the above species, and replicated three times in each site.

Herbaceous layer production was assessed by clipping and a temporally cage method, above ground plant cover was monitored using a point frame method. Soil fertility status was measured using standard methods. Soil water was monitored up to 90 cm depth using a neutron probe.

The canopy zone in the **Riverine** site had significantly less ($P < 0.05$) ANPP (3.37 tons $ha^{-1}$) compared to the sub canopy and open zones (4.54 and 4.32 tons $ha^{-1}$ respectively). The **Glade** plot had at least 50 % (0.95 tons $ha^{-1}$) less ANPP in the canopy and sub canopy zones compared to the open zone (1.78 tons $ha^{-1}$) (significant at $P < 0.05$). In contrast, the canopy zones in the **Bare open** and **Bare enclosed** plots had at least 2 times more production in the canopy zone (2.94 and 3.32 tons $ha^{-1}$ respectively) than in the open (1.37 - 1.49 tons $ha^{-1}$) (significant at 5

%). There was consistently more cover under the canopy zones of all the plots than in the open areas. The species composition under the canopy zone was more in abundance relative to the open zones. Mineral nutrients were also higher under the canopy zones than in the open zones in all the plots. Available soil water was consistently more in the open zone of the **Riverine** plot than in the under canopy zone. However, the opposite was the case in the rest of the plots.

Available soil water explained at least 60 % of the variations in ground layer ANPP among the zones and the sites, while soil nutrients, especially, Nitrogen, Phosphorous and Potassium accounted for at least 30 % of the variations. Most of the soil water and soil nutrients under the canopy zone may have resulted from runoff from the adjacent open areas, litter decomposition, and other exogenous sources like dung deposition from mammals. Conservation and management efforts of the range should give cognition to the differential response in ANPP to the presence of the woody species in various range sites.

## CHAPTER I

# INTRODUCTION

Of the Kenya's total land area, more than 80 percent (some 40 million hectares) is unsuitable for arable farming and intensive livestock production for various reasons, but mainly because of too little rain (G.O.K. Sessional paper No 1 1986). These Arid and Semi Arid lands (ASALs) form the bulk of the Kenyan rangelands and are characterised by a diverse vegetation mosaic, high spatial and temporal rainfall variations, little precipitation, high temperatures, rough topography, poor soil fertility and pests and diseases. Because of these characteristics the Arid and Semi arid lands pose enormous challenges to range resource managers.

As Kenya's human population increases so does the demand for livestock products and range resources, that puts these fragile environments under pressure. How to sustain rangeland productivity, to provide for more and more people, is the challenge facing range resource managers and planners today.

The large numbers of wild and domestic ungulates rely almost entirely on the herb-layer for their nutritional needs, while shrubs and trees furnish browse and shelter. It is widely accepted that the rangelands face retrogression to less productive conditions (Hansen et al 1986). Bush encroachment has been one of the major problems which have caused not only reduced forage production but have also made forage produced in dense thickets inaccessible (Heady 1960; Kinyamario 1985, Thomas and Pratt 1967; Pratt and Gwynne 1977). Massive efforts and resources have therefore been expended in bush clearing and methods of control. However, justification for 'bush clearing' has been related traditionally to the enhancement of livestock production as a result of increased forage production. It has often been argued that increase in trees and shrubs relates to a concomitant decrease in herb-layer forage production. These claims have been made in the absence of any supportive evidence showing proportional loss of herb layer forage as a result of the presence of shrub and tree stands.

Trees and shrubs however, have been recognised for their role in maintaining favourable climate, prevention or reduction of wind and water erosion, creation of favourable conditions for the cycling of soil nutrients and addition of humus and nitrogen to the soil. Proper management of the ligneous layer must therefore consider joint production relationships. The interaction of the woody species with herbaceous layer is complex, having adverse as well as beneficial impact on each other. Trees are known to compete with the herb-layer for nutrients, light and water beneath their canopy which are beneficial to the herb layer. Not least to this interaction, is the allelopathic effects - plant exudates that normally interfere with another plants growth and performance. The net effects of these levels of interactions have not been very well understood and the results from one region or group of species are hardly suitable for generalisation. Of major importance in the above relationships, is the role played by the woody canopy in influencing the understory characteristics. The canopy exerts a major influence on the temperature, vapour concentration, and radiation regimes. Interception and transmission of precipitation are also affected as are soil temperatures (Maranga 1984, Belsky *et al* 1989) and soil heat flow. Indirect influence on soil moisture and soil temperature, residue decomposition and other soil microbial processes are all pertinent to the understory performance. Additionally, the trees and shrubs not only offer a real opportunity for upgrading the soil and improving micro-climates and livestock production conditions, but also aid in halting the incessant and attendant erosion hazards in the arid and semi arid areas - which might lead to desert like conditions.

However there is a conspicuous absence of data showing the extent to which the understory characteristics are affected by the canopy in the arid and semi arid areas.

The findings of the few studies conducted in Kenyan's southern rangelands (Belsky *et al* 1989, Georgiadis 1989) can hardly be generalised to more degraded situations, This study therefore attempts to quantify the amount of understory, Above - ground Net Primary Production (ANPP) as influenced by *Acacia etbaica* and *Acacia tortilis* canopy. The study also investigates some soil fertility parameters and soil moisture beneath and beyond the woody canopies. The importance of the study is further emphasised by the considerable indiscriminate tree and shrub removal from the study area by a combination of natural and anthropogenic factors; felling of trees and shrubs for both fire wood and charcoal burning.

The dual role of woody species seems to be as source of forage to animals in the dry season as well as refuge for perennial plant species. A quantitative analysis of the vegetation and other ecological parameters under the canopy of the woody vegetation in comparison to areas beyond the canopy is crucial in explaining the particular micro- environment found under the canopy of the trees and or shrubs. This study therefore sought to quantify the levels of production not only as it was affected by the tree's canopy, but also as affected by site differences

The objectives of the study were;

a) Determine the above ground Net Primary Production (ANPP) under the canopy, Sub canopy and open zones of *Acacia etbaica* and *Acacia tortilis* in relation to four range sites.

b) Describe the cover and understory species composition of the canopy and outside the canopy.

c) Determine the soil fertility status and changes in soil moisture beneath the *Acacia etbaica* and *Acacia tortilis* canopy and in the open.

d) Correlation of (c) above to herb - layer performance (a and b).

## HYPOTHESIS

1) The Above ground net primary production in the three zones is the same

2)The four range sites (Riverine, Glade, Bare open and Bare enclosed) influenced the Above ground net primary production in the three zones similarly

3)There is similarity of herblayer cover levels and species composition in the three zones and the four sites.

4)There are no differences in soil fertility status and soil moisture levels in the three zones in the four sites.

# CHAPTER II

## 2.0 LITERATURE REVIEW

### 2.1 RELATIONSHIP BETWEEN WOODY SPECIES AND UNDERSTORY

Most of the problems of the rangelands, and in particular bush encroachment emanates from the type of management or use system in practice. For instance decrease of frequency and intensity of fire and an increase in livestock grazing pressure has been reported to lead to bush encroachment. Thomas and Pratt (1967) and Heady (1960) reported that heavy bush thickets reduce herbaceous forage production and that most forage that is produced in dense thickets is invariably inaccessible to livestock. While this finding is true and describes a prevalent problem in the range areas, it implies that more resources should be devoted to removal of bushes which would lead to a concomitant rise in herbaceous forage production. Indeed there has been a general negative attitude toward the role of woody plants on rangelands which has provided an impetus for intensive research on control methods and implementation measures. This approach to the complex interaction between the ligneous layer and herbaceous layer interface, is largely fallacious and overly simplistic (Le Houerou 1989, Wenner 1981 Rattiff *et al* 1991) Ligneous species not only have important contributions to the societal demands; animal fodder, fire wood and charcoal wood and fibre, but also plays an important role in creating the necessary micro-environment conducive to the herbaceous layer material production. The fast growth of human and animal population resulting in over exploitation of natural resources, sedentarisation of previously nomadic pastoralists and development of bush clearing and the fast growing expansion of cultivated areas (Le Houerou 1980 Wenner 1981) are the major threats to trees and shrubs. This might indirectly threaten the herb layer.

Georgiadis (1989) noted that production in treeless grasslands is largely dependent on rainfall, on soil types and nutrient availability and by grazing intensity. Woody species in relation to understory provide an interface through competition, allelopathy (toxic exudates) modification of microclimate, for example through shading, interception of precipitation and provision of "run-on" areas under the tree where other processes like decomposition take place.

One of the principle components of the woody species that has been of major influence to the herb layer characteristics has been the crown canopy (Lee 1978). The canopy has been recognised to modify the micro environment of the understory either favourably or unfavourably. Lee (1978) pointed out that a dense forest canopy drastically modifies climate near the ground especially net radiation, wind speed and relative amount of precipitation. He found out that on average, rainfall deficits under mature hard wood canopies may vary from less than 10% during the leafless period to more than 20% during the growing season, while the relative humidity near the ground exceeds that above the canopy.

Wenner (1981) noted that trees preserve the vegetation cover through shade, which help maintain a better microclimate thus permitting humus generation instead of humus reduction. The canopies of the trees in areas of heavy rainfall, also prevent raindrop erosion, and serve as windbreak and therefore reduce evapotranspiration. On the negative side, the tree canopies are important in reducing through fall (precipitation reduction) (Belsky *et al* 1989), and amount of radiation received.

## 2.2 EFFECTS OF THE WOODY SPECIES ON THE HERB LAYER PRODUCTION.

It should be pointed out that the majority of studies on the overstory understory interactions were carried out in the temperate environment, with only a handful relating to the tropical range situation.

Most workers have found an inverse relationship between the canopy cover and the herb layer production. Pase (1958) found that all herbaceous plant groups - grasses, forbs, and shrubs increased proportionally with the decrease in crown cover. The same finding was reached by several workers, notably; Cooper (1959) Bennet *et al* (1987) Jameson (1967), McConnell and Smith (1965) Woods *et al* (1984), Conroy *et al* (1982) Hobbs and Mooney (1986) Collins and Picket (1988) Heitschmidt and Dowhower (1991), and Pieper (1990).

Although most of these studies reached the same finding in principle, there are outstanding disparities, in causal effects as well as responses of particular taxa; Pase (1958) working with pines reported that species reacted differently to changes in crown canopy, with graminoids showing the greatest response in weight per unit area to reduction in crown diameter. He found that some species, virtually disappeared at crown densities greater than 40%, while Cooper (1959) predicted that no herbaceous vegetation would be found at crown densities above 75%.

A similar species distinctive response was also found by Pyke and Zamora (1982), who found that the graminoid production was not significantly related with any of the measured overstory structures in both single and multiple independent variable models. The reasons ascribed to the reduction are wide and far ranging, but the underlying denominator in this group of studies is the competitive interaction between the woody species and herb layer implied. Arnold (1964) found less production in the zone, where lateral roots were expected, whereas a higher production was recorded in a zone beyond the canopy. He suggested that competition for soil moisture and sunlight could have been responsible for the observed effect. Other workers that reached the same conclusion include Jameson (1967), who also suggested that possible antagonistic chemical effects and Woods *et al* (1984), on competition for light, soil moisture and nutrients. Competition was therefore highlighted as the principle factor responsible for reduced production beneath the canopy. Allelopathic effects were also suggested to be possible factors but scanty literature was found to this effect, possibly because it is not easy to separate the effects of competition from those of allelopathy.

Seasonality of the herb layer production was also detected in the influence of the crown canopy in some studies. Scrifes *et al* (1982) reported that the influence of huisache canopy on grass production was most pronounced in years when rainfall amount and / or distribution were most favourable for growth of warm season species. This study's finding was significant in distinguishing the warm season grass (which performed better in the absence of the canopy) and Texas winter grass which increased concurrently with the increase in canopy cover Heitschmidt and Dowhower (1991) also found that the biomass dynamics were closely linked to seasonal patterns of precipitation, they further suggested that the major factors affecting herbage production within the canopy area are climatic factors, particularly precipitation rather than presence or absence of the trees.

Different types of overstory affect understory production differently, possibly through a shading effect, with closed perennial canopies registering less herb layer production than more open canopies (Ratliff *et al* 1991). These types of canopies influence production in contrasting manner during drought and wet periods, with the closed canopies being more beneficial to the understory during the drought.

Areas of different potentials also respond differently in terms of productivity to the canopy cover. This is important because range lands comprise different range sites (Pratt and Gwynne 1977). Rattiff *et al* 1991 reported that areas with alluvial soils, which receive runoff water as well as normal amounts of precipitation registered higher production levels of the understory in the open than under the canopy.

This suggested that the areas beyond the canopy received the beneficial effect of full sunlight.

Although most of the extant literature reviewed found an inverse relationship between the woody canopy and the understory production, a handful were able to distinguish warm season and cold season species, with the latter found to have a positive relationship with the change in canopy: notably Pieper (1990) found that the biomass of two cool season grass species - pinyon rice grass and new Mexico mainly was positively related to the canopy cover.

Most of the bush control methods have traditionally used the above generally prevalent view that perceives the effect of the woody canopy as mainly deleterious to the herb layer production. However, as pointed out these mainly "temperate" findings must necessarily be distinguished from the tropical situation. Firstly in the temperate conditions, where one growth period is mainly experienced per year, irradiance, takes pre-eminence in relation to growth. In contrast, production in the tropics is often assumed to take place through out the year (Cox and Waithaka 1989), and is normally limited by precipitation (Kinyamario and Macharia 1992; Boutton et al 1988) and low soil moisture.

Owaga (1980) found that production in Athi Kapiti plains (Kenya) only took place during and immediately after the rainy season. Boutton *et al* (1988) also found that both Nairobi National Park and Masai Mara game reserve showed significant seasonal changes in plant biomass, with rainfall accounting for 81% of the biomass variations.

Response of the ANPP to the canopy in the tropics is normally positive with little or no production being registered beyond the canopy area. Wenner (1981) reported that grassland in an arid area of Arizona (annual rainfall 330 mm) the ground under the canopies of *Prosopis* trees had dense stands of perennial grasses with a biomass of 1,146 Kg $ha^{-1}$ compared with the areas outside the canopies with a biomass of 239 kg $ha^{-1}$. Georgiadis (1989) detected the growth response being consistently low in open soils compared to responses in sub-canopy of the *Sericocomopsis pallida* stems. Belsky *et al* (1989) recorded higher productivity under the canopy than in the open; ranging from 959 gm $m^{-2}$ under the canopy to 309 gm $m^{-2}$ in the open. The majority of the workers who recorded higher biomass production under the canopy ascribed it to the ameliorating influence of the tree canopy in a hot dry environment and to increased soil fertility found under tree canopies.

However, some studies in the tropics have also found inverse relationship between tree canopy and herb layer productivity and attributed the low productivity beneath the canopy to reduced rainfall (drought effect) and to competitive interactions between trees and herbs. Indeed, it appears that whether or not higher or lower productivity is recorded is highly dependent on the balance of competition (of light, soil moisture and nutrients) and inhibitory effects of the canopy ( e.g. reduced through fall) on one hand, with the ameliorating effects on the other hand. Belsky *et al* (1989) underscores the importance of foreign materials brought under the canopy of the tree, which in turn enhances productivity in the understory. Instances of distinction between different range sites in these form of studies, are rare. This recognition is important given the high variability in a given range area in terms of soil types, soil moisture vegetation and topography. From the foregoing literature reviewed it appears that the amounts and response of understory to the canopy is subject to existing conditions of a particular local area and generalisation of findings from one area to a highly diverse arid and semi arid area might not be appropriate.

## 2.3 INFLUENCE OF THE CANOPY OF WOODY SPECIES ON UNDERSTORY COMPOSITION AND COVER

While there is a general agreement in the literature that the canopy of woody species has a major influence on the understory composition and cover, there is conspicuous lack of agreement on the form, nature and context of this influence. Species respond differently to changes in crown canopy (Pase 1958, Cooper 1959, Arnold 1964, Rattiff *et al* 1991). Scrifes *et al* (1982) found that warm season grasses dominated in the open, vis - avis the winter grass found beneath the canopy. Abundance of all herbaceous species was found to decline greatly after formation of a closed canopy of 2-3 years in a study carried out by Hobbs and Mooney (1986). Heitschmidt and Dowhower (1991) however, did not register any changes in species composition regardless of the treatment subsequent to the removal of the canopy.

The main reasons suggested in the foregoing literature review the centres on the effect of the canopy in blocking adequate light to the understory. Hence different levels of light intensities as affected by varying crown densities seem to affect the species composition beneath the canopy (Pase, 1958, Cooper 1959, Scrifes et al 1982, Hobbs and Mooney 1986). Arnold 1964 also suggested that the increased soil moisture due to stem flow could also have been responsible for the absence of vegetation, immediately around the stem.

Other workers, however, have normally reported more species abundance as well as higher cover levels beneath the canopy than areas beyond it. Wenner (1981) for example reported that the ground under the canopies of *Prosopis* trees had dense stands of perennial grasses cover (24%) compared with the areas outside the canopies with 4% covered. This was in an area with an annual rainfall of 330 mm, typical of most of Kenyan rangelands. Georgiadis (1989) also reported that the variation in grass cover and height with increasing distance from *Sericomopopsis pallida* stems was highly significant. Some grass species e.g. *Panicum maximum* are phytosociologically related to certain woody species while others do better in the open spaces free of the shading effect (Maranga 1984). Belsky *et al* (1989) detected domination of the under canopy by the stoloniferous perennial grass (*Cynodon nlemfluensis*) with the transition in species composition from understory to open grassland occurring abruptly at the edge of the canopy. These findings from the tropical range areas are quite relevant to most of the local rangelands which seem to have been subjected to various forms and degrees of abuse, with the areas beyond the canopy being bare or dominated by ephemeral species. In Tsavo National Park (which might be regarded as fairly pristine in relation to most other range areas outside the park), Belsky *et al* (1989) observed that relative to the under canopy vegetation the open grasslands were more patchy at all sites. In light of the above foregoing, it is apparent that in hot tropics, compared to the temperate conditions, the woody canopies play an important role, harbouring more species abundance and cover relative to the areas beyond the canopy.

## 2.4 WOODY SPECIES INFLUENCE ON SOIL FERTILITY.

Nutrient status in the soil is a major factor influencing the productivity of herb layer in the rangelands. However measures of soil fertility and the relative importance of each mineral nutrient to range production have not been evaluated (Jones *et al* 1983). Owaga (1980) suggested that soils played some part in differing productivity rates. The limitation of the nutrients in the range soils, could result in competition for nutrients among the various species.

Some workers have argued that trees increase fertility by bringing up nutrients from great root depths (nutrient pumping) and return them to the ground as litter, (Wenner 1981, Charley 1977, Njoroge 1992), National Academy of sciences (1979) calculated that a leguminous crop can add up to 500 kg of Nitrogen to the soil per hectare per year. Apart from the direct contribution of the woody species to the enhancement of the soil nutrients, spatial transfer of nutrients is considerable even under normal grazing practice. This is more so due to animal movement to shade and watering points. Miyazaki (1987) noted that on warm days when the temperature exceeded $27^0$ c, 44-53 % of urination and 26-29 % of defecation occurred in the shaded area. This is very significant in that exogenous sources of nutrients might be able to compensate for the competition and even enhance productivity in the herbaceous plants layer. Indeed, Belsky *et al* (1989) suggested that the higher mineral nutrients found under the tree canopy relative to the open areas could be due to import of nutrients from surrounding areas. Observation from Laikipia shows that the presence of woody species provides a " run on " area where, the ground beneath the canopy is enriched with nutrients from areas beyond the canopy. Rattiff *et al* (1991) found that the soil under blue oak had more humus, better water holding capacity and a better nutrient status. They further found that average standing crops were greater under blue oak than in the open, possibly because of the better soil conditions. It has been observed that soil beneath canopies often show chemical characteristics quite distinct from those of inter spaces. Charley (1977) observed that the degree of difference in mineral composition of organic residues are most influential. When adequate soil moisture is present the nutrients most likely to impose limits on plant production is Nitrogen. Indeed, Le. Houerou (1989) argued that contrary to the belief that water is the major constraint to primary production, nutrients are often the limiting factor particularly Phosphorous and Nitrogen. Jones et al (1983) reported that soil fertility was more closely related to yield than such physical factors as slope, elevation, texture, bulk density or water holding capacity over the range soils.

Literature reporting actual data pertaining to the canopy, relative to areas beyond the canopy are few. However, interesting data have been generated by Georgiadis (1989) who determined that sub canopy soil had 5 times the nitrogen content and twice the carbon content of open soil as well as higher pH. The undercanopy soil was also rich in magnesium and low in exchangeable sodium. Belsky *et al* (1989) also detected higher soil organic matter (0-10 cm depth) and extractable phosphorous, Potassium and Calcium (0- 15 cm soil depth) adjacent to trunks of two tree species (*A. tortilis* and *Adansonia digitata*), with a sharp decline within the canopy zone. Differences however, due to the type of species, were not detected.

Higher level of organic carbon beneath the tree canopy was also detected by Kironchi (1992).

There is an apparent general consensus in most of the literature reviewed that there appears to be higher soil fertility (nutrient status) beneath the canopy than outside. The higher soil fertility might be responsible for better herb-layer performance in spite of any anticipated competition between the two components (woody & herbaceous). The conventional case of competition would be expected to reduce the amount of soil nutrient available to each competing component. Hence the higher levels of nutrients above seems to rule out competition as a major influence in affecting the herbaceous layer characteristics. Indeed, it is normally argued that while the woody species draw in nutrients from deeper layers, the herbaceous plants seem to get their plant nutrients from the top 45 cm thus stratifying the nutrient source horizons. However, some perennial grasses have been found to have roots as deep as 6 m in the soil and in such a case competition can not be ruled out

## 2.5 EFFECT OF THE CANOPY OF WOODY SPECIES ON SOIL MOISTURE

Probably few environmental factors are as important to the survival and growth of range plants as is the availability of water. Strange (1980) suggested that, since most plant growth depends on sufficient available soil moisture (some water also being absorbed through leaves) the effective proportion of rainfall is mostly only that amount which remains after subtraction of losses from evaporation surface runoff or seepage, and which is held by the soil within reach of plant roots. Factors which influence the effectiveness of rainfall in terms of soil moisture reserves include; vegetal ground cover which influences the rate of surface runoff and soil penetration, rainfall intensity, soil type, topography and evaporation rate.

Limitation of moisture in the soil is expected to result in competitive association between woody species and the herb layer. Furthermore the sheltering effect of the canopy may enhance the drought effect due to root competition for moisture (Moges 1992). This is in addition to the interception of precipitation by the canopy. Activities such as overgrazing may also indirectly diminish soil water reserves through accelerated runoff, which can result in a low soil moisture regime akin to a drier climate (Strange 1980). The amount of available water in the soil at a time is directly related to the amount of precipitation and the amount of water lost through transpiration and evaporation (Hocker Jr 1979, Liniger 1988, 1992a, 1992b).

Studies of water depletion rates in forest stands indicate that water is removed from all portions of the soil occupied by roots (Hocker Jr 1979). Further, these studies suggested that during the growing season and after a protracted period of the soil draw down, the lower soil horizons are nearly exhausted of water. Therefore the upper part, particularly the organic layer, play an important role in supplying water to plants during the remainder of the growing season. Boutton *et al* (1988) found a strong correlation between biomass production and soil moisture in Masai Mara ($r = 0.94$) and in Nairobi National Park ($r = 0.90$). The study also found that soil moisture accounted for 71% and 88% of the variation in seasonal value of live biomass at Nairobi National Park and Masai Mara respectively.

Singh et al (1990) reported that soil moisture under the tree cover was higher in surface layers (0-30 cm) than subsurface layers (30-60 cm) in two seasons. This has the important implication that the trees derive their water mainly from the subsurface horizons. This would tend to preclude competition for water between woody species and the herb layer. Another interesting finding that strengthens this hypothesis was that in grassland moisture in situ was observed to be higher in subsurface layer (30-60 cm) than the surface layer (0-30 cm) in dry season, while in wet period the trend was reversed. However there is no general consensus in this in the reviewed literature.

It has been found that plants of different life forms are associated with one another in definite zonal patterns; Arnold (1964) suggested that competition for soil moisture may account for the differences in composition among the zone under the canopy, root zone and away from the influence of the trees. Less biomass production was found in the third zone where a lot of root hairs were found, which probably depleted soil moisture rapidly. Other workers have also recognised the positive role of the tree canopies in longer retention of soil moisture by slowing the drying process (Rattiff et al 1991). Belsky et al (1989) also found that at the beginning of the two rainy seasons in November and March soil water contents were higher in the open than under the trees. However later during the dry season and over the January - March dry period, soil water contents were higher beneath the tree canopies at all depths (5- 10 cm, 15- 20 cm and 25 - 30 cm). This underscored the importance of the canopies in slowing down the drying process, probably through lower temperatures and reduced radiant energy. Belsky et al (1989) also found no reduction in productivity due to competition and suggested that the negative effect of competition could be more than compensated for by increased soil fertility and improved plant water relations

From the foregoing it is clear that little has been done on tropical soils in semi arid regions of Africa. Attempts to relate the overstory - understory interactions in soil water relations are rare and scarce. Monitoring the water in order to define the amount of available water and its change throughout the season, provides very important information for crop performance and water balance (Liniger 1988, 1992 a 1992 b).

## 2.6 OTHER FACTORS INFLUENCING HERB LAYER PERFORMANCE

There are other factors that are potentially useful to herb layer productivity. These includes surface temperatures (Maranga, 1984), relative humidity (Lee, 1978), evapotranspiration and wind speed under the canopy relative to open areas. Belsky *et al* (1989) reported lower temperatures under the canopy relative to open areas. Irradiance was also found to reduce by 65 % during 5.5 hours of shade and by 45 % during 20 hours. The reduction of irradiance in the tropics is potentially beneficial as it may reduce the level of albedo (i.e. reflected radiation).

Direction of water flow as determined by configuration of the ground can greatly affect the amount of soil moisture in any place and consequently the growth of plants. This effect is most noticeable in arid regions. vegetation grow in valleys and depressions due to rain water concentration that creates the effect of a better rainfall regime (Strange 1980). This recognises the inherent topographical variability, resulting in varied potentials in Kenyan rangelands

## CHAPTER III

## 3.0 MATERIALS AND METHODS

### 3.1 STUDY AREA (see appendix 1 and 2)

The studies were carried out in Mukogodo - Doldol division, in Laikipia district. This was in a catchment located in ILpolei group ranch. The catchment is about 252 hectares in size and is located between Longitudes $37^0$ 03' E and $37^0$ 04 'E, and Latitudes $0^0$ 49' N and $0^0$ 05' N: a distance of approximately 40 km off the Nanyuki - Doldol all weather roads. It is along the Doldol - Ol Kimenjoi road.

#### CLIMATE

The area has a bimodal rainfall varying between 380 mm and 600 mm (Kironchi, 1992, Mwihuri in prep, Liniger 1992). The rainfall has peaks in April and November.

Rainfall from 1990 to 1992 recorded in the same study site (Mwihuri, in prep) meteorological station indicated that the annual average ranged from 219 to 247 mm.

The annual air temperatures are between 18 $^0$c to 20 $^0$c (Kironchi 1992) for the region. However the maximum and minimum temperatures recorded in the catchment from 1991 to 1993 varies from a monthly average of 10.0 $^0$c (minimum in August and September ) to 27.1 $^0$c (maximum in February).

The daily average evaporation rate recorded in the catchment in 1990 to 1992 varied from 4.6 to 7.8 mm, while the monthly average ranged from 13 mm in December to 26 mm in February.

## GEOLOGY

Laikipia district is underlain by metamorphic rocks of Precambrian age. This metamorphic complex is exposed to the surface in north eastern parts of the district, which includes most of Mukogodo division. This Basement complex consists of gneisses and migmatites (Liniger, 1992, Kironchi 1992).

## PHYSIOGRAPHY

Mukogodo division is dominated by rolling topography with many of the hilltops being dominated by gneisses, migmatites and granites of the basement complex (inselbergs). The elevation in the area lies between 1600 m to 1800 m. The general slope of the area lies between 0 to 16% (Liniger 1992a, Mwihuri, in prep ).

## SOILS

The soils in Mukogodo are mainly determined by the parent material (bedrock) which are predominantly gneisses and migmatites. The soils which have a flat to hilly relief with slopes of 2 - 20 % are excessively drained, very shallow to moderately deep, reddish brown friable to loose, loamy sand to sandy clay, very bouldery to rocky. They have weak, fine subangular blocky structures (Mainga *et al* 1992).

Mainga *et al* (1992)'s study differentiated the soils of the foot slopes and the soils of the uplands. The soils found in slopes varying from the 2 - 5 % were found to have originated from colluvial material derived from basement system rocks, with undulating to rolling relief. These soils were described as, well to moderately drained, dark brown to dusky red, friable loamy sand to clay. In contrast the soils up the slope which are eroded, well drained shallow to moderately deep, reddish brown to dark reddish brown, friable strongly calcareous, sandy loam to clay with iron and manganese concretions. These natural soil variations together with vegetation aspects were used as deciding factors for the location of the experimental plots.

The soil reaction is medium to slightly acid. The catchment area, has had moderate to severe soil erosion especially where vegetation cover has been abused or removed (Njoroge 1992).

## VEGETATION

The vegetation has been described by Taiti (1992) as being constituted of *Acacia mellifera* bushland. The vegetation reflects the edaphic conditions (topography, soil and drainage) of the landscape which determine its ecological potential.

As the implied classification suggests the woody layer is dominated by *Acacia mellifera* (multi stemed bush, with shiny leaves and short hooked spikes). Others includes *Acacia etbaica, Acacia tortilis Commiphora africana,* and *Carissa edulis.* The perennial grass species found in the area included *Pennisetum mezianum, Pennisetum stramineum* and *Eragrostis* species. Other conspicuous grasses include *Cynodon dactylon, Aristida* species, *Tragus beteronianus* and a high presence of *Cyperus* species.

However the ground layer is patchy and mainly clustered under the trees and bushes, while most of the area between the trees is exposed for most of the year (see plate 1)

## 3.2 SOCIO- ECONOMIC BACKGROUND

The historical background of Mukogodo can be traced back to 1936 when the native reserve was established in northern Laikipia and remained isolated throughout the colonial history, bounded by large scale private ranches, with closed fences along the Southern and Western perimeters of the division. Herren (1991) noted that the isolation of Mukogodo has not changed much since independence.

Herren (1991) estimated the population in the division to be 11,000, a decline from the official 1979 census, which gave a population figure of 14,000. He suggested that the decline in population could be a result of emigration.

The local population is constituted of five ethnic groups with a common "Masaai denominator".

The area was estimated to have 12,800 heads of cattle and 65,400 small stock. These utilise an area of about 51,000 hectares, giving an average stocking rate of 2.5 ha / livestock equivalent.

The formation of the Native reserve had profound result on the present day range condition and trend. The curtailing of the migratory patterns led to the over concentration of livestock in a small area resulting in sustained overuse of the vegetation resource. Mwihuri (in prep) noted that the communal use of the reserve over time has led to vast differences in vegetation between the reserve and the `neighbouring privately owned ranches.

**Plate 1.** Patchy ground layer in the fore ground compared to the more dense cover under the canopy of an *Acacia tortilis*

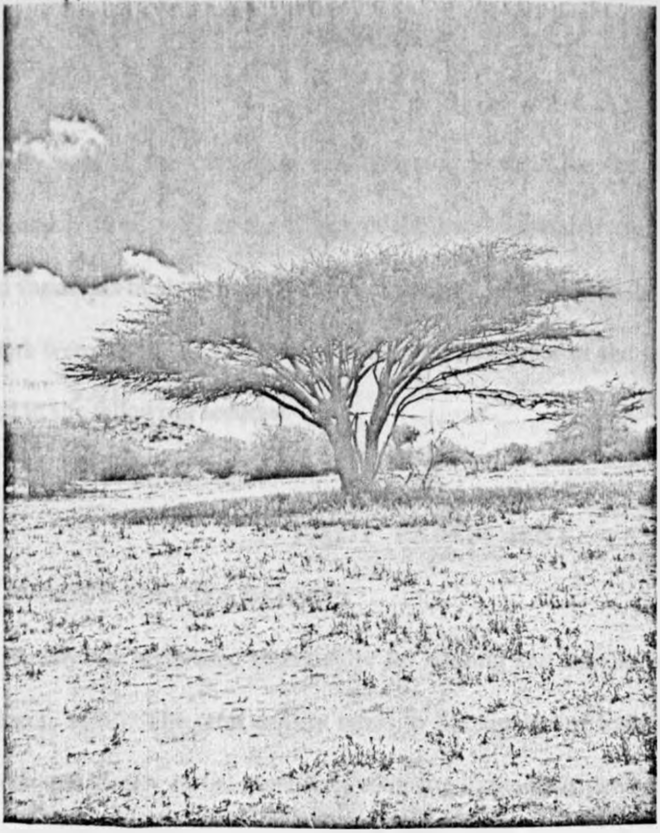
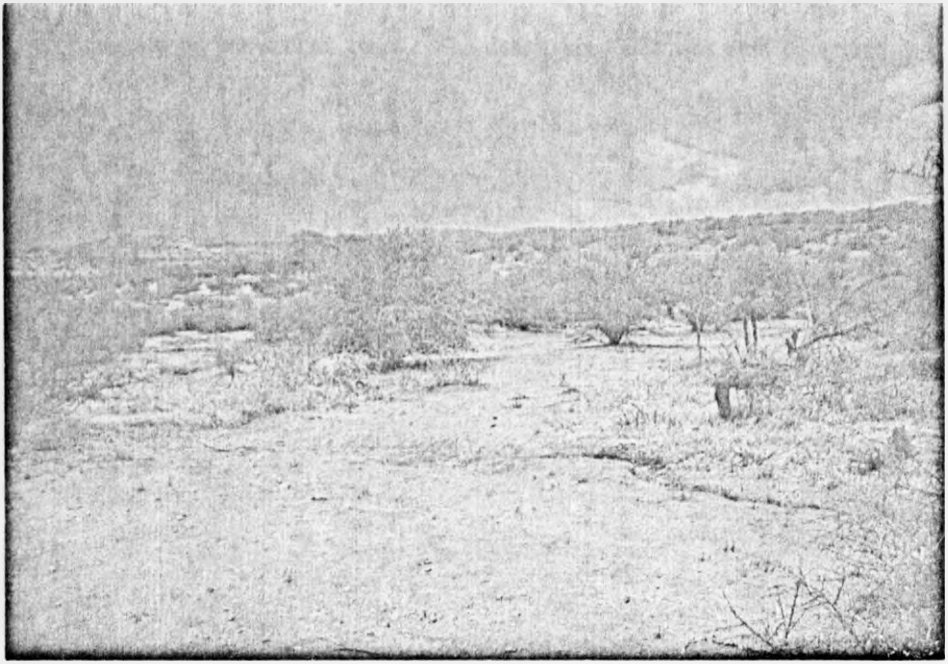


**Plate 2.** Bare patches in Mukogodo in late October 1992, before the start of the study.



## 3.3 TREATMENT DESCRIPTION AND EXPERIMENTAL DESIGN

Preliminary data of the catchment was collected to facilitate the location of the experimental plots as well as the choice of the experimental trees. The sampling followed variations in slope and the depth of the soil. In this exercise, the following parameters were assessed; woody species density and cover of the herb -- layer as described in the following sections.

### 3.3.1 PILOT EXPERIMENT

**WOODY SPECIES DENSITY**

Species density has been used successfully for reading and monitoring shrubs and trees (Pieper, 1990) The term density refers to the number of individuals per unit area. It denotes density as the number of counting individuals per unit area. In this exercise the belt transect method was used. Three, 30 m by 5 m belt transect in each area was used. All individual trees and shrubs with a height exceeding 1 meter were counted on per species bases. The density per area was then computed as follows;

$$\text{Density/ha} = \frac{n * 10000\ m^2/ha}{(30 * 5)\ m^2}$$

where,

n is the number of trees counted.

**PERCENT BASAL COVER**

The Percentage basal cover was determined using three 30 meter line transects in four areas chosen according to their soil characteristics as well as slope variations. The herbaceous materials were then categorised into forbs, perennial grasses and annual grasses. The herbaceous basal cover was then computed as follows;

$$\% \text{ basal cover of spp. a} = \frac{n \text{ cm} \times 100\ \%}{(30 \times 100) \text{ cm}}$$

Where,

n is the number of cm on the transect covered by species as basal area.

Four representative areas were subsequently chosen based on the above vegetation and soil characteristics described below in the following sections.

**(i) RIVERINE**

This area is a long an ephemeral river bed and serves as an accumulation zone (Plate 3). It generally had a higher density of taller woody species (333 trees $ha^{-1}$) with more closed canopy. This belt running along the dry river bed had a slope of between 0 - 2%, and supported a rich sward of perennial grasses as well as a host of ephemeral forbs under the bushes. The total basal cover was estimated at 3.2 % at the start of the experiment (late October).

**(ii) GLADE**

The presence of glades has been recognised through out the Laikipia ecosystem, in Kenya (Young ,1992). Isolated glades occur within Acacia bushland and Woodland communities resulting from old bomas or cattle corral. Some glades are several decades old and are recognised by the absence of woody species within the glade.

In the study area, the glade that measured 15 m by 25 m was conspicuously better covered by creeping grass primarily *Cynodon dactylon*. It had a gentle slope of 5% to 7% and was open to grazing through out the experiments. The density of the woody species within the perimeter of the glade was estimated at 333 trees $ha^{-1}$, while the basal cover was 5.1 %. (See Plate 4)

**(iii) BARE OPEN**

Apart from the above special case, most of the catchment was characterised by bare ground or patches between the bushes, with shallow gravelly soils, with a few scattered mature woody species (Plate 5). The total woody density was estimated at 267 trees $ha^{-1}$ and a low ground basal cover of 2.7 %. The slope varied from 5-15%.

**(IV) BARE ENCLOSED**

An enclosure measuring 60 x 70 m had been made six months earlier before the experiment was started. The exclosure was in an area similar to Bare open described above (iii). The aim of the exclosure was to investigate vegetational changes as a result of animals' exclusion. The differences in condition over the study period qualified the site as an area with a different potential, hence a different site (Plate 6)

**Plate 3.** A rich sward of perennial grasses in the fore ground and clumped trees and bushes in the **Riverine** plot (mid January 1993)

**Plate 4**. Perennial grass cover (*Cynodon dactylon*) in a glade, showing harvester ants patch in the fore ground (mid January 1993)

**Plate 5.** Scattered cover in the open areas between the trees in the **Bare open** Plot in mid January 1993.

**Plate 6.** Scattered cover in the Bare enclosed plot showing a movable cage in the right mid ground, the fence (local material) is visible on the left side and in the background.

### 3.3.2 EXPERIMENTAL SET UP

In the first two, Riverine and Glade, *Acacia etbaica* trees that were the second most dominant were chosen for the experiments. *Acacia mellifera* that is the most dominant, was excluded because it develops into an impenetrable thicket. This would have had the effect of the experiment of excluding animals from grazing under the canopy. It was therefore disqualified and the second dominant species taken. *Acacia etbaica*, was described by Bogdan and Pratt (1961) as a medium sized (in alluvial soils) or small sized tree of irregular shape, sometimes with a distinctive ball shaped canopy. The thorns are mixed; both long and straight, and short and hooked, occurring together, the latter usually predominating. The stalk is hairy, the flowers are white or cream, in round heads, and the pods are of medium size (1- 2 cm wide), straight and flat, with thin walls. The subspecies *platycarpa* is the one found in Mukogodo, while subspecies *uncinata*, is normally found above 5000 feet especially in Baringo district.

Three *Acacia etbaicas'* in **Riverine** and **Glade** situations were chosen in each site based on the similarities in height and crown diameter shown in Table 1.

In the **Bare open** and **Bare enclosed** sites, the only *Acacia etbaicas* found were either too small or had crowns sweeping the ground, and were not adequate to make a sample. In contrast some *Acacia tortilis* in the area of equal size to *Acacia etbaicas* were found in abundance within the experimental site. It was therefore decided to include *Acacia tortilis* in place of any unsuitable *Acacia etbaica.*

In the **Bare open** two *Acacia etbaicas* and one *Acacia tortilis* trees of the dimensions given below were chosen, while two *Acacia tortilis* and one *Acacia etbaica* were selected in **Bare enclosed** site. The underlying assumption was that *Acacia etbaica* and *Acacia tortilis* both of them being legumes of the same genera have similar influences on the underlying herb layer.

### 3.3.3 TREATMENTS

The selected trees in each site were treated as the experimental units, replicated three times, around which sampling was carried out.

Three zones were subsequently marked out around each tree namely ;

(i) Canopy: This zone extended from the tree trunk to the edge of the canopy.

(ii) Sub-canopy : A belt measuring approximately half the radii of the canopy, running around the edge of the canopy was marked out (see table 1)

(iii) open:- this was the area lying approximately three radii of the canopy away from the stem.

**Table 1. Dimensions of the experimental trees and the area covered by the canopy (average radius, m).**

| Description of the trees | | | | |
|---|---|---|---|---|
| | Riverine | Glade | Bare enclosed | Bare open |
| 1 | 3.9 | 3.3 | 3.7 | 2.3 |
| 2 | 3.7 | 3.5 | 3.5 | 3.2 |
| 3 | 3.1 | 3.1 | 2.6 | 3.3 |
| Average | 3.6 | 3.3 | 3.3 | 2.9 |
| Area (m2) | 40.7 | 34.2 | 34.2 | 26.4 |

## 3.4 ABOVE GROUND NET PRIMARY PRODUCTIVITY (ANPP) MEASUREMENT

Above ground Net Primary Production (ANPP) is defined as the mass per unit of time which is incorporated into the aerial parts of the plant community. This is one of the parameters of most value for rational range development (Defosse and Bertiller 1991). The method used for assessment of ANPP, was a summation of positive increments of total phytomass between harvests as described in Defosse and Bertiller (1991). Standing crop biomass was assessed under conditions of continuous grazing.

There are basically two methods of determining herbage weight under continuous grazing; use of moveable exclosures, and the use of small movable cages. Cages have been used more often than exclosures, (Cook and Stubbendieck 1986) and have advantages over movable exclosures. Cages measuring 1 m x 1 m x 1 m, with 2 cm mesh were placed in each of the three zones around the tree designated as canopy, sub-canopy and open (see Plate 7). Prior to the placement of the cages the standing biomass was harvested using 0.25 $m^2$ quadrat in each of the zones. The amount of standing herbage assessed was designated as $\mathbf{B_0}$. The harvest following the placement of the cage, was done by removing the cage from its position and clipping the amount in the cage, over and above the one in the open area adjacent to the cage (this is assumed to be equal to the amount used in the open by the animals). This was harvested into a separate set of bags designated as $\mathbf{A_1}$. The remaining amount assumed to be equal to the stubble outside the cage was also clipped at the ground level and designated as $\mathbf{B_1}$. All other subsequent clippings followed the same procedure. The duration between one harvest and another varied with the level of the rains, but it was normally five weeks during the rains and seven weeks during the dry spells.

ANPP over a given period was then calculated as follows;-

$$P_1 = (A_1 + B_1) - B_0$$

Where,

$P_1$ = Production over period one

$A_1$ = Amount of herbage equal to the used herbage

$B_1$ = Amount of herbage, equal to the unused biomass outside the cage

$B_0$ = Initial standing biomass.

All the harvest materials were separated into perennial grasses, annual grasses and forbs. These were then bagged and oven dried for 24 hours at $70^0$C and weighed. The cages were shifted to the adjacent area within their respective zones after every clipping.

The Means of the herbage weight calculated above of perennials, annuals and forbs were summed up over the study period and compared between the three treatment zones using a one way Nested Analysis of Variance (ANOVA) (Steel and Torrie 1980). Comparison of the means was also done among the four range sites. The Means were then separated by Tukey's W procedure outlined in Steel and Torrie (1980)

**Plate 7.** The cages used in ANPP measurement, two of the cages in the fore ground of a mature *Acacia etbaica*, and the third one in the right side in the background.

## 3.5 HERBLAYER COVER AND SPECIES COMPOSITION MEASUREMENT

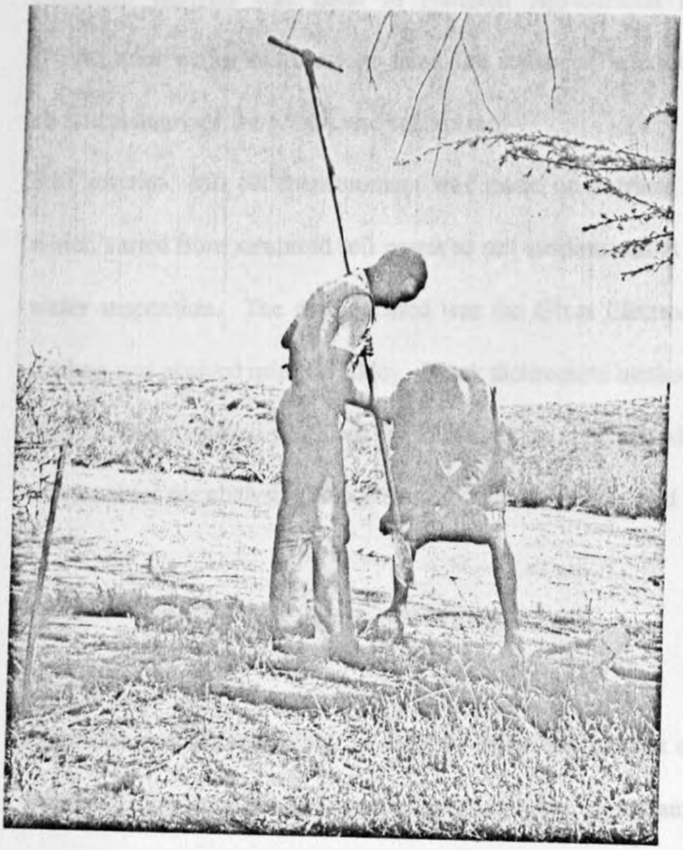
Cover is one of the primary attribute of Vegetation in ecological or range studies (Cook and Stubbendieck 1986). It is used as a basis for comparison among plants of differing life forms. Ten point frame method was used for regular cover assessment. The Philip-Harris$^R$ - point frame, containing 10 pins spaced 5 cm apart was used. The pins pass through a hole in the frame and are sharpened to a point. The point frame was placed four times in each zone around each tree, and hits recorded. Distinction was made between perennial grasses, annual grasses and forbs. In this study aerial hits were used. Percentage means per vegetation class were then computed among the zones, and range sites. The trend over time was then plotted, in time to show the cover change.

Species composition was done by cover percentage bases. Philip - Harris$^R$, point frame was therefore used for this purpose. Individual hits were recorded per species. The point frame was placed four times in each sampling zone at random and hits per species recorded. The percentage abundance of each species was computed and tabulated.

## 3.6 SOIL FERTILITY

Soils were sampled to assess the levels of some selected soil nutrients to indicate the levels of soil fertility. Soil samples were taken from 0-10, 20-30, 30-45 cm depths. The main assumption was that most of the herblayer plants derive their nutrient from these levels (except for a few perennial grasses). Three samples were collected in each zone around the tree (canopy, sub-canopy and open). The three samples were then pooled together (to reduce the cost) to make one sample, replicated three times for chemical analysis.

**Plate 8.** Soil sampling using an auger in Mukogodo.



## LABORATORY ANALYSIS

Chemical analysis was done in National Agricultural Research Laboratories (NARL) for major nutrients to show the status of soil fertility. The following chemical analyses were therefore carried out;-

Soil reaction; soil pH measurement was made on extracts from soil suspensions which varied from saturated soil pastes to soil suspensions at a ratio of 1:2.5 solid : water suspension. The method used was the Glass Electrode Method. Organic Carbon was assayed using Walkley - Black dichromate method as outlined in Ladon (1991). Olsen method was used for Phosphorous analysis, while Flame photometer was used for the analysis of Potassium, Sodium, Calcium and Magnesium

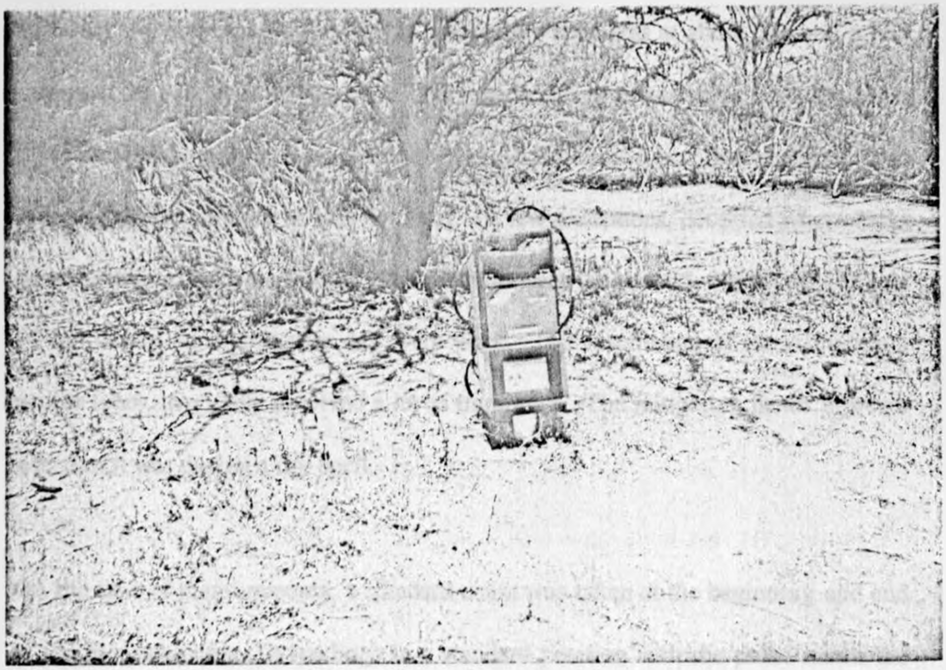
## 3.7 SOIL MOISTURE

Monitoring of the Soil Water in order to define the amount of available water and its change through out the season, provides very important information for the vegetation performance and the water balance.

Various attempts have been made to determine moisture content by indirect but non-destructive methods which include determinations based on nuclear electromagnetic, hygrometric and remote sensing, (Ladon 1991). However gravimetric determinations and measurements based on the neutron probe are the most widely used methods in the field. The neutron probe is the most satisfactory instrument for determining volumetric soil water in situ (Plate 9).

The probe was lowered into a 50 mm diameter access hole cased with aluminium tubing. A radioactive source in the probe emits fast neutrons which are slowed down or thermalised by hydrogen atoms in the soil before being counted by a detector. Since most of the hydrogen forms part of water molecules, the concentration of thermalised neutrons is related to the volumetric soil water content.

**Plate 9**: The Neutron probe used to measure soil moisture (CPN$^{R}$ 503 Hydroprobe), sitting on an access tube, in Mukogodo



### 3.7.1 INSTALLATION OF ACCESS TUBES

A 5 cm diameter auger was used to drill an access hole up to a depth of 110 cm. An aluminium tube of equal diameter was then driven into the drilled hole, leaving a protruding end of 10 cm.

One tube was thus installed in each of the three zones around the tree. The tube in the canopy zones was normally installed at a point half the radius of the canopy from the tree stem, while the tube in sub-canopy zone was at about one and a half radius of the canopy from the stem. The tube in the open zone was placed at about three radii of the canopy from the tree stem. All the three tubes, were installed in as much along the contour, as was practical. (A few exceptions, occurred where rocks beneath the surface were found). The readings were taken at 15, 30, 45, 60, 75, and 90 cm depths, at a particular day every week. The installation of the Aluminium access tubes, inevitably involved a lot of trampling. The mitigating factor however was that it was during a dry spell.

On the days of measurements, a standard count was taken at the beginning and end of the measurements (10 readings in a standard position with the probe inside the housing). For all depths, the ratio of the reading divided by the standard count was used for further analysis.

### 3.7.2 CALIBRATION OF THE NEUTRON PROBE

The neutron probe required calibration against gravimetric measurements to establish a calibration equation for predicting volumetric water content of the soil from count ratio measurement.

"Dry period" and "Wet period" calibration were done to give the Wilting point estimate and Field capacity respectively.

### 3.7.3 'DRY' SEASON CALIBRATION

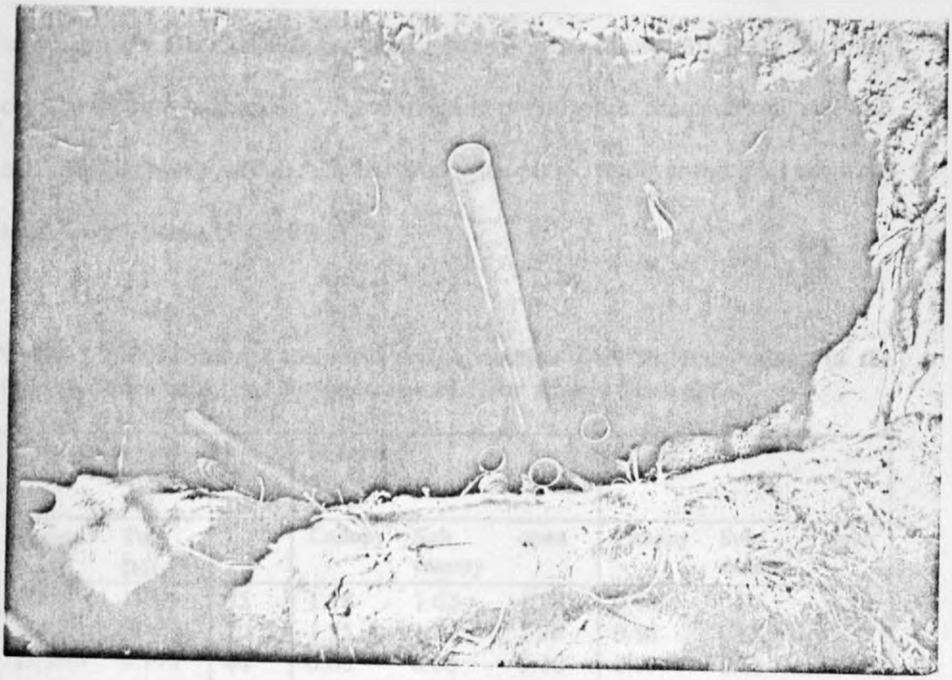
Calibration was done on a separate access tube installed outside the experimental zones. It was carried out towards the end of the dry season when the vegetation (grass and forbs) had dried up. This was on 24 March 1993.

Five readings at each of the 18, 30, 45, 60, 75 and 90 cm and twenty standard counts were taken using the neutron probe. Five core ring (110 $cm^3$), undisturbed soil samples were then taken from each depth and put into plastic bags. The samples were subsequently weighed and oven dried for 24 hours at $105^0C$. They were then weighed again and the difference in weight recorded

### 3.7.4 WET CALIBRATION

An aluminium access tube installed 3 m away from the 'dry' calibration access tube was used for wet calibration in 24 June 1993. Metal sheets were placed around the tube at a radius of 1.5 meters from the pipe. The metal sheet was 15 cm high and inserted 5 cm deep. The space around the pipe within the metal sheet confinement was filled with grass mulch. An average of about 400 litres of water was then applied every day and covered using plastic sheets to avoid evaporation losses. The watering was done for six days to reach field capacity and the water allowed to drain for a day. The field capacity was estimated to have been reached after the daily probe readings were found to be constant. Gravimetric samples were taken at each depth. The samples were then oven dried at 105 degrees centigrade for 24 hours and the percentage water by volume worked out by difference. An equation was then developed from both the dry and wet calibrations.

**Plate 10.** Excavation of an access tube during a calibration process; the 5 core rings used for gravimetric sampling are clearly visible.



CHAPTER IV

# RESULTS

## 4.1 HERBACEOUS - LAYER PRODUCTION

There were 4 production periods resulting from the 5 harvests employed over the study period. The first two production periods spanned over 10 weeks each and covered the first rain season. The subsequent period was a comparatively dry spell and stretched over 6 weeks. The last production period was over the short rains and lasted over 8 weeks (Table 2).

**Table 2. Above ground net primary production (ANPP), tons values in the Canopy, sub canopy and the open zones in four sites in Mukogodo.**

| Growth period | | No. of Days | Riverine | | | Glade | | |
|---|---|---|---|---|---|---|---|---|
| From Date | To Date | | Canopy | Sub canopy | open | Canopy | Sub canopy | open |
| 28/10/92 | 11/1/93 | 75 | 1.18 | 1.62 | 1.27 | 0.03 | 0.03 | 0.12 |
| 11/1/93 | 22/3/93 | 70 | 1.25 | 1.72 | 1.78 | 0.86 | 0.68 | 1.37 |
| 22/3/93 | 6/5/93 | 44 | 0.06 | 0.00 | 0.00 | 0.00 | 0.11 | 0.15 |
| 6/5/93 | 2/7/93 | 58 | 0.79 | 0.99 | 0.54 | 0.02 | 0.13 | 0.10 |
| Total | | 247 | 3.28 | 4.32 | 3.59 | 0.92 | 0.96 | 1.74 |

| Growth period | | No. of Days | Bare open | | | Bare enclosed | | |
|---|---|---|---|---|---|---|---|---|
| From Date | To Date | | Canopy | Sub Canopy | open | Canopy | Sub Canopy | open |
| 28/10/92 | 11/1/93 | 75 | 1.31 | 0.43 | 0.22 | 0.24 | 0.66 | 0.17 |
| 11/1/93 | 22/3/93 | 70 | 1.46 | 1.30 | 0.73 | 2.02 | 0.72 | 0.89 |
| 22/3/93 | 6/5/93 | 44 | 0.00 | 0.29 | 0.28 | 0.00 | 0.10 | 0.00 |
| 6/5/93 | 2/7/93 | 58 | 0.08 | 0.18 | 0.08 | 1.06 | 0.27 | 0.09 |
| Total | | 247 | 2.84 | 2.20 | 1.31 | 3.32 | 1.75 | 1.06 |

All the plots registered production over the first growth period, ranging from 0.03 tons $ha^{-1}$ in the Glade plot to 1.31 tons $ha^{-1}$ in the canopy of the Bare open plot. This increased in all the plots in the second period (11/1/93 to 22/3/93). Only a modest level of production was registered in the dry spell between 22/3/93 to 6/5/93. However the production improved over the short rains between 6/5/93 and 2/7/93.

The total production of the herblayer between the zones is shown below in Fig. 1. Production was noticeably lower in the canopy zones of both the Riverine and Glade plots while more was registered in the open zones. However, in both the Bare open and Bare enclosed sites there was a clear gradient decreasing from the canopy zones towards the open zones. In all the zones in the Riverine the production was more than 3 tons / $ha^{-1}$ whereas only the canopy zones of both the bare plots approached this level. The level of production in the Glade situation was much lower than in all the other plots.

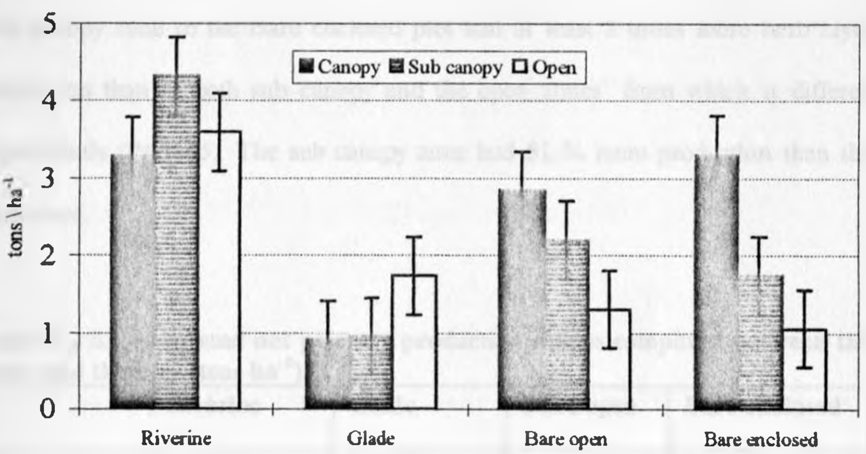



**Fig. 1. Production of the herblayer under the canopy, sub-canopy and open zones of *A. etbaica* and *A. tortilis* in four sites, in Mukogodo, Laikipia district.**

The treatment means of the total production for all the plots are shown in table 3. The tabulated results show that the sub canopy zone of the Riverine plot had significantly more production than both the canopy and open zones.($p < 0.05$). The canopy and open zones had 30 % and 25 % less production than the Sub canopy zone in Riverine plot.

In the Glade plot the herb layer production in the open zone was approximately double the amount in either the canopy or sub canopy zones. This was statistically significant at $P < 0.05$ level. The sub canopy zone had the same level of production as the open zone.

In the Bare open plot the canopy zone had at least 2 times more herb layer production than in the open zone and about 30 % more than in the sub canopy (significant at $P < 0.05$). The sub canopy zone had also significantly ($P < 0.05$) more production than the open zone.

The canopy zone in the Bare enclosed plot had at least 2 times more herb layer production than in both sub canopy and the open zones from which it differed significantly ($P < 0.05$). The sub canopy zone had 51 % more production than the open zone.

**Table 3. Above ground net primary production means compared between the zones and the sites (tons $ha^{-1}$).**

| | Riverine | Glade | Bare open | Bare enclosed |
|---|---|---|---|---|
| **Canopy** | $3.28^{1a*}$ | $0.92^{1b}$ | $2.84^{1a}$ | $3.32^{1a}$ |
| **Sub canopy** | $4.32^{2a}$ | $0.96^{1b}$ | $2.20^{2c}$ | $1.75^{2c}$ |
| **open** | $3.59^{1a}$ | $1.74^{2b}$ | $1.31^{3bc}$ | $1.16^{3c}$ |

*Means with different number superscripts down the columns and different letter superscripts across the table are significantly different at $P < 0.05$

The Above ground net primary production in the canopy zones of Riverine and Bare enclosed did not differ significantly ($P < 0.05$), while the canopy zone of the Bare open plot , though significantly different, was only 15% less than in the Riverine.

However the canopy zone in the Glade was at least 3 times lower than in all the other sites. The production in the canopy zone in the Riverine plot, though significantly lower than the other zones within the same site, had similar levels of production as those recorded in the canopy zones of the other plots except in the Glade. This implied that the levels of production in the zones beyond the canopy in the Riverine were as a result of increased production and not because of a decline in production in the canopy zone.

All the sites exhibited remarkable differences in their open zones. The open zone in the Riverine represented a 28 % increase from the canopy, while that in the Glade represented 84 % increase from the canopy. However the herb layer production in the open zones of both the Bare open and Bare enclosed plots represented a decline of 53 % and 55 % respectively (table 3).

In conclusion, the results show that the hypotheses a); The Above ground net primary production in the three zones is the same, and b); The four range sites (Riverine, Glade, Bare open and Bare enclosed) influenced the Above ground net primary production in the three zones similarly, are rejected.

## 4.2 HERB LAYER VEGETAL COVER AND SPECIES COMPOSITION

Cover values were computed and presented in the figure 2. The cover readings was compared with rainfall values over the respective reading periods.

Generally cover development followed closely the seasonal rainfall fluctuation.

RIVERINE

The cover in all the zones started low, less than 5 % over the low October rains (< 5 mm in the whole of October). With the increase in precipitation in the following month, the sub canopy and open zones registered more cover than the canopy zone. However by the peak rainfall, cover in the canopy zone had increased more than in the other zones by a margin of about 10 %. The maximum cover values recorded were during the peak rainfall in late January at 88 %, 80 % and 76 % in the canopy, open and sub canopy zones respectively. During the dry spell in March and April the cover values in all the zones had dropped to less than 10 %. At the end of the study the open zone had 30 to 20 % more than the other zones.

GLADE

Cover values started low, at less than 4 %. The maximum cover increased to about 55 % in all the zones at the peak rainfall. Although the response in cover values to the rains were not as pronounced as in the Riverine, there was more cover in the canopy zone than in the other zones during the long rains (May - July).

BARE OPEN

Although the cover values started at the same levels of less than 4 %, there was consistently more cover in the canopy zone than in any other zone through out the study period The maximum cover reading was 80 % in the canopy zone. This was more than 2 times the vegetal cover in the sub canopy and open zones.

BARE ENCLOSED

The pattern in cover development followed closely that monitored in the Bare open. However the peak values in the sub canopy and open zones were higher than in the latter plot.

There was overall more foliage cover in the Riverine plot than in any other site. However, over the rain season, cover development in the canopy zones in both the bare sites matched those recorded in the Riverine site. During the dry season cover in all the sites was less than 10 %. The results therefore indicates that the zones influenced the cover differently, with the canopy zone being more favourable in cover development in all the sites. The effects of the canopy are much more pronounced in the "upper slope" sites.

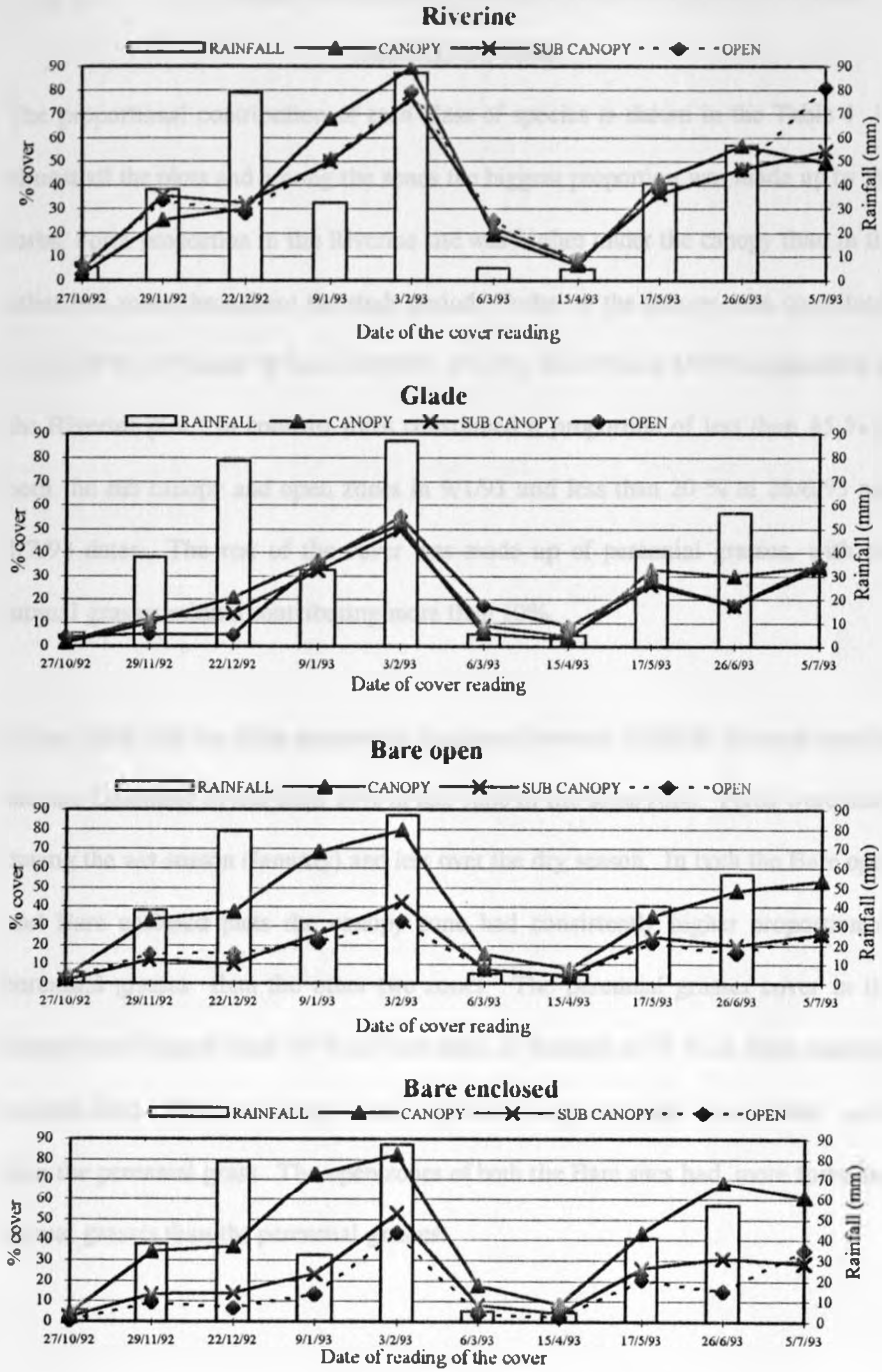



**Figure 2. The aerial cover of the herblayer of the canopy, sub canopy and open zones in four sites in Mukogodo, Laikipia district.**

### 4. 2.1 MAIN SPECIES CLASSES CONTRIBUTING TO THE AERIAL COVER

The proportional contribution of each class of species is shown in the Table 4 In almost all the plots and among the zones the biggest proportion was made up by the forbs. Forbs proportion in the Riverine site was higher under the canopy than in the other two zones throughout the study period. Forbs in the canopy zone constituted 60 %, 78 %, 50 % and 78 % in 22/12/92, 9/1 /93, 26/6/93 and 5/7/93 respectively in the Riverine plot. In contrast forbs constituted a proportion of less than 45 % in both the sub canopy and open zones in 9/1/93 and less than 20 % in 26/6/93 and 5/7/93 dates. The rest of the cover was made up of perennial grasses, with the annual grasses seldom contributing more than 10%.

In the Glade plot the forbs proportion fluctuated between 100% in the open zone in the late December to less than 10% in late June in the same zone. Forbs were more during the wet season (January) and less over the dry season. In both the Bare open and Bare enclosed plots the canopy zone had consistently higher proportion of perennial grasses than the other two zones. The perennial grasses cover in the canopy zone ranged from 35 % in Bare open in January to 58 % in Bare enclosed around June. The sub canopy zone registered proportionately more forbs' cover than the perennial grass. The open zones of both the Bare sites had more forbs and annual grasses than the perennial grasses.

**TABLE 4. Proportion of species classes contributing to aerial cover in Mukogodo.**

| | Riverine | | | Glade | | | Bare open | | | Bare enclosed | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Date of cover reading 22/12/92** | | | | | | | | | | | | |
| **Class** | can | sub | open | can | sub | open | can | sub | open | can | sub | open |
| **Pere** | 40.0 | 53.8 | 55.9 | 36.0 | 82.4 | 0.0 | 46.7 | 16.7 | 36.8 | 42.2 | 5.9 | 0.0 |
| **Ann** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 8.3 | 0.0 | 0.0 | 5.9 | 0.0 |
| **Forb** | 60.0 | 46.2 | 44.1 | 64.0 | 17.6 | 100 | 53.3 | 75.0 | 63.2 | 57.8 | 88.2 | 100 |
| **Date of cover reading 9/1/93** | | | | | | | | | | | | |
| **Pere** | 23.2 | 44.1 | 49.2 | 2.3 | 42.9 | 9.3 | 31.7 | 12.9 | 3.8 | 39.1 | 14.3 | 6.3 |
| **Ann** | 1.2 | 6.8 | 11.5 | 2.3 | 7.1 | 4.7 | 12.2 | 6.5 | 17.3 | 4.6 | 0.0 | 12.5 |
| **Forb** | 75.6 | 49.2 | 39.3 | 95.5 | 50.0 | 86.0 | 56.1 | 80.7 | 78.9 | 56.3 | 85.7 | 81.3 |
| **Date of cover reading 26/6/93** | | | | | | | | | | | | |
| **Pere** | 42.6 | 80.4 | 73.2 | 38.9 | 52.4 | 47.6 | 44.8 | 37.5 | 36.8 | 56.1 | 45.9 | 0.0 |
| **Ann** | 7.4 | 7.1 | 8.9 | 22.2 | 33.3 | 42.9 | 27.6 | 12.5 | 42.1 | 12.2 | 43.2 | 88.9 |
| **Forb** | 50.0 | 12.5 | 17.9 | 38.9 | 14.3 | 9.5 | 27.6 | 50.0 | 21.1 | 31.7 | 10.8 | 11.1 |
| **Date of cover reading 5/7/93** | | | | | | | | | | | | |
| **Pere** | 23.9 | 69.2 | 63.9 | 39.0 | 25.0 | 40.7 | 40.6 | 29.0 | 9.7 | 37.0 | 32.4 | 19.0 |
| **Ann** | 0.0 | 12.3 | 11.3 | 4.9 | 20.8 | 33.3 | 7.8 | 48.4 | 29.0 | 11.0 | 50.0 | 59.5 |
| **Forb** | 76.1 | 18.5 | 24.7 | 56.1 | 54.2 | 25.9 | 51.6 | 22.6 | 61.3 | 52.1 | 17.6 | 21.4 |

Key

| Group of species | | Zone | |
|---|---|---|---|
| **pere** | Perennial grasses | **can** | canopy |
| **ann** | annual grasses | **sub** | sub canopy |
| **forb** | forbs | **open** | open |

### 4.2.2 SPECIES COMPOSITION

The results of species composition data are shown in Table 5.

**TABLE 5: The dominant species composition (%) in the zone within the four sites.**

| | Riverine | Glade | Bare open | Bare enclosed |
|---|---|---|---|---|
| **Canopy** | | | | |
| *Pennisetum stramineum* | 29.2 | 0 | 47.9 | 49.3 |
| *Physelis peruviana* | 13.8 | 0 | 0 | 0 |
| *Cynodon dactylon* | 12.3 | 0 | 6.5 | 6 |
| *Hoslundia opposita* | 10.8 | 0 | 0 | 0 |
| *Galinsoga parviflora* | 9.2 | 0 | 0 | 0 |
| *Commelina africana* | 9.2 | 8.1 | 10.9 | 0 |
| *Portulaca oleracea* | 7.7 | 8.1 | 4.4 | 8.4 |
| *Eragrostis tenuifolia* | 4.6 | 7.9 | 6.5 | 2.4 |
| *Sedges* | 3.1 | 22.2 | 21.8 | 9.6 |
| *Chenopods* | 0 | 51.3 | 0 | 0 |
| *Amaranthus hybridus* | 0 | 2.2 | 0 | 0 |
| *Cortyledon barbuyii* | 0 | 0 | 0 | 13.2 |
| *Oxygonum sinuatum* | 0 | 0 | 0 | 3.6 |
| *Commelina beng*halensis | 0 | 0 | 0 | 7.2 |
| **TOTAL** | 99.9 | 99.8 | 98 | 99.7 |
| **Sub-canopy** | | | | |
| *Cynodon dactylon* | 67.3 | 52.4 | 25 | 17.9 |
| *Portulaca oleracea* | 9.9 | 14.3 | 25 | 2.6 |
| *Pennisetum stramineum* | 9.8 | 0 | 0 | 25.6 |
| *Sedge* | 3.3 | 14.3 | 8.3 | 10.3 |
| *Microchloa kunthii* | 3.3 | 0 | 5.6 | 0 |
| *Eragrostis tenuifolia* | 3.3 | 19 | 8.3 | 25.6 |
| *Galinsoga parviflora* | 1.6 | 0 | 0 | 0 |
| *Chenopods* | 1.4 | 0 | 0 | 0 |
| *Abutylon mauritianum* | 0 | 0 | 22 | 0 |
| *Commelina beng*halensis | 0 | 0 | 5.6 | 0 |
| *Tragus berteronianus* | 0 | 0 | 0 | 10.3 |
| *Portulaca quadrifida* | 0 | 0 | 0 | 7.7 |
| **TOTAL** | 99.9 | 100 | 99.8 | 100 |
| **open** | | | | |
| *Cynodon dactylon* | 42.8 | 47.6 | 35.5 | 0 |
| *Pennisetum stramineum* | 30.3 | 0 | 0 | 0 |
| *Gynadropsis gynadra* | 7.1 | 0 | 0 | 0 |
| *Galinsoga parviflora* | 7.1 | 0 | 0 | 0 |
| *Sedge* | 5.3 | 33.3 | 14.2 | *0* |
| *Portulaca oleracea* | 3.6 | 0 | 14.2 | *11.1* |
| *Microchloa kunthii* | 3.6 | 0 | 0 | 0 |
| *Chenopods* | 0 | 9.5 | 0 | 0 |
| *Eragrostis tenuifolia* | 0 | 9.5 | 35.5 | 88.9 |
| **Total** | 99.8 | 99.9 | 99.4 | 100 |

In the Riverine site the situation under the canopy registered a higher level of species mixture, nine species contributing to over 99% cover. *Pennisetum stramineum* was at least two times more dominant than any other species. The major species observed during the rains, under the canopy included both perennial grasses, annual grasses and forbs. Perennial grasses included *Pennisetum stramineum* (29%) and *Cynodon dactylon* (12%), while the dicotyledons included *Physelis peruviana* (13%), *Hoslundia opposita* (10%) *Galinsoga parviflora* (9%) and *Commelina africana* (9%). The annual grasses were not well represented but *Dactyloctenium aegyptium* was casually observed.

However, the sub - canopy area was strongly dominated by *Cynodon dactylon* (67%), while other species like *Pennisetum stramineum* as well as weedy herbs, were found at proportions of less than 10%. The open zone in the Riverine however, had strong representation of *Pennisetum stramineum* (30%) as well as *Cynodon dactylon* (43%). Weedy herbs, noted included *Gynadropsis gynadra, Galinsoga perviflora, Portulaca oleracea*. Annual grasses were found across all the zones in the Riverine in low levels of 2-4%. These were mainly represented by *Microchloa kunthii*.

The canopy zone situation in the Glade was dominated by *Chenopodium ovarifolium* (52%) and *Cyperaceae spp* (24%). The subcanopy, as in the Riverine was also dominated by *Cynodon dactylon* (52%) while annual grasses like *Eragrostis tenuifolia* (20%) *Cyperaceae spp* (14%) and the herb *Portulaca oleracea* (14%) were noted in the respective levels. *Cynodon dactylon* together with *Cyperaceae spp*, were the most dominant in the open zone.

In both the Bare open and Bare enclosed the dominant species was *Pennisetum stramineum*, comprising 48% and 49% of the total respectively. Other species under the canopy of these two plots included *Commelina africana, cyperus spp* and *Eragrostis tenuifolia*. The species in the sub canopy of the two plots included *Commelina africana, cyperus spp* and *Eragrostis tenuifolia*. The open zone of these two plots was dominated by *Cynodon dactylon* at 18 to 25% respectively. The rest of the species were *Pennisetum stramineum* in Bare enclosed (25%) and *Portulaca olearacea* in Bare open. Others of less importance in magnitude included *Eragrostis tenuifolia, Microchloa kunthii, Portulaca quadrifida, Tragus berteronianus, Abutylon mauritianum* as well as *cyperus spp*. *Cynodon dactylon* dominated the open zone of Bare open (35%) while *Eragrostis tenuifolia* (88%) dominated the open zone of Bare enclosed, and was also strongly represented in Bare open at 35%. The results indicate that the sites influences the species composition differently, while the zones, especially the bare sites have more perennial species under the canopy contrary to the other zones. However both Riverine and Glade sites had opposite results. Having more perennial species in the sub canopy and open zones.

## 4. 3 SOIL FERTILITY RESULTS

The results of the soil analysis are shown in table 6.

The soil pH varied from 5.8 in the canopy zone (30 - 45 cm) in the Riverine to 7.6 in the open zone (30 -45 cm ) of the Glade situation. The soil tended to be more acidic under the canopy of the trees than outside. In the Riverine site the pH in both under the canopy and in the sub canopy zones were the same (6.1). The pH decreased in both the 10 -20 and 30 -45 cm depths relative to the top 10 cm. In all the other sites the pH of the soil was less under the canopy of the tree than areas beyond the canopy, and increased further away. However, unlike in the Riverine plot, pH in all the other plots was slightly higher in the lower depths than in the surface 0 - 10 cm depth.

**Na, K, Ca, Mn, and Mg**

In almost all the plots, Na (m.e %) was relatively Lower under the canopy than in the zones beyond the canopy and exhibited no variation by depth.

K (m . e %), was more in the open zone than in the other zones in all the sites except in the Riverine where there was more K (m. e %) in the canopy zone in the top 10 cm. Except in the Glade site, there was a sharp decline in levels of K (m. e %) in the lower depths from the surface layer in all the other sites.

In nearly all the plots, Ca (m. e %), was at least 27 % more under the canopy than in the adjacent sub canopy zone, and at least 11 % more than the further away open zone. However, Ca (m.e %) levels were more in the open zone of the Glade and in the Bare open sites than in the other two zones. Ca (m. e %) levels in the lower depths was at least 50 % less than that recorded in the upper 10 cm in the Riverine. The other plots had similarly low levels of Ca (m. e %) in the lower depths but in less proportions. The Bare enclosed site had higher levels of Mg (m. e. %) than any other site. There was no variation by depth. Riverine site exhibited a clear gradient of the Manganese content declining away from the canopy . The levels of Mn (m. e %) varied from 0.27 (270 ppm) in the 20 - 30 cm, in the sub canopy zone of the

Glade, to 2.52 (2500 ppm) in 30 - 45 cm zone in the Riverine. This level was within the usual range of 20 - 10,000 given by Ladon (1992).

### Phosphorous, Nitrogen, and Organic Carbon

Levels of P (ppm) varied from 23.67 in 30 - 45 cm of the sub canopy of Bare enclosed to 144 in the 0 - 10 open zone of the Glade. These levels are high according to Ladon (1992) interpretation of available P. In both the Riverine and Bare enclosed plots, P ppm was at least 10 % more under the canopy than in the other zones. However the open zones in the Glade and Bare open plots had exceptionally high levels of P relative to the canopy zones. The lower depths recorded 10 - 50 % lower P levels than in the top 15 cm, in all the plots.

The levels of Nitrogen (%) ranged from a high of 0.44 in the top 10 cm depth in the Riverine to a low of 0.03 in the same depth, in the open zone of the same site. These values therefore ranged from very low to medium levels according to the classification reported in Ladon (1992). In almost all the plots, N (%) levels was more in the canopy zone than in the other zones: the Canopy zone of the Riverine had approximately 6 times and about 14 times more than in the sub canopy and canopy zones respectively. Differences in N (%) levels in the 'Upper slopes' (Bare open and Bare enclosed sites) were not very pronounced between the canopy and sub canopy zones, but were slightly lower in the open zones of both sites. There were also sharp declines in N levels from the top 15 cm and the other two lower depths.

**Table 6. Nutrient status in Mukogodo in the zones within the sites.**

| Element | Depth | Riverine | | | Glade | | | Bare open | | | Bare enclosed | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Can | sub | ope | Can | sub | ope | Can | sub | ope | Can | sub | ope |
| pH | | | | | | | | | | | | | |
| | 0-10 | 6.13 | 6.13 | 6.33 | 6.27 | 6.60 | 6.87 | 6.80 | 6.40 | 6.80 | 6.00 | 6.13 | 6.33 |
| | 20-30 | 6.27 | 6.27 | 6.40 | 6.67 | 6.77 | 7.23 | 6.60 | 6.70 | 7.07 | 6.27 | 5.97 | 6.43 |
| | 30-45 | 5.80 | 6.13 | 5.90 | 6.67 | 6.77 | 7.63 | 6.47 | 7.30 | 7.27 | 6.60 | 6.13 | 6.27 |
| Na m. e. % | | | | | | | | | | | | | |
| | 0-10 | 1.35 | 1.10 | 1.08 | 1.05 | 0.78 | 1.36 | 0.98 | 0.83 | 1.43 | 0.89 | 0.81 | 0.65 |
| | 20-30 | 0.75 | 0.81 | 0.92 | 1.35 | 1.03 | 1.72 | 0.87 | 0.90 | 1.63 | 0.89 | 0.78 | 0.83 |
| | 30-45 | 0.88 | 0.77 | 0.71 | 1.09 | 1.13 | 1.72 | 0.79 | 1.45 | 1.91 | 1.04 | 0.70 | 1.08 |
| K m. e. % | | | | | | | | | | | | | |
| | 0-10 | 2.50 | 2.03 | 1.82 | 2.23 | 1.78 | 2.99 | 1.99 | 1.75 | 2.25 | 1.94 | 1.71 | 1.30 |
| | 20-30 | 1.29 | 1.49 | 1.91 | 2.50 | 2.11 | 3.30 | 1.81 | 1.72 | 2.53 | 4.55 | 1.32 | 2.17 |
| | 30-45 | 1.28 | 3.81 | 1.06 | 2.11 | 2.13 | 3.13 | 1.43 | 1.96 | 2.97 | 1.69 | 1.02 | 2.19 |
| Ca m. e. % | | | | | | | | | | | | | |
| | 0-10 | 14.60 | 10.8 | 9.93 | 11.00 | 8.60 | 16.00 | 11.33 | 8.33 | 10.00 | 8.73 | 10.67 | 5.27 |
| | 20-30 | 7.33 | 7.27 | 9.33 | 11.33 | 11.47 | 18.13 | 9.20 | 8.73 | 18.00 | 7.67 | 7.67 | 7.00 |
| | 30-45 | 7.60 | 6.60 | 7.27 | 10.00 | 11.80 | 14.50 | 9.33 | 10.40 | 13.00 | 10.00 | 8.00 | 7.73 |
| Mg m. e. % | | | | | | | | | | | | | |
| | 0-10 | 0.84 | 0.56 | 0.71 | 0.47 | 0.57 | 0.70 | 0.60 | 0.63 | 0.63 | 0.97 | 1.43 | 1.10 |
| | 20-30 | 0.56 | 0.68 | 0.63 | 0.57 | 0.53 | 0.97 | 0.67 | 0.53 | 0.60 | 0.97 | 1.50 | 1.33 |
| | 30-45 | 0.54 | 0.54 | 0.59 | 0.53 | 0.73 | 0.67 | 0.70 | 0.50 | 0.60 | 1.07 | 1.50 | 1.27 |
| Mn m. e. % | | | | | | | | | | | | | |
| | 0-10 | 1.52 | 1.07 | 1.03 | 0.61 | 0.64 | 0.67 | 0.60 | 0.72 | 0.65 | 0.50 | 0.54 | 0.41 |
| | 20-30 | 1.93 | 0.71 | 0.84 | 0.36 | 0.27 | 0.59 | 0.57 | 0.53 | 0.75 | 0.69 | 0.50 | 0.47 |
| | 30-45 | 2.52 | 0.67 | 0.94 | 0.57 | 0.74 | 0.70 | 0.59 | 0.59 | 0.65 | 0.63 | 0.61 | 0.50 |
| P p. p. m. | | | | | | | | | | | | | |
| | 0-10 | 70.0 | 63.3 | 56.0 | 85.3 | 58.0 | 144 | 72.8 | 78.8 | 112 | 47.8 | 26.8 | 42.0 |
| | 20-30 | 38.0 | 42.0 | 56.0 | 81.8 | 50.8 | 38.9 | 52.3 | 64.8 | 66.0 | 42.0 | 27.3 | 41.8 |
| | 30-45 | 38.7 | 39.3 | 44.7 | 43.3 | 60.8 | 112 | 33.8 | 38.7 | 46.3 | 36.8 | 23.8 | 28.0 |
| N % | | | | | | | | | | | | | |
| | 0-10 | 0.44 | 0.07 | 0.03 | 0.12 | 0.06 | 0.11 | 0.11 | 0.09 | 0.07 | 0.10 | 0.10 | 0.09 |
| | 20-30 | 0.14 | 0.07 | 0.05 | 0.08 | 0.08 | 0.11 | 0.09 | 0.07 | 0.09 | 0.06 | 0.06 | 0.08 |
| | 30-45 | 0.07 | 0.05 | 0.07 | 0.08 | 0.08 | 0.07 | 0.07 | 0.08 | 0.10 | 0.08 | 0.08 | 0.06 |
| C % | | | | | | | | | | | | | |
| | 0-10 | 0.92 | 0.49 | 0.58 | 1.03 | 0.50 | 0.70 | 1.10 | 0.77 | 0.89 | 1.24 | 1.00 | 0.74 |
| | 20-30 | 0.43 | 0.44 | 0.40 | 0.89 | 1.08 | 0.85 | 0.82 | 0.77 | 0.83 | 1.10 | 1.07 | 0.94 |
| | 30-45 | 0.60 | 0.28 | 0.40 | 0.67 | 0.67 | 0.40 | 0.99 | 0.83 | 0.89 | 0.97 | 0.74 | 0.77 |

Carbon % levels varied from 0.28 % in the sub canopy zone (30 - 45 cm depth) of The Riverine to 1.24 % in the canopy zone (0 -10) of the Bare enclosed plot. the C % in the canopy zone in all the plots was 24 to over 100 % more than in the other zones.

There were also more C % in the top 10 cm than the lower depths in all the sites in the canopy zones.

The results therefore indicated that among the major nutrients, N, P and Organic carbon, the canopy zones always had more than the other zones.

## 4.4 SOIL WATER RESULTS

### 4.4.1 CALIBRATION OF THE NEUTRON PROBE

The data collected during the dry season calibration and the wet season calibration was combined to form one set of data which was used to compute a linear regression curve. The neutron probe reading ratio was regressed against the volumetric water content. However, the data from the 75 cm depth was found to be outlying in both the dry season and wet season data set. This was possibly because of a band of gravel concretions encountered during the excavation of the tube. The layer was approximately 10 cm and was probably responsible for the low level of volumetric moisture realised in this depth. The depth was therefore excluded from the rest of the data in the regression analysis.

The linear regression Equation ($r^2$ = .95) obtained was;

**$\% V = 19.49 * R - 6.22$ ($r^2 = 0.95$)**

**where,**

**% V = % volume water content**

**R = Count ratio; the ratio of a reading to the standing count**

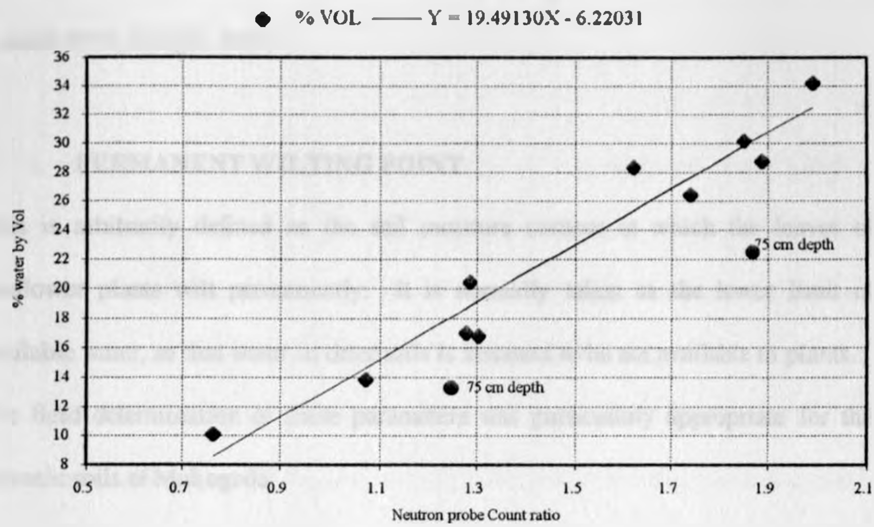



**Figure 3. Neutron Probe calibration curve**

### 4. 4. 2 AVAILABLE WATER CAPACITY (AWC)

The amount of the available water in the soil is greatly influenced by the clay silt and fine sand fractions. The available soil water is usually taken as the difference between the field capacity and wilting point.

#### FIELD CAPACITY (FC)

Field capacity refers to the maximum water content that the soil will hold following free drainage. It represents the condition of each individual soil after the larger pores have drained freely under gravity. FC is therefore usually taken as the moisture content of a soil which has drained freely for 1 or 2 days after saturation. The field capacity used in this study was therefore determined in the field in the wet period calibration. Recent studies in soil moisture have shown that laboratory determination of FC is largely unsatisfactory and should be determined *insitu* after natural drainage, rather than in the laboratory of a predetermined water potential (Ladon 1991, Liniger 1988)

### PERMANENT WILTING POINT

This is arbitrarily defined as the soil moisture content at which the leaves of sunflower plants wilt permanently. It is normally taken as the lower limit of available water, so that water in drier soils is assumed to be not available to plants. The field determination of these parameters was particularly appropriate for the chromic soils of Mukogodo.

The setting of wilting point was field calibrated for every depth and every treatment. It was taken to be the lowest moisture (% volume) level during the dry season. The Available water capacity (AWC) values for the various depths are shown in the table 7.

**Table 7. Profile available soil moisture at 6 depths in Mukogodo**

| Depth (cm) | Field Capacity | Wilting point | Dry calibration | % by volume |
|---|---|---|---|---|
| 18 | 28.30 | 7.06 | 10.11 | 21.24 |
| 30 | 26.45 | 11.64 | 13.84 | 14.81 |
| 45 | 28.75 | 15.51 | 17.02 | 13.24 |
| 60 | 30.15 | 16.90 | 20.44 | 13.25 |
| 75 | 22.47 | 16.41 | 13.28 | 6.06*1 |
| 90 | 34.18 | 16.67 | 16.78 | 17.51 |

NB the wilting point used here was the average for all the lowest moisture points in each depth, in all 12 treatments (3 zones in each plot). This was a slightly lower than the wilting point realised during the dry period calibration, possibly because the calibration which was done at one site did not take into account the differences in soils physical parameters in various sites.

*1 A band of gravel layer was encountered in this depth during the 'wet period' and was probably responsible for the low yield of AWC (% Vol.) realised.

NB - Vol. % = 1 mm water per 10 cm soil depth

### 4.4.3 AVAILABLE SOIL WATER

The results of soil water analysis are shown in the figure 4.

In the Riverine site there was clear variation of Available soil water (ASW) between the three zones, with under the canopy zone having at least 3 times ASW of the open zone, and about two times that of the sub canopy. The highest peak was about 105 %, meaning that it exceeded the field capacity over the period, in the open zone. The dry spell showed no differences in ASW between the zones. Throughout the study period the available soil water was above zero (at least 2 mm) even during the driest spell over late February to mid April.

The highest ASW recorded for the Glade site during mid December to mid January rains was 35% of Available water capacity (AWC) while the lowest recorded was 0 mm in the open zone during the dry spell. The open zone, always having at least 1/3 less ASW than the other two.

In contrast to what was observed in the Riverine site, in the Bare open site, the Available soil water in the canopy zone increased to a high 60 % compared to 27 % in sub canopy and 15 % in the open zone. During the dry period (period of relatively low precipitation in February, March and April), the canopy zone always recorded a higher ASW, close to 10 %, relative to 0 % and 2 % in subcanopy and open zone respectively.

The onset of the long rains around mid May was able to replenish the canopy zone more rapidly than the other two zones always registering more than double that of the subcanopy. However, subcanopy zone recorded about double ASW that recorded in the open zone upto the end of the rains.

The Bare enclosed site exhibited the same trend as the Bare open zone. The highest ASW recorded was 55 % in the canopy zone, which was about twice the amount in the subcanopy and that found in the open zone. At no time did the canopy zone deplete the ASW levels to less than 5 mm while the other two zones frequently dropped below zero during the dry period (indicating levels below the permanent wilting point).

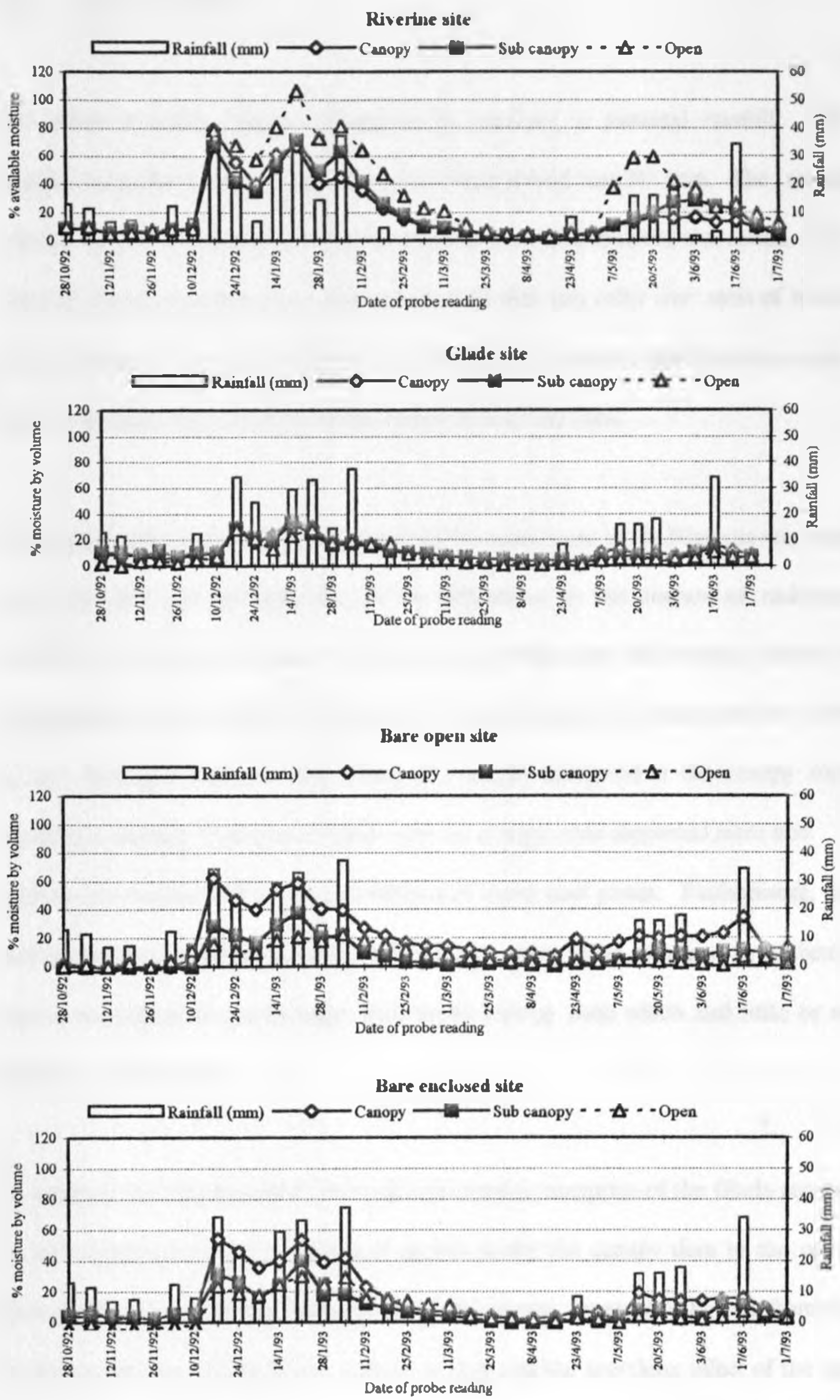



**Fig. 4. The effect of the canopy, sub canopy and open zones on available soil water in a 90 cm soil profile, in four sites in Mukogodo.**

## 4.5 DISCUSSION

The plants standing biomass fluctuated in response to seasonal rainfall. The recorded cumulative total rainfall over the whole period was 381 mm. The results showed a clear distinction among the various sites and between the zones. The Riverine clearly had more herb layer production than any other site most of which was in the open zone. In the "upper - slopes" plots (Bare open and Bare enclosed), more production was recorded in the canopy than in the open.

The reason why more ANPP was found in the open zone of the Riverine site than under the tree was probably due to the differences in the amount of radiation received in the respective areas. Although the whole plot had identical levels of precipitation, run off and illuviation from the upper slopes, the open patches seems to have benefited from the full effects of sunlight compared to the canopy zone which was shaded. This could explain why the canopy zone supported more non graminoids material which have preference to moist cool places. Furthermore, the well established perennial grasses genera in the open zones appeared to be better placed to respond to precipitation than in the canopy zone which had little or no perennial grass cover.

In contrast, the "upper slopes" sites with the notable exception of the Glade seemed to have clear advantage in factors of growth under the canopy than in the open This could probably be due to the fact that the canopy appeared to benefit from the ameliorating effect on the micro climate in reducing the scorching effect of the sun relative to the open zone. In addition the canopy areas appeared to enjoy, a 'run on' effect compared to 'erosion' in the open zones. Therefore the canopy zone was less eroded and had the effect of trapping the nutrients and water washed under the tree hence enhancing its ability to support more standing biomass.

The Bare enclosed site recorded similar levels of production to the Bare open site probably because it had not been in place long enough, nor was there an observed intense grazing pressure in the Bare open site. The unique Glade site had a higher herblayer production level in the open in the measured areas running to the glade indicating that the area was relatively suitable for growth than in the other zones. The figures obtained in this study relates to those found in other studies very well. Kinyamario and Macharia (1992) recorded 3.35 tons $ha^{-1}$ (with 245 mm of rainfall) in Nairobi National park and Owaga (1980) reported production levels of 308.99 gm $m^{-2}$ (3.09 tons $ha^{-1}$) in Athi Kapiti plains which compares with the canopy zone production in the present study which, with the exception of the Glade site, were 3.28, 2.84 and 3.32 tons $ha^{-1}$ in the Riverine, Bare open and Bare enclosed plots respectively.

The values obtained in this study are also within range of those obtained by Boutton *et al* (1988), 3.26 to 4.99 tons $ha^{-1}$, and Belsky's *et al* (1989) lower range of 3.09 tons $ha^{-1}$ (Tsavo national park). This is in spite of the rainfall levels in both Nairobi and Tsavo national parks (700 to 800 mm ) being higher than those recorded in this study (about two times). However the production levels recorded in zones beyond the canopy with the exception of the Riverine, were 1.74, 1.31, and 1.75 tons $ha^{-1}$ in the Glade, Bare open and Bare enclosed respectively. These values differed markedly from those recorded by Owaga (1980), Boutton *et al* (1988) and Kinyamario and Macharia (1992) in Nairobi National Park and Belsky's *et al* (1989) in Tsavo. This divergence was not surprising, differences in precipitation and degree of degradation might be responsible. The fact that the beneath the canopy herb layer production paralleled those reported in higher rainfall areas, but not those outside the canopy (except in the Riverine) could only mean that the canopies were able to maintain conducive growth conditions analogous to those found in higher rainfall areas.

This study found a production trend similar to that reported by Belsky *et al* (1989)in only two out of the four sites. The upper slope plots (Bare open and Bare enclosed) had a similar production trend as those observed by Belsky *et al* (1989) but in smaller scale. Wenner (1981) also reported clear differences between the canopies and the open areas; 1.14 tons $ha^{-1}$ and 0.24 tons $ha^{-1}$ under the tree, and away from the trees respectively. The other two sites, Riverine and Glade, especially the former had production levels suggesting negative effects by the tree canopy on herb layer production. The lower production values reported in the open zones of the "upper slope" sites could generally be attributed to the low rainfall experienced in the area and poor management leading to over grazing due to heavy stocking rates ( Herren 1991, Liniger 1992, Mwihuri in prep). The observations reported from the Riverine plot were as surprising as they were unique. The results suggest that responses to the presence of the canopy in mesic conditions where soil water is probably not a limiting factor to herb layer production, then the sunlight and temperature becomes important in influencing the performance of the herb layer. It also illustrated the inherent variability in range areas which results in differential responses in herb layer production to micro - environmental variations. The Glade was also a unique situation in that it was devoid of woody species within it's perimeter, but had a ring of woody species in it's periphery. The results reflected the differences in herb layer production within the Glade which normally has a good cover of perennial grasses than in the periphery. The low values obtained under the canopies in this site was probably more related to the small sizes of the trees, due to the limited number immediately on the periphery than any thing else. The differences in Above ground net primary production among the sites and treatments was a clear illustration of the micro - climatic influences of the canopy, ground configuration, differences in sites and past use of the area.

The results of cover data showed a close fluctuation of cover in response to rainfall. The response to rainfall among the treatments was more pronounced during the wet seasons than during the dry season. In the Riverine cover values in the canopy was consistently lower before the peak rainfall than the other zones, this was probably because of the higher perennial proportion in the sub canopy and open zones than in the canopy zone. But the reaction of cover to rainfall was always greater in the canopy zone than in the other zones. This was because the ephemerals (forbs) which were predominant in that zone, grow faster than the perennial grasses. Also, the broad leaves of the dicotyledons (forbs) were probably responsible of more hits in the point frame than the 'thin' leaves of the grasses. The equally faster decline in cover in the same zone during the dry season could also be due to the early maturing and subsequent drying of these ephemerals, while the perennial grasses stay longer.

However, in the 'upper slopes' plots (Bare open and Bare enclosed) the cover in the canopy zone consistently remained higher throughout the study period. This could be attributed to the high perennial cover under the trees which normally maintains more vegetal cover even during the dry season. Additionally the canopy of the trees could have provided more moist conditions due to reduced evaporative losses and 'run on' water, in addition to improved soil conditions, which also promoted the growth of the forbs together with the existing perennial cover. In contrast the zones beyond the canopies which are more eroded did not have any of these advantages, consequently, the forbs that came up were of different species, less broad leafed, smaller in size and therefore had less cover scores.

The general trend in cover conforms with those reported by Wenner (1981), who reported more cover under the trees than outside. Mutunga (in prep), working in Mukogodo, noted a pronounced cover response to the rainfall fluctuations

Species composition are important for any grazing management practices. Edward and Bogdan (1951) reported that species composition determines the productivity and condition of a range and have important implications in the type and amount of cover they afford the soil. The presence of rainfall is reflected in the predominant form of grasses: Places of high average moisture supports relatively more numerous creeping grasses with less tufted perennial species and annuals. The proportion of tufted perennial grasses and annuals tends to increase as rainfall declines with annuals becoming the major types in very dry regions (Strange, 1980). Although, virtually all the grasses contribute to the fodder supply, distinction between those of high and low economic value have been recognised (Edwards and Bogdan, 1951). This classification is mainly on the bases of palatability and nutritive value (e g crude protein). Those of high economic value includes genera such as *Themeda Hyparrhenia*, *Setaria*, *Digitaria*, *Cenchrus*, *Chloris*, *Panicum*, and *Bothriocloa*. On the other hand those listed by Edwards and Bogdan (1951) as being of low economic value included the fibrous, those with repulsive smells as well as those with tough sharp awns. These includes some species of *Pennisetum*, *Aristida*, and *Cymbopogon*. The present study revealed clear absence of the high economic value species, while it showed clear dominance of those species regarded as being of low value. This probably reflected the low levels of annual rainfall experienced in the catchment (less than 300 mm over the study period) and due to high concentration of livestock with limited migratory patterns, in the reserve since early 1930s leading to over grazing and general degradation (Herren, 1991, Liniger, 1989b, Mwihuri, in prep). Strange (1980) noted that the above scenario could occur when key species (usually more preferred) are heavily defoliated, they are then unable to produce healthy root system leading to deterioration and death. These are then normally replaced by grasses which are either less demanding or less palatable to grazing animals. In addition some species like *Themeda triadra* require regular fire occurrence for continued existence. Remnants of these key species were casually observed along the episodic river banks. In contrast, range areas with better rainfall regimes, like Nairobi national park, Masai Mara game reserve, Tsavo national park and Serengeti were observed to have in varying quantities these key species (Kinyamario and Macharia, 1992, Boutton *et al*, 1988, Belsky *et al* ,1989).

The above results suggested that the under canopy areas in mesic conditions as those observed in the Riverine plot supported more dicotyledonous material than graminoids. This could be because of the reduced levels of radiation reaching the ground under shade which favoured the forbs in relation to perennial grasses. This was illustrated by the exceptionally high presence of the perennial grasses in the open and sub canopy zones compared to the zone under the canopy. However, in the `upper slope' sites more perennial species were found under the canopy than in the open. This could be because of improved micro-climatic conditions afforded under the tree's canopy in comparison to the more eroded open spaces between the trees. Consequently ephemeral herbs and annual grasses in between the woody vegetation come up during the rains and are grazed. So for much of the year the ground is bare between the shrubs and trees. Some species however only appeared under the tree's canopy - *Pennisetum stramineum* and *Commelina* (in the "Upper slope" sites) species - while others like *Cynodon dactylon*, *Microchloa kunthii*, *Eragrostis tenuifolia*, and *Tragus berteronianus* only appeared in significant proportions only on the edges of the canopy and beyond. Although this could be related to the over use in the open areas, Belsky *et al* (1989) reported that there are species that are generally associated with the under canopy of the tree - *Cynodon nlemfluencis*, *Panicum maximum* and *Commelina benghalensis*, while others like *Bothriocloa radicans*, *Chrolis roxburghiana*, *Digitaria macroblephara* and *Eragrostis caesipitosa* appeared only in the open zones.

The soil fertility results revealed that most of the macro nutrients (N, P, K, and C) were more under the canopy than the areas beyond. This could possibly be due to nutrients returned to the soil through such processes as decomposition (due to improved microclimate, more suitable for microbial activity), retention of fertile top soil beneath the canopy that has been eroded from open areas between trees more susceptible to erosion, and enrichment of the soil through litter fall. The above results shows that these processes could be more than enough to offset any competition between the herb layer and the roots of woody species that could be present in the canopy zone. Similarly there was no major decline in nutrient levels in the sub canopy zone, indicative of major competition between the above two components as would be expected in the root zone. This could probably be due to the possibility of the tree species being deep rooted and hence avoids competition for nutrients. Additionally, the possibility of more exogenous sources, from spatial transfer of nutrients is considerable even under normal grazing practice. Miyazaki *et al* (1987) reported that when temperatures exceeded 27 $^{0}$c 44 - 53 % of urinations and 26 - 29 % of defecations by cattle occurred in the shaded area. The nature of the elluviation soils found in the Riverine could probably account for the higher levels of nutrients in this site. The higher levels of nutrients in the top 10 cm in all the canopy zones of every site supports the possibility of nutrients being primarily exogenous in origin.

Although, the canopy zone in the Riverine site was more nutrient rich, it had less Above ground net primary production relative to the zones beyond the canopy in the same plot. The most likely reason for this could be that nutrient levels were not limiting and therefore the differences in radiation amounts received in the respective areas could be the dominant factor in herb layer production. The 'Upper slopes' sites, especially the Bare open and Bare enclosed, had more nutrients in the canopy zone, and likewise, supported more herb layer production.

The above results corroborate the findings reported by Georgadis (1989): N % ( ranging from 0.02 - 0.18 ) and C % (0.44 - 0.99) under the canopy, was 5 times and 2 times more than in the open areas respectively, while, Belsky *et al* (1989), reported more O. M, P, K and Ca, under the canopy than areas beyond the canopy. Further, the results concurs with the levels of nutrients reported in Mainga *et al* (1992) and Njoroge (1991) in the same catchment of the study.
The C % levels were also comparable to those found by Kironchi (1992) and Mutunga (in prep).

The results of Available soil moisture (ASW) further explained the variation in levels of production, cover and species composition. Soil moisture clearly fluctuated with the levels of rainfall. Rainfall less than 10 mm level did not seem to cause any response in soil moisture.

In the Riverine plot more ASW was found in the areas beyond the canopy zone than under the canopy. This was also the zone that reported more ANPP than under the canopy. This suggested that a significant proportion of rainfall could have been intercepted by the canopy, hence reducing the amount of rainfall reaching the ground.

This was at variance with the findings from the 'upper plots' that is Bare open and Bare enclosed where there was more ASW under the canopy zone than in the areas in the open resulting in more ANPP as well as more cover. The ASW in the canopy zone of the Glade situation was also just slightly more than that in the open zone. The main reason for more available soil moisture in the canopy zone in both the Bare open and Bare enclosed sites was probably due to more water resulting from the 'run on' erosion coming from the more erosion susceptible open areas. This form of erosion was more easily retained due to the existing perennial cover under the tree. Also due to higher infiltration rates under the trees' canopy (Kironchi 1992) as well as due to reduced evaporation and plant transpiration rates due to lowered temperatures and radiant energy under the tree. This confirms Liniger's (1992b) suggestion that soil type is not as important as the soil cover in influencing the infiltration of water. Kironchi (1992) and Liniger (1992b reported that good grass cover improved the infiltration rate relative to an over grazed surface. Similarly Mutunga (in prep) reported lower runoff levels in areas with good protective cover than those with poorer covers. The above discussion suggests that more water is retained where the perennial cover is good.

## 4.6 MULTIPLE REGRESSION

### 4.6.1 REGRESSION EQUATIONS

Multiple regression analysis was done using total perennial grass biomass, annual grass biomass, forbs biomass and total herb layer production as dependent variables. The predictor variables used were soil pH, K (m. e %), Mg (m. e %), P (ppm), N %, C % and soil moisture. These variables are shown in table 8.

**Table 8. Dependent and Independent variables used in the Multiple regression equations.**

| Code | Variables | Units |
|---|---|---|
| **Dependent Variables** | | |
| Y1 | perennial grass | tons/ha |
| Y2 | annual grass biomass | " |
| Y3 | forbs biomass | " |
| Y4 | total production | " |
| **Independent Variables** | | |
| X1 | pH | - |
| X2 | K | m e % |
| X3 | Mg | " |
| X4 | P | ppm |
| X5 | N | % |
| X6 | C | % |
| X7 | Soil moisture | mm |

Biomass was partitioned into various components, perennial grass, annual grasses and forbs. This revealed differences in emphasise in several soil parameters. The equations obtained are shown below.

**Y1 = 6.34 - 2.68X1 + 3.18X2 + 0.20X3 - 0.02X4 - 11.8X5 + 5.67X6 + 0.01X7**
**Y2 = -2.29 + 0.52X1 - 0.03X2 - 0.08X3 - 0.01X4 + 0.34X5 - 0.45 + 0.0001X7**
**Y3 = 0.79 - 0.42X1 - 2.27X2 + 0.48X3 + 0.06X4 + 3.29X5 - 2.00X6 + 0.002X7**
**Y4 = - 0.81 + 0.13X1 + 1.14X2 - 0.66X3 - 0.04X4 + 6.41X5 - 0.18X6 + 0.004X7**

a one tailed t - test of the regressors was carried out.

Most of the site dynamics in the perennial grass ( table 9) biomass was attributable to ASW ($r^2 = 0.60$). While the variations observed in the annual grasses (table 10) were explained by C % ($r^2 = 0.81$), P ppm ($r^2 = 0.72$) and pH ($r^2 = 0.83$) (all of these parameters were statistically significant at 5 % level). On the other hand the differences observed in forbs ( table 11) among the plots and zones were explained by K m e % ($r^2$ = 0.52), P ppm ($r^2$ = 0.31), C % ($r^2$ = 0.27) and Soil Water ($r^2$ =0.29)

**Table 9. Regression coefficient, t - test and partial $r^2$ for perennial grasses biomass.**

| variable | coefficient | STD ERROR | t (df = 4 ) | Partial $r^2$ |
|---|---|---|---|---|
| pH | -2.60 | 4.84 | -0.55[1] | 0.071 |
| K m e % | 3.17 | 2.84 | 1.12 | 0.238 |
| Mg m e % | 0.19 | 3.18 | 0.062 | 0.001 |
| P ppm | -0.02 | 0.12 | -0.216 | 0.012 |
| N % | -11.80 | 19.62 | -0.602 | 0.083 |
| C % | 5.67 | 4.35 | 1.301 | 0.297 |
| AWC (mm) | 0.012 | 0.005 | 2.46* | 0.602 |

digits with * (asterisk) are significant at 5 % level of significance

**Table 10. Regression coefficient, t - test and partial $r^2$ for annual grasses biomass.**

| variable | coefficient | STD ERROR | t (df = 4 ) | Partial $r^2$ |
|---|---|---|---|---|
| pH | 0.52 | 0.12 | 4.453*[1] | 0.832 |
| K m e % | -0.03 | 0.07 | -0.47 | 0.053 |
| Mg m e% | -0.08 | 0.08 | -1.027 | 0.21 |
| P ppm | -0.01 | 0.00 | -3.24* | 0.72 |
| N % | 0.342 | 0.48 | 0.712 | 0.114 |
| C % | -0.446 | 0.12 | -4.20* | 0.815 |
| AWC (mm) | 0.0001 | 0.00 | 0.88 | 0.16 |

[1]digits with * (asterisk) are significant at 5 % level of significance

**Table 11. Regression coefficient, t - test and partial $r^2$ for forbs biomass.**

| variable | coefficient | STD ERROR | t (df = 4 ) | Partial $r^2$ |
|---|---|---|---|---|
| pH | -0.42 | 1.83 | -0.23 | 0.013 |
| K m e % | -2.27 | 1.08 | -2.11 | 0.53 |
| Mg m e% | -0.48 | 1.20 | 0.40 | 0.03 |
| P ppm | 0.06 | 0.04 | 1.35 | 0.32 |
| N % | 3.29 | 7.43 | 0.44 | 0.05 |
| C % | -2.01 | 1.65 | -1.22 | 0.27 |
| AWC(mm) | 0.002 | 0.00 | 1.29 | 0.29 |

The total herb layer production over the study period was regressed with the same soil parameters to explain the variations found between the zones and the plots. The results are shown in the equation Y5, and table 12. The results indicates that most of the variations were explained by the soil moisture ($r^2$ = 0.48). In addition, 86 %, of the observed variations among the plots and zones were explained by these soil parameters

**Table 12. Regression coefficient, t - test and partial $r^2$ for total herb layer production.**

| variable | coefficient | STD ERROR | t (df = 4 ) | Partial $r^2$ |
|---|---|---|---|---|
| pH | 0.13 | 2.31 | 0.055 | 0.001 |
| K m e % | 1.14 | 1.36 | 0.838 | 0.149 |
| Mg m e% | -0.66 | 1.52 | -0.433 | 0.045 |
| P ppm | -0.04 | 0.06 | -0.640 | 0.093 |
| N % | 6.41 | 9.38 | 0.684 | 0.105 |
| C % | -0.18 | 2.08 | -0.087 | 0.002 |
| AWC(mm) | 0.005 | 0.00 | 1.932 | 0.483 |

### 4.6.2 DISCUSSION

The above results demonstrate the predominant factors affecting herb layer production. The variations in standing biomass among the zones and sites was mainly due to available soil moisture and to a smaller extent due to soil nutrient differences. This illustrates the crucial role played by moisture in arid and semi arid environments. However when the standing biomass was separated to various components, only perennial grasses were shown to be influenced to a greater extent by soil moisture (60 % ). On the other hand ephemerals that show seasonal appearances, appeared to be predominantly influenced by the mineral nutrient variations, with soil moisture explaining only 16 % and 29 % in annual grasses and forbs respectively. These mineral nutrients were mainly carbon (81 %) Phosphorous (72 %) and soil acidity (83 %) in the case of the annual grasses, and carbon (27 %), phosphorous (32 %.) and potassium in the case of forbs (53 %). This is probably because soil water, when these annual materials occurs, is not limiting and hence the soil nutrient differences plays a greater role in the variations observed. The overall herbaceous layer production was mainly influenced by the soil water (48%) Potassium (15 %) nitrogen (10 %) and phosphorous confirming the comparative role played by soil water and minerals.

Other researchers else where have confirmed in general the relationship of the soil water and mineral nutrients. Belsky *et al* (1989) suggested that soil nutrients differences did not explain species composition differences, nor did it explain the herblayer productivity. The study further suggested that soil moisture was the most dominant factor in influencing the biomass and production variations. Boutton *et al* (1988) reported that soil moisture explained 71 % and 88 % of seasonal biomass dynamics in Nairobi national park and Masai Mara game reserve respectively.

# CHAPTER V

## 5.0 CONCLUSION AND RECOMMENDATIONS

### 5.1 CONCLUSION

The Influence of the canopy cover of *Acacia etbaica* and *Acacia tortilis* on herb layer characteristics was investigated in an episodic stream catchment with respect to it's effect on Above ground net primary production, aerial cover and species composition. In addition, soil nutrient status as well as seasonal variations in soil water were determined.

The study revealed that there were considerable variations in Above ground net primary production in the zones under the canopy and those beyond the canopy. Further, the results showed that there were differences in herblayer production and cover percentages among the sites. Canopy zones in mesic conditions influenced the herb layer production and cover negatively. However, the tree canopy in the sites further up the slopes provided profound advantage to the herb layer compared to the open zones. Therefore the canopy zones in these latter plots had more cover and production relative to the open areas. More over the greater proportion of the herb layer comprised perennial grasses.

Similarly, the canopy zones seemed to host a richer species composition in all the plots compared to the open zones. The results also suggested that some species are more suited to shaded environment while others like *Cynodon dactylon* only appeared in significant proportion in open zones.

The soil chemical results showed higher acidity, P ppm, N %, C % and K % in the canopy zone compared to the open zones in all the plots. In the plots higher up the slope (Bare open and Bare enclosed), more Available soil water (ASW) was recorded in the canopy zone relative to the open areas suggesting that the tree canopy zone has better water infiltration, less runoff, reduced evaporation and also received run off water from the bare adjacent patches. However in the site conterminous to the stream, there was less moisture recorded under the canopy than in the open area. This was possibly because the thicker crown cover of the tree reduced the through fall, hence reducing the level of moisture reaching the ground. The multiple regression analysis carried out showed that soil moisture is the major factor affecting the cover and production variations observed in the area. Some soil nutrients, notably, Nitrogen, Phosphorus, Potassium coupled with soil acidity, were important in influencing the herb layer production. Further analysis revealed that soil water is more crucial to perennial grass than to either the annual grasses and the dicots. The latter two being influenced more by mineral nutrient variations, possibly because the soil water is not limiting during the wet season, when these ephemerals occurs.

The study gives an interesting overview of the present situation as well as what would be expected under less denuded circumstances. Casual observation in the study area revealed that the role played by the canopy zone was not limited to the above two woody species, other tree species had similar herb layer concentration under the canopy compared to the bare open patches irrespective of the genera.

## 5.2 RECOMMENDATIONS

The degradation of Mukogodo range land is well documented (Herren 1991, Liniger 1992b, Mwihuri, in prep, Kironchi 1992). This degradation has come about as a result of encapsulation and sedentarisation of a large group of pastoral people in a small semi arid reserve. The high grazing pressure has exacerbated the situation further. Little or no attempts have been made in the form of rehabilitative measures to improve the range condition. As noted in Herren (1991), the Group ranch in the area, is largely inoperative. Furthermore, once adjudicated, no follow up policy was made and the ranch is therefore acutely deficient with regard to inventory, ranch development plans, and proper stock quotas, while credit for the necessary inputs have never been secured. In addition, the group ranch lacked 'grass root' support and therefore lacked decisive impact in grazing management. The prospects of the group ranch are further threatened by the impending and contemplated subdivision into small individually owned units which are ecologically unsustainable. With the foregoing scenario, certain recommendations are crucial for the restoration of the range land.

1) Recognition must be given to different range site potentials. Areas adjacent to the river bed appear to be more suited to the harvesting of the woody species as this might lead to increased herb layer production and cover. However, the continuing harvest of the trees, in the upper slopes, is especially deleterious as it leads to the depletion of the herb layer, with heavy consequences on the soil loss, and run off. More efforts should be made to conserve the existing woody species.

2) Less grazing pressure as well as excluding the animals from certain areas for extended periods, is not effective in restoring herbaceous layer cover, or in improving biomass production in the short term. Hence a longer term study period is required to show the length of time necessary to restore an effective soil cover.

3) The existing richer species composition under the canopy, is useful in serving as basis for further spreading to the open bare patches.

4) This study, has demonstrated the importance of soil water, hence effective conservation is crucial. This could involve pitting in the higher slopes and better cover establishment.

5) Reseeding, though expensive should be considered seriously to restore some level of productivity. This should be coupled with a study of suitable species and the period necessary to be effective .

6) Finally a more effective way of managing the resource, enjoying the necessary, political good will, and 'grass root' support is essential. The preservation of the group ranch to avoid subdivision into smaller units with proper management practices would be the first step.

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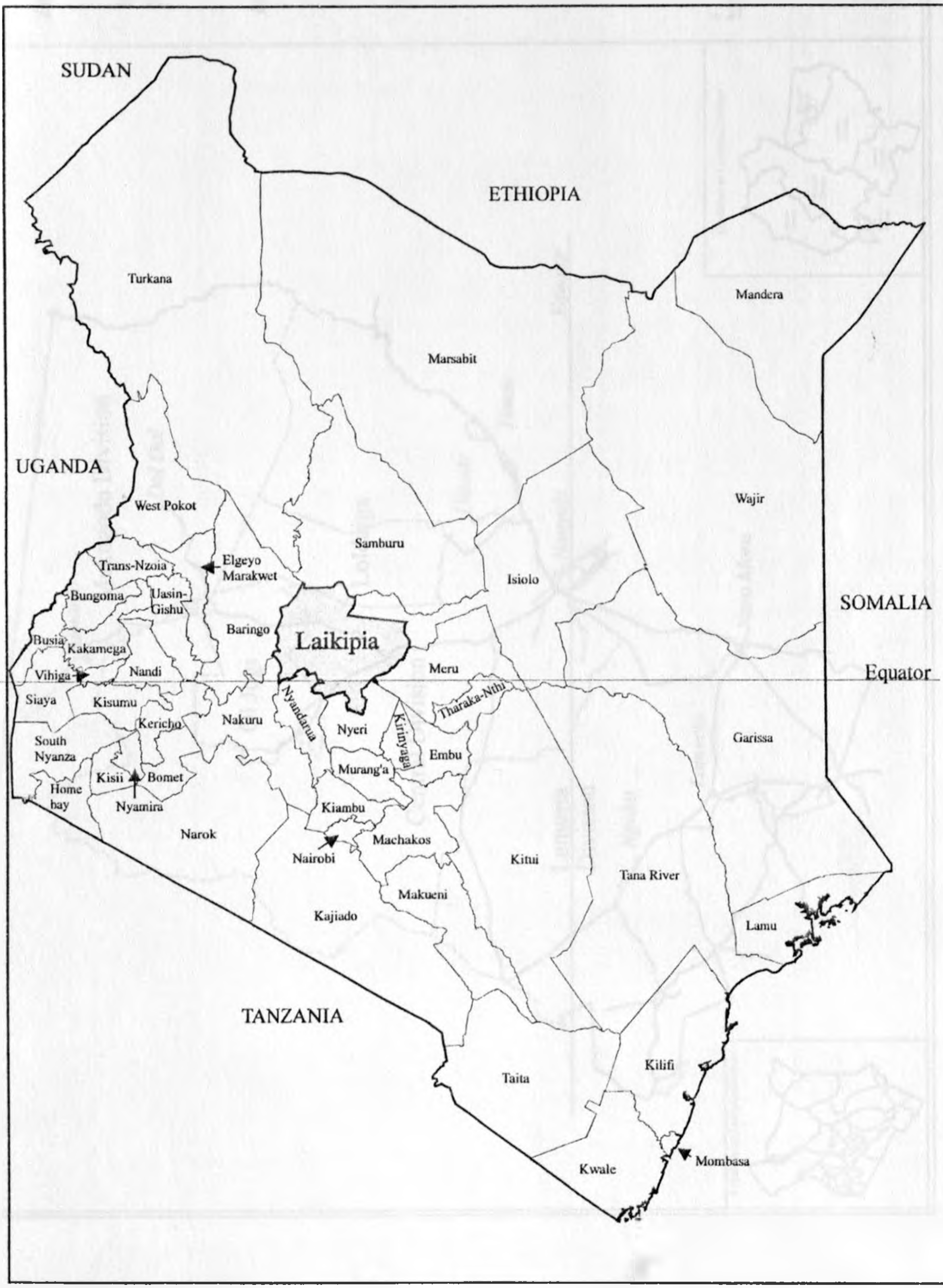
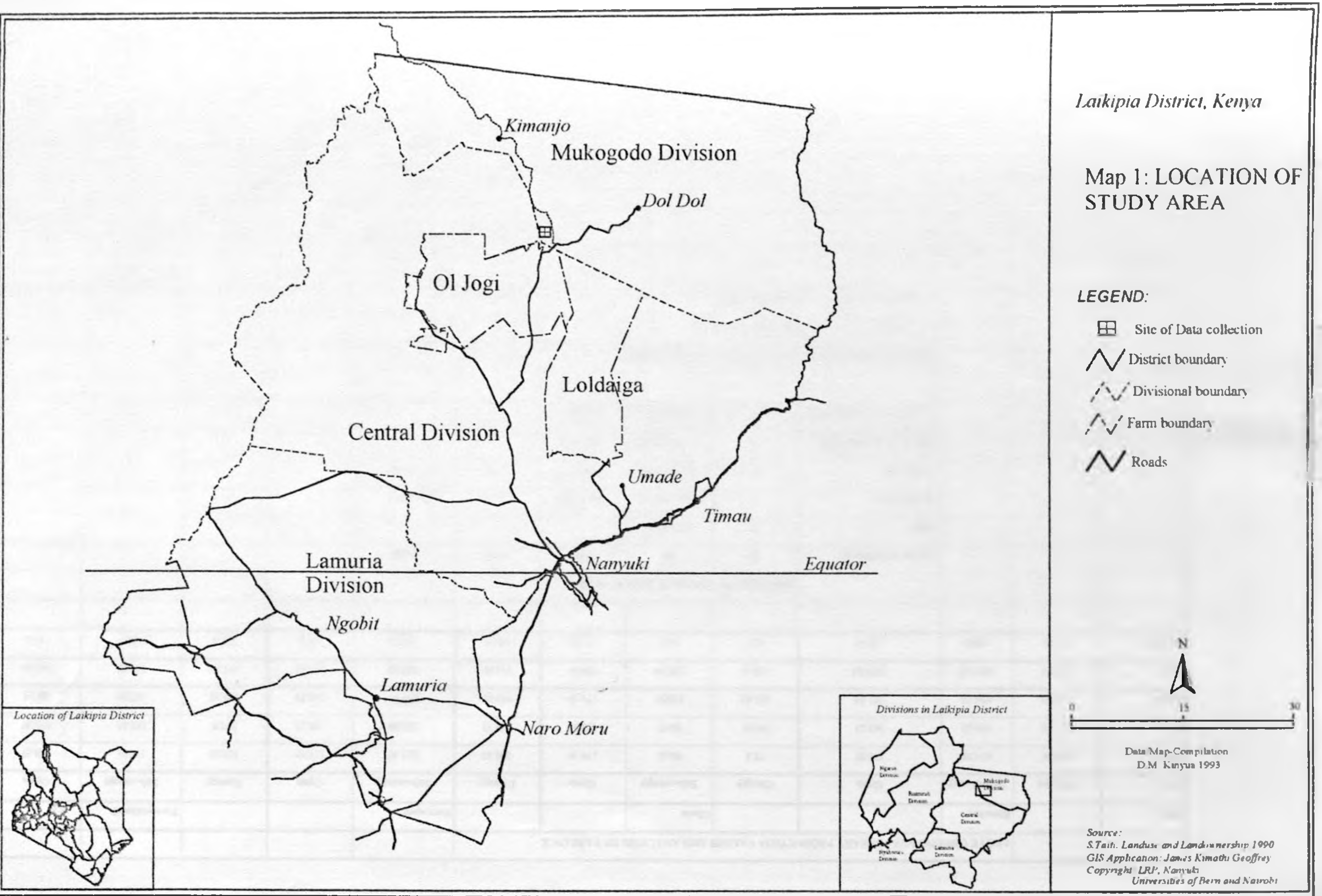
# Laikipia District
## National Context




Laikipia District, Kenya
Map 1: LOCATION OF STUDY AREA
LEGEND:
Site of Data collection
District boundary
Divisional boundary
Farm boundary
Roads
Kimanjo
Mukogodo Division
Dol Dol
Ol Jogi
Loldaiga
Central Division
Umade
Timau
Nanyuki
Equator
Lamuria Division
Ngobit
Lamuria
Naro Moru
Location of Laikipia District
Divisions in Laikipia District
N
0
15
30
Data/Map-Compilation
D.M Kinyua 1993
Source:
S.Taiti. Landuse and Landownership 1990
GIS Application: James Kimathi Geoffrey
Copyright LRP, Nanyuki
Universities of Bern and Nairobi

# Appendix 3

**ABOVE GROUND NET PRIMARY PRODUCTION VALUES AND ANALYSIS OF VARIANCE**

| Sites | Riverine | | | Glade | | | Bare open | | | Bare enclosed | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Zones | Canopy | Sub-canopy | Open | Canopy | Sub-canopy | Open | Canopy | Sub-canopy | Open | Canopy | Sub-canopy | Open |
| Tree 1 | 297.66 | 435.58 | 344.07 | 78.4 | 88.01 | 179.56 | 280.26 | 225.46 | 111.65 | 303.95 | 177.01 | 128.27 |
| Tree 2 | 336.68 | 426.63 | 362.27 | 89.14 | 92.07 | 173.31 | 252.72 | 225.38 | 131.62 | 352.5 | 180.52 | 133.57 |
| Tree 3 | 349.68 | 433.76 | 371.74 | 109.06 | 108.51 | 171.52 | 319.02 | 209.51 | 149.75 | 340.68 | 167.29 | 86.15 |
| Total | 984.02 | 1295.97 | 1078.08 | 276.6 | 288.59 | 524.39 | 852.00 | 660.35 | 393.02 | 997.13 | 524.82 | 347.99 |
| Average | 328.0 | 432.0 | 359.4 | 92.2 | 96.2 | 174.8 | 284.0 | 220.1 | 131.0 | 332.4 | 174.9 | 116.0 |

**ANALYSIS OF VARIANCE TABLE: ANPP**

| Sources of Variation | df | SS | MSE | Fcal | Ftab |
|---|---|---|---|---|---|
| Total | 35 | 447615.970 | | | |
| Among Zones | 11 | 439114.3097 | 39919.483 | 112.7** | 2.64 |
| Among sites | 3 | 298517.9273 | 99505.976 | 5.67* | 5.42 |
| Among Zones within sites | 8 | 140596.3824 | 17574.548 | | |
| Among trees within Zones | 24 | 8501.6603 | 354.236. | | |

**SEPARATION OF ZONAL MEANS: TUKEY'S W PROCEDURE**

w = qa(p.fety' = 5.1(12,24) x $(354.236/3)^{1/2}$ = 55.42

* significant at 0.05 and ** is significant at 0.001

Appendix 4.

| | | Values and parameters used in regression analysis | | | | | |
|---|---|---|---|---|---|---|---|
| | Regression of average annual grass biomass with soil parametes | | | | | | |
| **Annual grass** | **pH** | **K** | **Mg** | **P** | **N** | **C** | **Soil Moist** |
| 0.19 | 6.07 | 1.69 | 0.65 | 48.89 | 0.21 | 0.65 | 523.57 |
| 0.28 | 6.18 | 2.44 | 0.59 | 48.22 | 0.07 | 0.40 | 626.26 |
| 0.33 | 6.21 | 1.60 | 0.64 | 52.22 | 0.05 | 0.46 | 893.20 |
| 0.07 | 6.53 | 2.28 | 0.52 | 70.11 | 0.09 | 0.86 | 327.76 |
| 0.29 | 6.71 | 2.01 | 0.61 | 56.44 | 0.07 | 0.75 | 339.08 |
| 0.19 | 7.24 | 3.14 | 0.78 | 98.28 | 0.10 | 0.69 | 284.72 |
| 0.24 | 6.62 | 1.74 | 0.66 | 52.89 | 0.09 | 0.97 | 679.60 |
| 0.32 | 6.80 | 1.81 | 0.56 | 60.67 | 0.08 | 0.79 | 238.76 |
| 0.30 | 7.04 | 2.58 | 0.61 | 74.78 | 0.08 | 0.87 | 236.54 |
| 0.10 | 6.29 | 1.73 | 1.00 | 42.11 | 0.08 | 1.10 | 490.93 |
| 0.11 | 6.08 | 1.35 | 1.48 | 25.89 | 0.08 | 0.94 | 348.03 |
| 0.35 | 6.48 | 1.89 | 1.23 | 37.22 | 0.08 | 0.82 | 238.57 |
| | Regression of average forb biomass with the soil parameters | | | | | | |
| **Forbs** | **pH** | **K** | **Mg** | **P** | **N** | **C** | **Soil moist** |
| 3.65 | 6.07 | 1.69 | 0.65 | 48.89 | 0.21 | 0.65 | 523.57 |
| 2.23 | 6.18 | 2.44 | 0.59 | 48.22 | 0.07 | 0.40 | 626.26 |
| 4.76 | 6.21 | 1.60 | 0.64 | 52.22 | 0.05 | 0.46 | 893.20 |
| 1.31 | 6.53 | 2.28 | 0.52 | 70.11 | 0.09 | 0.86 | 327.76 |
| 1.23 | 6.71 | 2.01 | 0.61 | 56.44 | 0.07 | 0.75 | 339.08 |
| 1.78 | 7.24 | 3.14 | 0.78 | 98.28 | 0.10 | 0.69 | 284.72 |
| 2.31 | 6.62 | 1.74 | 0.66 | 52.89 | 0.09 | 0.97 | 679.60 |
| 2.98 | 6.80 | 1.81 | 0.56 | 60.67 | 0.08 | 0.79 | 238.76 |
| 1.41 | 7.04 | 2.58 | 0.61 | 74.78 | 0.08 | 0.87 | 236.54 |
| 2.55 | 6.29 | 1.73 | 1.00 | 42.11 | 0.08 | 1.10 | 490.93 |
| 1.74 | 6.08 | 1.35 | 1.48 | 25.89 | 0.08 | 0.94 | 348.03 |
| 0.92 | 6.48 | 1.89 | 1.23 | 37.22 | 0.08 | 0.82 | 238.57 |

Appendix 4.

| | Values and parameters used in the regression equitions | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | Regression of average perennial grasses with the soil parameters | | | | | | |
| **Perennial grass** | **pH** | **K** | **Mg** | **P** | **N** | **C** | **Soil moist** |
| 1.97 | 6.07 | 1.69 | 0.65 | 48.89 | 0.21 | 0.65 | 523.57 |
| 5.61 | 6.18 | 2.44 | 0.59 | 48.22 | 0.07 | 0.40 | 626.26 |
| 6.48 | 6.21 | 1.60 | 0.64 | 52.22 | 0.05 | 0.46 | 893.20 |
| 0.44 | 6.53 | 2.28 | 0.52 | 70.11 | 0.09 | 0.86 | 327.76 |
| 0.20 | 6.71 | 2.01 | 0.61 | 56.44 | 0.07 | 0.75 | 339.08 |
| 1.18 | 7.24 | 3.14 | 0.78 | 98.28 | 0.10 | 0.69 | 284.72 |
| 3.91 | 6.62 | 1.74 | 0.66 | 52.89 | 0.09 | 0.97 | 679.60 |
| 0.47 | 6.80 | 1.81 | 0.56 | 60.67 | 0.08 | 0.79 | 238.76 |
| 0.46 | 7.04 | 2.58 | 0.61 | 74.78 | 0.08 | 0.87 | 236.54 |
| 7.91 | 6.29 | 1.73 | 1.00 | 42.11 | 0.08 | 1.10 | 490.93 |
| 1.35 | 6.08 | 1.35 | 1.48 | 25.89 | 0.08 | 0.94 | 348.03 |
| 0.59 | 6.48 | 1.89 | 1.23 | 37.22 | 0.08 | 0.82 | 238.57 |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| Regression of Above ground net primary production with the soil parameters | | | | | | | |
| | | | | | | | |
| **Production** | **pH** | **K** | **Mg** | **P** | **N** | **C** | **Soil moist** |
| 3.28 | 6.07 | 1.69 | 0.65 | 48.89 | 0.21 | 0.65 | 523.57 |
| 4.32 | 6.18 | 2.44 | 0.59 | 48.22 | 0.07 | 0.40 | 626.26 |
| 3.59 | 6.21 | 1.60 | 0.64 | 52.22 | 0.05 | 0.46 | 893.20 |
| 0.92 | 6.53 | 2.28 | 0.52 | 70.11 | 0.09 | 0.86 | 327.76 |
| 0.96 | 6.71 | 2.01 | 0.61 | 56.44 | 0.07 | 0.75 | 339.08 |
| 1.74 | 7.24 | 3.14 | 0.78 | 98.28 | 0.10 | 0.69 | 284.72 |
| 2.84 | 6.62 | 1.74 | 0.66 | 52.89 | 0.09 | 0.97 | 679.60 |
| 2.20 | 6.80 | 1.81 | 0.56 | 60.67 | 0.08 | 0.79 | 238.76 |
| 1.31 | 7.04 | 2.58 | 0.61 | 74.78 | 0.08 | 0.87 | 236.54 |
| 3.14 | 6.29 | 1.73 | 1.00 | 42.11 | 0.08 | 1.10 | 490.93 |
| 1.50 | 6.08 | 1.35 | 1.48 | 25.89 | 0.08 | 0.94 | 348.03 |
| 0.90 | 6.48 | 1.89 | 1.23 | 37.22 | 0.08 | 0.82 | 238.57 |

RAINFALL RECORDS FROM 1990 TO 1993.

| | YEARS | | | | AVERAGE | |
|---|---|---|---|---|---|---|
| MONTH | 1990 | 1991 | 1992 | 1993 | 1990-1992 | 1993 |
| J | 0.0 | 2.4 | 2.1 | 125.9 | 1.50 | 32.59 |
| F | 0.0 | 0.0 | 0.0 | 11.0 | 0.00 | 2.75 |
| M | 0.0 | 37.4 | 4.0 | 3.9 | 13.80 | 11.33 |
| A | 0.0 | 35.4 | 45.6 | 9.7 | 27.00 | 22.68 |
| M | 0.0 | 29.0 | 7.9 | 49.5 | 12.30 | 21.60 |
| J | 0.0 | 5.8 | 11.4 | 39.0 | 5.73 | 14.05 |
| J | 15.9 | 35.4 | 30.1 | 14.6 | 27.13 | 24.00 |
| A | 18.2 | 12.2 | 15.0 | 22.6 | 15.13 | 17.00 |
| S | 0.0 | 4.6 | 3.5 | 0.0 | 2.70 | 2.03 |
| O | 93.4 | 13.5 | 23.1 | 11.6 | 43.33 | 35.39 |
| N | 29.6 | 19.9 | 24.4 | 32.3 | 24.63 | 26.54 |
| D | 62.5 | 35.1 | 80.2 | 1.0 | 59.27 | 44.70 |

RAINFALL RECORDS SHOWING RAINFALL AMOUNTS IN THE MONTHS COINCIDING WITH THIS STUDY.

| YEAR | 90/91 | 91/92 | 92/93 | 90/92 AVERAGE |
|---|---|---|---|---|
| MONTH | | | | |
| O | 93.4 | 13.5 | 23.1 | 53.45 |
| N | 29.6 | 19.9 | 24.4 | 24.75 |
| D | 62.5 | 35.1 | 80.2 | 48.80 |
| J | 2.4 | 2.1 | 125.9 | 2.25 |
| F | 0.0 | 0.0 | 11.0 | 0.00 |
| M | 37.4 | 4.0 | 3.9 | 20.70 |
| A | 35.4 | 45.6 | 9.7 | 40.50 |
| M | 29.0 | 7.9 | 49.5 | 18.45 |
| J | 5.8 | 11.4 | 39.0 | 8.60 |
| J | 35.4 | 30.1 | 14.6 | 32.75 |
| | | | | |
| TOTAL | 330.9 | 169.6 | 381.3 | |

SOURCE: LAIKIPIA RESEARCH PROGRAMME

Appendix 6

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | AVERAGE MONTHLY TEMPERATURES | | | | | | |
| | 1990 | | 1991 | | 1992 | | 1993 | |
| | MAXIMUM | MINIMUM | MAXIMUM | MINIMUM | MAXIMUM | MINIMUM | MAXIMUM | MINIMUM |
| J | * | * | 25.70 | 10.50 | 25.30 | 10.70 | 22.20 | 12.40 |
| F | * | * | 27.70 | 10.30 | 27.70 | 11.20 | 23.90 | 11.30 |
| M | * | * | 27.10 | 11.50 | 27.50 | 11.90 | 26.70 | 10.30 |
| A | * | * | 26.00 | 12.90 | 26.50 | 13.90 | 27.10 | 11.40 |
| M | * | * | 26.40 | 13.10 | 26.90 | 12.40 | 27.10 | 11.70 |
| J | * | * | 26.30 | 12.30 | 26.50 | 12.90 | 26.30 | 11.30 |
| J | * | * | 24.30 | 11.40 | 24.40 | 11.20 | 25.20 | 10.10 |
| A | * | * | 25.40 | 10.90 | 24.70 | 11.50 | End of the study | |
| S | 27.10 | 19.20 | 26.10 | 9.90 | 26.50 | 11.10 | | |
| O | 25.60 | 19.00 | 26.60 | 11.60 | 26.50 | 11.70 | | |
| N | 24.20 | 17.30 | 24.60 | 13.20 | 23.70 | 12.90 | | |
| D | 23.40 | 10.70 | 24.20 | 11.90 | 23.10 | 13.00 | | |
| AVG | 25.08 | 16.55 | 25.87 | 11.63 | 25.78 | 12.03 | 25.50 | 11.21 |
| | * missing data | | | | | | | |