VEGETATION AND HYDROLOGIC RESPONSES TO GRAZING MANAGEMENT IN A SOUTH KENYA RANGELAND

BY

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DECLARATION

(a). This thesis is my original work and has not been presented for a degree in any other university.

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DEDICATION

I dedicate this thesis to my parents, Mr. and Mrs. Mworia, my brother Muriuki, and my sisters; Nkirote and Makena, for the love and moral support they gave me during my study.

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ABSTRACT

Title: Vegetation and hydrologic responses to grazing management in a South Kenya rangeland

By: J.K. Mworia

A study was conducted to evaluate the effects of three selected stocking densities on infiltration rate, bulk density, sediment production and animal performance in a south Kenya rangeland. The stocking densities used were 0, 4, 8, and 16 heifers/Ha, hereafter referred to as control (CL), light density (LD), medium density (MD) and high density (HD) respectively. Each treatment was replicated twice on plots measuring 0.5 Ha each. The study was done at National Range Research Center, Kiboko. The study site is classified as a bushed grassland with species of *Acacia* and *Commiphora* as the dominant woody plants, while *Digitaria macroblephera* and *Chloris roxburghiana* are the most dominant grasses. The texture of the soils at the site is sandy clay loam.

The highest stocking density, HD, gave the highest animal output per hectare yielding a peak weight gain of 104 kg/Ha, which however declined after pasture deterioration. The HD treatment also produced the highest soil loss, lowest infiltration rate, and highest bulk density. The LD treatment maintained the highest animal output per head and had the least negative impact on the pasture hydrologic conditions and vegetation. Infiltration rate after 30 minutes of simulated

rainfall in HD plots was 45% and 27% lower than in CL and LD plots respectively, making a significant difference ($p<0.05$). Sediment production on the last sampling date was 1115 kg/Ha in HD treatment, which was significantly ($p<0.5$) more than 226 and 517 kg/Ha for the CL and LD respectively. Bulk density, 0-5cm, in HD increased by 15% by the end of the experiment and was significantly higher ($p<0.05$) than CL and LD.

It can be concluded from this study that the effects of high stocking densities on the range were, increased land bareness, reduced infiltration rates, increased soil loss, and increased soil compaction. The linear relationship of stocking density to output per head developed in this study could vary from year to year due to climatic and other environmental variations; further studies are necessary to develop long-term relationships.

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Chapter 1

INTRODUCTION

The Kenya rangelands which form the bulk of the grazing land for livestock and wildlife constitutes about 80% of the country's land area. The production systems in this vast area are based more on subsistence strategies than on commercial practices. With Kenya's high population increase, land in the semi-arid regions, like elsewhere, becomes a shrinking resource. Under this pressure, the objective of the pastoral society is to support more people per hectare. This leads to an inevitable increase in livestock numbers.

Grazing management has been described as the heart and core of range management. In the last two decades a large number of experiments have concentrated on grazing systems involving numerous combinations of rest periods and rotations. However, due to the high expenses for such experimentation over a wide range of stocking rates, the large number of systems devised can not be adequately tested on rangelands. To design appropriate experimental grazing models initial research on the range type should be carried out within small plots subject to grazing with variations in parameters such as stocking density, length of rest period or season of grazing. Subsequent larger scale research is then carried out to validate the observations.

Grazing livestock will affect the plant community and soils in several interrelated ways. Some effects include plant defoliation, nutrient removal and redistribution through excreta, mechanical manipulation of soil and plant material through trampling.

The levels of stocking density chosen by the livestock manager will therefore have profound effects on the vegetation and soils both on short-term and long-term basis. An understanding of this responses is vital in acquiring information relevant to the design of grazing management models suitable to semi-arid regions of Kenya. Previous studies in Kenya rangelands assessing the effect of livestock on hydrologic condition have either simulated trampling or have compared grazing systems. The study's aim was to describe quantitatively the effects of three selected stocking densities on; infiltration rate, bulk density, herbage standing crop, vegetation cover, litter accumulation and animal performance.

Chapter 2

LITERATURE REVIEW

2.1 ANIMAL RESPONSE TO DIFFERENT STOCKING RATES

Stocking rate is regarded as a major factor influencing animal production. The stocking rate level will affect animal performance through restricting the amount of feed or by limiting the animal's choice of the more nutritious pasture components (Wilson and Macleod, 1991). Several relationships between animal production and the stocking rate have been proposed based on studies by various workers. Majority of the studies have shown that on a given pasture, productivity per animal declines as stocking rate increases, and productivity per hectare rises to a maximum before it also declines (Wilson, 1986). Jones and Sandland (1974) gave the general relationship between gain per animal (Y1) and stocking rate (X) to be of the linear, i.e $Y1=a-bx$ where a and b are constants, and that between gain per hectare (Y2) and stocking rate (X) to be of the quadratic form $Y2=ax-bx^2$. Wilson (1986) illustrated the relationship to consist of three phases. In the first phase of low stocking rate, production is not influenced by the stocking rate, in the second phase of moderate stocking rate production declines linearly as the stocking rate increases. In the third phase of high stocking rate pasture deterioration occurs and there is an accelerated decline in production per head.

A major deficiency of the model is that the relationship of a given stocking rate to productivity in both per animal and per hectare varies from year to year according to seasonal conditions (Wilson and Macleod, 1991). For example, Musimba (1986) showed that steers on a Kenya rangeland to have gained weight at higher rate when forage is green and growing than when it was mature. He reported the intake of digestible organic matter and crude protein to have fallen when the forage was mature and consequently attributed the low growth rates of steers to inadequate intake of digestible nutrients. This fluctuations reduce the apparent simplicity but not applicability of the model. This is especially so in the arid pastoral areas of Africa where erratic and variable rainfall both in time and space, leads to corresponding seasonal fluctuations in plant biomass (Sandford, 1983). In this fluctuating climates, rainfall, will have a greater impact on plant growth and consequently herd performance, than marginal changes in grazing pressure caused by different stocking rates (Behnke and Scoones, 1990; Ellis and Swift, 1988). This means that in such pastoral areas characterized by erratic rainfall and uncontrollable swings in primary productivity, livestock production may decline because of little fodder, caused by too little rainfall rather than too many animals.

In terms of herd productivity, studies comparing animal output on per hectare basis of ranch and pastoral systems have been done. Pastoral systems which often have higher stocking rates, have shown pastoralism either equals or exceeds the commercial ranches. For example, Cossins (1985) compared the Borana pastoral system of Ethiopia with the ecologically equivalent commercial ranches of Lakipia, Kenya, in terms of per hectare output of animal protein and energy. The results showed the Borana pastoral system produced about as much animal protein per hectare and 56% more energy than the Lakipia commercial ranches. In the commercial ranches beef is the main output while in the Borana system milk is the main output. However, pastoral animals achieve mature weights much later than ranch animals, and mature body weights tend to be lower than those of similar breeds in ranching situations. This is not a surprise because the primary goal of pastoral production is subsistence security of the short and long term, which is largely achieved through accumulation of animals (Grandin, 1987). For example in the group ranches of Kajiado, milk is the primary output on a year round basis and most is consumed by the household (De leeuw et al. 1984).

Livestock carrying capacity expressed in either animal-unit-days (AUD) or animal-unit-months (AUM) per hectare represents the rate or level that should be stocked to achieve specified objectives under specified management options

(Scarnecchia, 1990). Thus a carrying capacity number alone without details used in optimizing the stocking level is technically meaningless. Scientists differentiate between the biological or ecological and the economic carrying capacities. At the biological carrying capacity production of forage equals the rate of consumption by animals and livestock population ceases to grow. At the economic carrying capacity the stocking rate optimizes net return, that is, the concept of marginality to revenue and costs is applied (Workman and Fowler, 1986). Also at the economic carrying capacity marginal costs will equal marginal revenue, these stocking rate will often be lower than the ecological carrying capacity.

Determination of carrying capacity and it's application in African arid environments has been an issue drawing differing views among ecologists. In African arid rangelands, where rainfall is variable both in time and distribution, pastoralism which employs a degree of mobility is the rational mode of utilization (Sandford, 1983). Due to herd mobility and the wide fluctuations in forage production application of the concept of carrying capacity becomes confusing (Behnke and Scoones, 1990). The application of the term 'overgrazed' to a pasture which has been over utilized by livestock is often shrouded with confusion due to differences in rangeland attributes which the scientist takes into consideration. For example, a scientist might consider changes in any one of the following attributes to constitute overgrazing; botanical composition, forage cover, soil loss, or livestock production. However, Wilson and Macleod (1991) proposed overgrazing to be observed as a loss of apparent linearity in the animal production to stocking rate relationship over a period of years. In practical terms this implies the pastures with the highest stocking rate will finally be absolutely less productive than at the beginning.

In the last two decades extensive studies in grazing systems have yielded few general principles, with results being limited to the location in which they are conducted (Wilson, 1986) and the specific sub-divisions applied. This is partially due to the high cost of conducting grazing studies and the large number of systems that may be devised over a wide range of stocking rates. Research in grazing systems should therefore start by concentrating on the responses of plants and animals in small grazed plots rather than ad hoc testing of systems.

2.2 VEGETATION RESPONSES

Grazing animals affect plants directly by defoliation and trampling as result of hoof action. Defoliation of living tissue will have differing effects according to intensity, frequency of defoliation and phenology of the plants at the time. Annual herbage production in the rangelands has been shown to depend largely on environmental factors especially precipitation and evapotranspiration (Le Horerou, 1977) and the level of soil nutrients, especially nitrogen and phosphorus. The effect of defoliation by herbivores on herbage production is superimposed on environmental effects.

Both the intensity and frequency of defoliation increase as a direct function of grazing intensity (Briske and Stuth, 1982). Responses of the plant to defoliation include, among others, increased production of cytokins, which promote increased tillering (McNaugton, 1983). However this does not necessarily lead to greater biomass production (Heady, 1975). The responses to defoliation depend critically on plant developmental stage and time of defoliation. However, severe defoliation will always lead to decreased standing crop and seed production(Allison et al.1985; Potter and Said, 1986). Production of seed from perennial grasses is low compared with many annual species and is also rather unpredictable, depending on the season, and on the timing of grazing activities (Harper, 1977).

For cattle producers, a high proportion of grasses on the pasture as compared to woody species is desirable. Grazing animals have been regarded as one of the mechanisms that brings about changes in vegetation structure, over time (Connell and Slatyer, 1977). For example Farah (1991) working on semi-arid parts of Machakos district, Kenya, showed that the locations with a long history of heavy continuous grazing, vegetation structure has shifted towards woody species. He also observed that in post-independent Kenya application of fires in rangelands had been regulated and attributed the increased woodiness to an interaction of grazing pressure and fire control.

Range grasses show a decline in vitro dry matter digestibility and in protein content as they approach maturity (Cogswell and Kamstra, 1976; Kamstra et al. 1958). Range grasses also show wide variation in nutrient levels with change in seasonality. For example Karue (1975) investigating the influence of seasons on the nutritive value of Themda triadra in Athi river ranch, Kenya, reported crude protein to varied from 3.21 to 9.46 in the long rains.

Stimulation of new growth by grazing has been shown to retard maturity, decrease the proportion of structural materials, and increase the percentage of crude protein (Heady, 1975). In a study to evaluate the effects of short duration grazing on the forage quality, the percent crude protein of ungrazed pastures was found to be generally lower in the grazed pastures (Heitschdt et al. 1982). In the same study the percent crude protein was always less at the conclusion of each grazing event lasting seven days. This was attributed to the selectivity of the grazing ruminant, removing the highest quality material. Variations in the percent crude protein of the available forage can therefore be said to be a function of the grazing treatment, physiological age of plant tissue, species and season. Studies evaluating nutritive value of pastures before and after short grazing periods in the varying seasons have not been done in the Kenya rangelands.

Fallen litter as a result of senescence and breakage by trampling has numerous beneficial effects on the range. Among the benefits is reduction in land bareness, increase in infiltration rates, decrease in rainfall impact, runoff and erosion (Branson et al. 1981). When grazed on a long term basis, high stocking intensity treatments have been shown to lower the amounts of fallen litter (Naeth et al. 1990b; Johnstone et al. 1971; Orodho et al. 1990).

2.3 WATERSHED RESPONSES

2.3.1 INFILTRATION RATE

Infiltration is the process through which water penetrates the surface and enters the soil. Infiltration is a surface phenomena controlled by conditions at the surface horizon, usually a few centimeters deep (Cook and Stubbendieck, 1986). Infiltration rate after several minutes of rain usually is much less than that at the beginning. This is due to changes in the soil surface which progressively lower it (Branson et al 1981). The decline in infiltration from an initially high rate can be attributed in part to deterioration of surface soil structure as result of rainfall impact leading to the detachment of pore-blocking particles which seal the surface. Also the swelling of soil colloids upon wetting reduces the size of pores through which water percolates. Sedimentation of suspended particles in muddy water as it enters the soil obstructs the pores leading to further reduction in infiltration. The rate of infiltration determines how much water will enter the root zone and how much surface runoff with it's accompanying danger of soil erosion will occur (Hillel, 1982). The importance of infiltration and runoff is further emphasized when it is recognized that the level of primary production potential and animal populations in the savanna is basically a function of available soil moisture and nutrients (Ellis and Swift, 1988).

Livestock grazing can alter infiltration rates of rangeland soils by causing changes in plant and litter cover. The influence of plant and litter cover has been shown in several studies. For example, Mccalla et al. (1984) studied infiltration rates of soils under pasture with the following treatments ; heavy continuous grazing, short duration grazing, moderate continuous grazing, and grazing exclusion. The results showed that infiltration was most strongly influenced by standing crop, total vegetation cover and soil bulk density. Even where complex rotational and deferred systems are employed, ground cover remains an important variable influencing soil loss. This was showed in an experiment conducted by Pluhar et al. (1987). In this experiment infiltration rate and sediment production were studied in the following treatments ; 16 paddock rotational grazing stocked at a heavy rate, 4-pasture 3-herd rotation, continuous grazing at moderate rate and ungrazed exclosure. The results showed that rotational grazing led to reduction in vegetation cover, standing crop, and an increase in the amount of bare ground regardless of the plant community. Thurow et al. (1987) found the total litter cover to have a linear relationship with infiltration rate and concluded the type of organic cover is not as important as the amount. Similarly, Ngethe and Mbakaya (1989) studying the effects of vegetation type on infiltration in Buchuma, Kenya, found infiltration rates to be higher and sediment production to be lower on vegetated plots as compared to bare plots.

Compaction of the soil surface has also been shown to influence infiltration. Other factors that influence infiltration include the initial water content, time from the onset of rains, soil texture, and degree of aggregation (Hillel, 1982; Branson et al. 1981).

Infiltration can be studied firstly, by analyzing rainfall and runoff data from natural watersheds and secondly by means of plot studies of natural rainfall or artificial applications of water. Small plots used in artificial simulation of rainfall are appropriate for the comparison of grazing effects or different soil and cover conditions, however care is needed in applying the results directly to watershed areas (Cook and Stubbedieck, 1986).

2.3.2 SEDIMENT PRODUCTION

The impact of raindrops not only detaches but also tends to destroy granulation. Surface runoff which results after water supply exceeds infiltration is responsible for most of the transportation of soil (Brady, 1984). The surface runoff collects in hills and gullies. Evaluation of soil loss from rangelands can be estimated by measurement of eroded material either in transit or accumulated at a point (Cook and Stubbendieck, 1986). Infiltrometer measurements have been used widely to compare and evaluate effects of treatments which alter vegetation cover, litter cover, soil stability and soil bulk density. The effects of grazing on sediment production have been evaluated by use of a rainfall simulator in several studies. For example Gamougon and Pieper (1984) evaluated sediment production in three grazing systems; continuous grazing, continuous moderate grazing, and rotation grazing. The results showed that sediment production was lowest in the exclosure and increased with stocking rate. Sediment production as a result of simulated trampling has been studied by Warren et al. (1986). They simulated trampling using digital pedometers at four intensities on bare ground. Bare ground was used to remove the confounding effects due to variability in vegetative cover and botanical composition. Warren et al. (1986) found that the more intensive the trampling under either moist or dry conditions the more the sediment production. Infiltration rate also declined with increasing trampling. This showed the levels of sediment production and infiltration rate are a response not only to vegetation removal by livestock, but also the changes in soil physical characteristics as a result of trampling.

The importance of cover is emphasized by Cheruiyot (1984) who studying the effects of prescribed burning on infiltration in Kiboko, Kenya, reported bare plots to produce 1015kg/Ha while plots vegetated with Digitaria macroblephera produced 344Kg/ha, with the soils initially wet. Gachimbi (1990) studying whether slashing bush and spreading it on denuded land would improve infiltration, simulated a ground cover of 20% on 8M^2 plots using timber. In the plots he either intercepted rainfall only or rainfall plus runoff, while control plots were left bare. From the results the highest volume of seasonal runoff was obtained from the bare plots. The highest seasonal soil loss was from bare plots, 65.7 tons/Ha, while the ones with rainfall and runoff interception produced 19 tons/Ha of soil. It therefore follows that grazing and in particular overgrazing and its attendant effects of depletion of plant cover and litter and trampling are important factors contributing to erosion (Branson et al. 1981). The consequences of high soil loss in rangelands are diminished productivity and pollution of the rivers and streams. Water erosion has become a big problem in the recent years of rather rapid development in the tropics because the indigenous systems of pastoralism and shifting cultivation have been operated intensively owing to increased human and stock population (Webster and Wilson, 1980).

2.3.3 SOIL BULK DENSITY

Bulk density is the mass of a unit of dry soil which includes both solids and pores. Soil bulk density provides an estimate for soil compaction (ASAE, 1971). The more intensely rangelands are grazed, the greater the opportunity for soil compaction, which may reduce growth of vegetation through its deleterious effects on soil aeration and infiltration (Cook and Stubbendieck, 1986). Compaction affects soil porosity by reducing the total pore space, especially the large pores, the non-capillary portion. Grazing effects on soil porosity and compaction have been elucidated by Orr(1960). He sampled soils inside and outside exclosures constructed between 5 and 20 years before the study. The results showed that large pore space to be significantly higher in the exclosures, with some having upto 100% more large pore space. The magnitude of differences in large pore between grazed and ungrazed range were highest in soils with high silt plus clay content. He also found bulk density of the 0-2 inch soil layer to be significantly higher on the grazed range than inside the exclosures. The greatest differences in bulk density were observed in soils with the highest silt plus clay content.

Studies have shown bulk density of the surface horizon to increase with trampling by livestock. Abdel-Magid et al. (1987a) simulated trampling using artificial hoofs and sods at four levels of intensity, for a maximum of 32 days and found bulk density to have increased by 4% and infiltration to have fallen by 57%. Other studies comparing ungrazed and grazed areas have shown bulk density to be influenced by grazing. For example, Orodho(1987) compared soil bulk density in ungrazed and grazed and one with a previous history of heavy grazing. The study was conducted on three topographic sites; hilltop, hillside, and swale. There were significant differences in bulk density between grazed and ungrazed areas and among the topographic sites. The study also showed that previous heavy grazing resulted in a mean increase in soil bulk density of

8.7% over the ungrazed area, with the greatest increase of 17.6% on the hilltop site.

Starting with a dry soil subjected to a certain compacting force, bulk density increases initially with increasing soil wetness, until a maximum is attained at an optimum soil wetness. Beyond this point of maximal bulk density, increasing wetness will lead to a decline in bulk density (Hillel, 1982). The relationship of increased bulk density leading to a fall in infiltration as also been shown in studies on grazing systems whereby bulk density is found to be one of the factors most strongly influencing infiltration (Mccalla et al. 1984).

Even though studies in the humid tropics have consistently showed increased bulk density with grazing conflicting results have reported in rangelands. A number of studies in rangelands have shown no significant difference in bulk density as result of grazing. For example, the effect of grazing was found not to have significantly influenced soil bulk density in study conducted by Laycock and Conrad (1969). The experimenters determined soil bulk density in exclosures constructed 15 years before the study and in adjacent grazed areas in Utah, U.S.A.. Even though there were no significant differences between the grazed and the ungrazed plots, significant differences were observed as a result of seasonal changes. These were attributed to differences in soil moisture. Grazing systems have also been reported to have produced no significant differences in bulk density. For example Abdel-Magid et al. (1987b) studied three grazing systems ; continuous, rotational deferment, and short duration with 3 stocking rates; heavy, 2.25 ha/steer and moderate, 3.0 ha/steer. The continuous grazing system was also stocked at a light rate, 5.25 ha/steer. The results showed bulk density was not significantly different ($p<0.05$) among grazing systems and stocking rate. This was attributed to the texture having a high percentage of sand. Despite the importance of bulk density in rangeland productivity no studies in Kajiado have attempted to evaluate its variation with increasing stocking rates.

After the review of literature it can be concluded that range managers have traditionally relied upon vegetation indicators to determine the condition and appropriate stocking rates. These indicators include the number of species termed as; increasers, invaders, and decreasers to assess condition (Stoddart et al. 1975). The amount of total consumable biomass produced annually which is then adjusted to a proper use factor, is the other vegetation indicator used to recommend an appropriate stocking rate. While vegetation indicators are important, it is also vital to integrate the soil physical responses and animal performance in stocking rate studies. It will be noted that no previous studies in

Kenya rangelands on trampling effects have been based on plot studies where the stocking densities are precisely known. Simulated trampling studies have been done (Dunne, 1977), however this excludes the animal effects of vegetation removal defoliation. Another study on Kenya rangelands by Mbakaya (1985) compared grazing systems which included; rotational grazing, high intensity low frequency, moderate continuous and livestock exclosures. Therefore studies in Kenya rangelands have not concentrated on stocking rate trials which integrate soil physical responses.

It is in the light of the foregoing discussion that a study was designed to investigate and evaluate the effects of three stocking densities on soils and vegetation of a semi arid rangeland of Kenya. The parameters assessed are infiltration rate, standing crop, vegetation cover, litter accumulation, and animal performance.

Chapter 3

MATERIALS AND METHODS

3.1 STUDY AREA

The study was conducted at the National Range Research Center, Kiboko, Kenya, which is about 170km south east of Nairobi. The center has an elevation ranging between 900m and 1,000m above sea level (Michieka and Van der Pouw 1977). It receives an annual rainfall of 600mm, with a long rainy season from March through May and a short rainy season during November and December. The monthly rainfall means for the last 10 years is shown on Figure 1. Rainfall recorded at the site for a duration of 1 year, including the period during which the study was conducted is shown on Figure 2.

The study site was located approximately 6.5km south east of the center headquarters and 2.5 km from Boma 8. The vegetation of the study area is classified as bushed grassland (Michieka and Van der Pouw, 1977). The dominant woody species in the area are Acacia senegal, Acacia mellifera, Grewia villosa, Cordia ovalis, and Balanites aegyptiaca. The dominant grass species are Digitaria macroblephara, Chloris roxburghiana. Bothriochloa insculpta. and Eragrostis caepitosa. The study site was situated on a very gently undulating basement complex. The soils are deep, reddish brown, ferrasole.

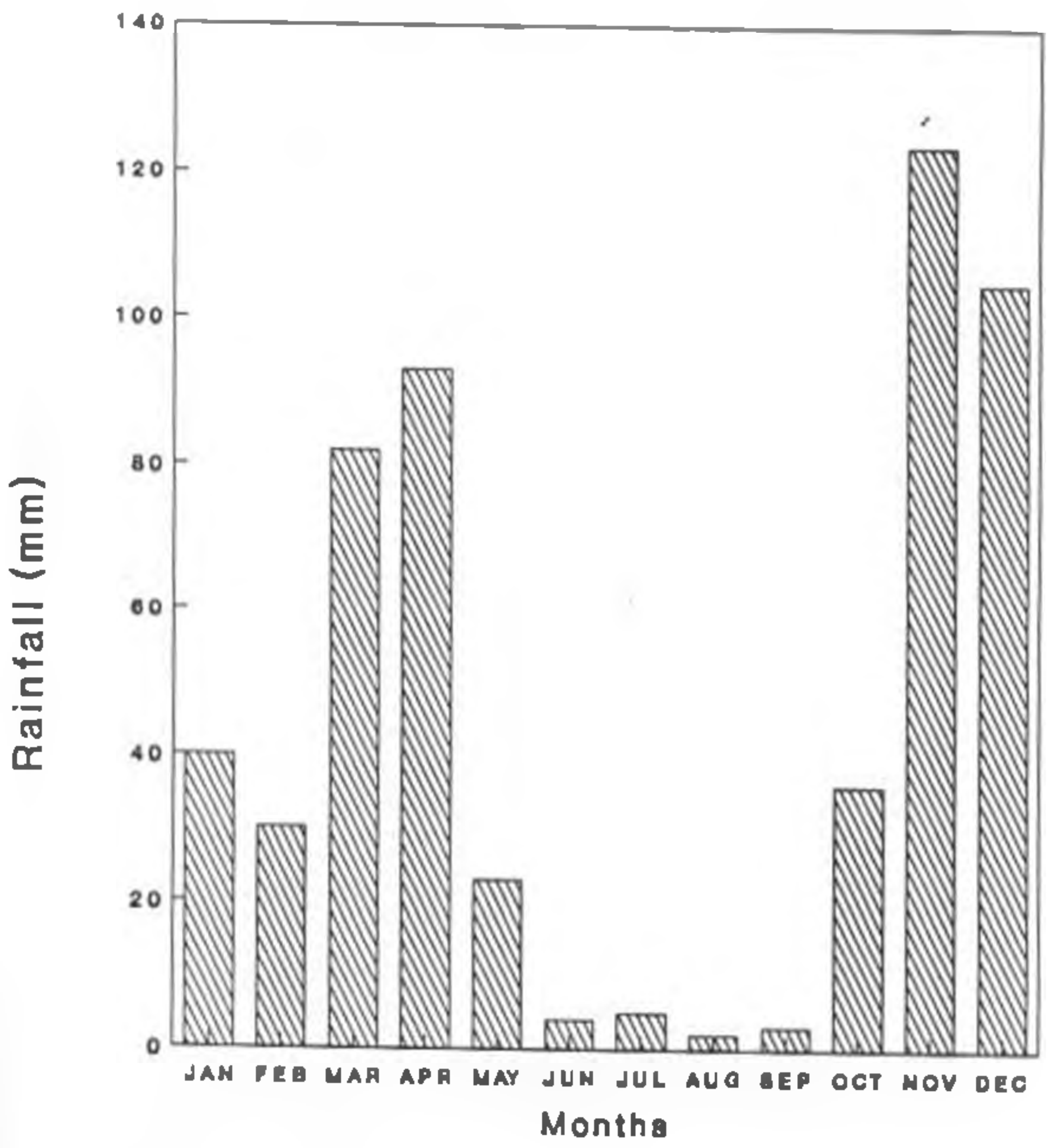

Figure 1. Monthly means of rainfall at Kiboko for the period 1981 to 1991.

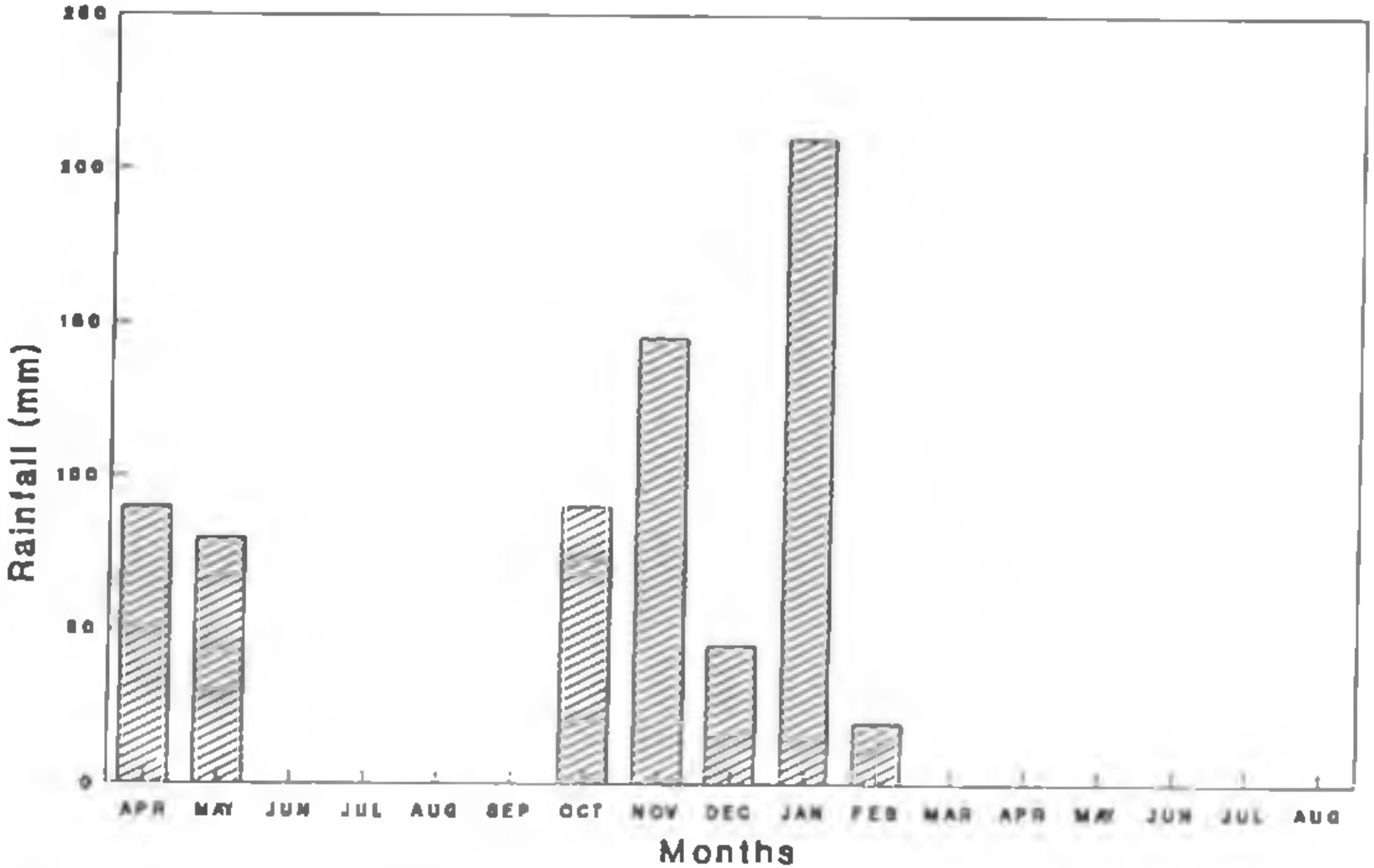

Figure 2. Rainfall received at the study site from April 1992 to August 1993.

3.2 TREATMENTS AND EXPERIMENTAL DESIGN

The treatment layout is factorial, with factor A being four stocking densities. While factor B is three periods of sampling. The stocking densities are 0 heifers/ha, 4 heifers/ha, 8 heifers/ha and 16 heifers/ha , hereafter referred to as CL, LD, MD and HD respectively. The three sampling periods are December 1992, March and May 1993. The sampling periods were set to coincide with the end of the short rains, end of the short dry season and end of the long dry season.

The treatments were applied in two replicates each measuring 2 hectares and sub-divided into four plots measuring 0.5 hectares each. The plots were 80 metres apart and demarcated using fencing. The treatments were randomly allocated to each plot.

The following parameters infiltration rate, bulk density, sediment production and litter accumulation were collected once in each of three sampling dates. The total number of samples collected across the three parameters were; 167 samples for bulk density and 120 simulated rainfall events for infiltration rate. To estimate sediment production and litter accumulation a total of 119 samples of each were collected. Herbage standing crop was sampled once every month with an exception of April with a total of 346 samples being collected.

Data was subjected to two way analysis of variance, in a completely randomized block design. The period of sampling was taken as blocks to bring out the effect of the period of sampling. In addition comparisons within each treatment across dates and within each date across treatments were made. Whenever the analysis showed significance, Duncans multiple range test was used to separate the means (Steel and Torie, 1980)

Regression analysis was used to derive the equation relating animal performance to stocking density. Simple correlation analysis was used to determine the variables influencing infiltration rate and soil loss. Data was analyzed using SAS statistical software at the Kenya Agricultural Research Institute.

3.3 VEGETATION

(i) HERBAGE STANDING CROP.

The standing crop of grasses and forbs was determined by clipping. Samples were clipped to a stubble height of 2cm using a circular $0.25M^2$ quadrat. The 2cm stubble height was so as to simulate intensive grazing. On each sampling date a total of 20 samples randomly located per treatment were collected; with half the number from each of the two replicates. The samples were then oven dried at 60 C for 48 hours, and the dry weight expressed in tons/ha.

(ii) HERBAGE COVER

Herbage cover was determined by use of the line intercept method as described by Canfield (1941). Data was collected on per species basis using 6 transects per treatment. Each transect measured 20 meters. Half the number of transects were located in each of the replicates.

(iii) LITTER ACCUMULATION

Litter accumulation was determined from the same plots on which rainfall simulation was done. Litter samples were obtained by hand collecting the dead vegetation material after clipping the plots to a 2cm stubble height. The samples were then oven dried at 60°C for 48 hrs, and the weights expressed in tons/ha.

3.4 INFILTRATION RATE AND SEDIMENT PRODUCTION

A mobile, drip-type rainfall simulator (Blackburn *et al*. 1974) was used to determine infiltration rate and sediment production. Simulated rainfall was applied at a rate of 10.5cm/hr for 30 minutes on plots measuring 37cm x 37cm. Runoff from each plot was collected regularly into holding bottles and measured at 5-minute intervals throughout the simulated rainfall event. Polythene tarpaulin were used as wind screens to minimize drift. To reduce variability caused by antecedent soil water content, the sample plots were pre-wet with 30 liters of water. The plots were then covered with polytene tarpaulin to minimize evaporation, and allowed to drain. Simulated rainfall was applied after approximately 24 hrs when the soils had drained to near field capacity. Infiltration rate (cm/hr) was calculated by determining the difference between applied rainfall and the quantity of water running off the plot. The following formula was used, infiltration (cm/hr);

$$=10.5cm-\frac{runoff\ vol\,[cm^3]}{plot\ area\ [cm^2]}X\frac{60min/hr}{5min/hr}$$

Whereby 10.5 cm/hr is the rainfall application rate.

At the end of each simulated rainfall event, the runoff collected from each plot was thoroughly mixed and 0.5 litter aliquot was taken. The subsample was filtered through a tared #1 whatman filter paper. Sediment remaining on the filter was oven dried at 105 C for 24 hrs, weighed and converted to sediment production (Kg/ha) based on area and total runoff from each plot. Prior to each rainfall simulation event a soil sample was collected adjacent to the runoff plot. The sample was used to determine soil moisture by the gravimetric method (Gardener, 1965).

3.5 SOIL BULK DENSITY.

The core method (Black, 1986) was used to determine soil bulk density to a depth of 5 cm, the diameter of the cores used was 5cm. The samples were then placed in metal cans, dried at 105°C, weighed and bulk density calculated. A total 20 samples per treatment, were collected at random on each sampling date. Soil texture was determined by use of the hydrometer method (Black, 1986)

3.6 ANIMAL PERFORMANCE

Twenty eight (28) heifers for the experiment were selected from the station Boran herd. The heifers selected were in good health, aged approximately 18 months and an average weight of 160kg. The allocation of heifers to treatments was done randomly. The treatments were 4 heifers/ha, 8 heifers/ha and 16 heifers/ha. The heifers were tagged, and confined in the treatment paddocks from 6.00 Hrs to 18.00 Hrs. The hours of confinement were only interrupted when routine management practices such as vaccination or weighing was being carried out. The heifers were penned at night. Fast weight was taken using a weigh bridge for a total of 9 times during the study.

Chapter 4

RESULTS

4.1 ANIMAL RESPONSE TO DIFFERENT STOCKING RATES.

The mean weight per head of the heifers in the different treatments is shown on Table 1. The average weight of heifers in all treatments initially increased before starting to decline after different grazing time periods. Heifers in the LD treatment gained a cumulative maximum of 17.3 kg/head after 63 days while the those in the MD and HD treatments gained 10.1 and 6.5 kg/head respectively after 40 days.

Animals in the LD and MD treatments maintained a positive average daily weight gain throughout the study (Figure 3) with a maximum of 0.31 kg/head/day for both treatments. In the HD treatment the maximum average daily weight gain was 0.24 kg/head/day on day 22. This fell to 0 kg/head on day 82 and became negative thereafter. The highest cumulative weight gain per hectare was 104 kg/ha in the HD treatment on the day 40 (Figure 4), this however eventually fell to a loss of 83.2 kg/ha on day 112. The maximum weight gain per hectare for LD treatment was 69.2 kg on the day 63 and 80.8 kg for the MD treatment on day 40.

It will be noticed from Figures 3 and 4 that in all treatments the maximum daily weight gain per head was realized earlier than the maximum gain per hectare.

Table 1.The average weight per (Kg) head of heifers by treatment and date of weighing after initiation of grazing treatments.

Days after initiation of grazing	Treatment Heifers/ha		
	4 [LD]	8 [MD]	16 [HD]
0	166^{a}	168^{a}	152^{a}
14	169^{a}	172^{a}	155^{a}
22	172^{a}	175^{a}	157^{a}
29	174^{a}	177^{a}	158^{a}
40	178^{a}	178^{a}	159^{a}
50	181^{a}	179^{ba}	158^{b}
63	183^{a}	177^{a}	156^{b}
82	182^{a}	177^{a}	152^{b}
112	180^{a}	174^{a}	147^{b}

^{abcd} row means with different superscript letters differ significantly ($p<0.05$)

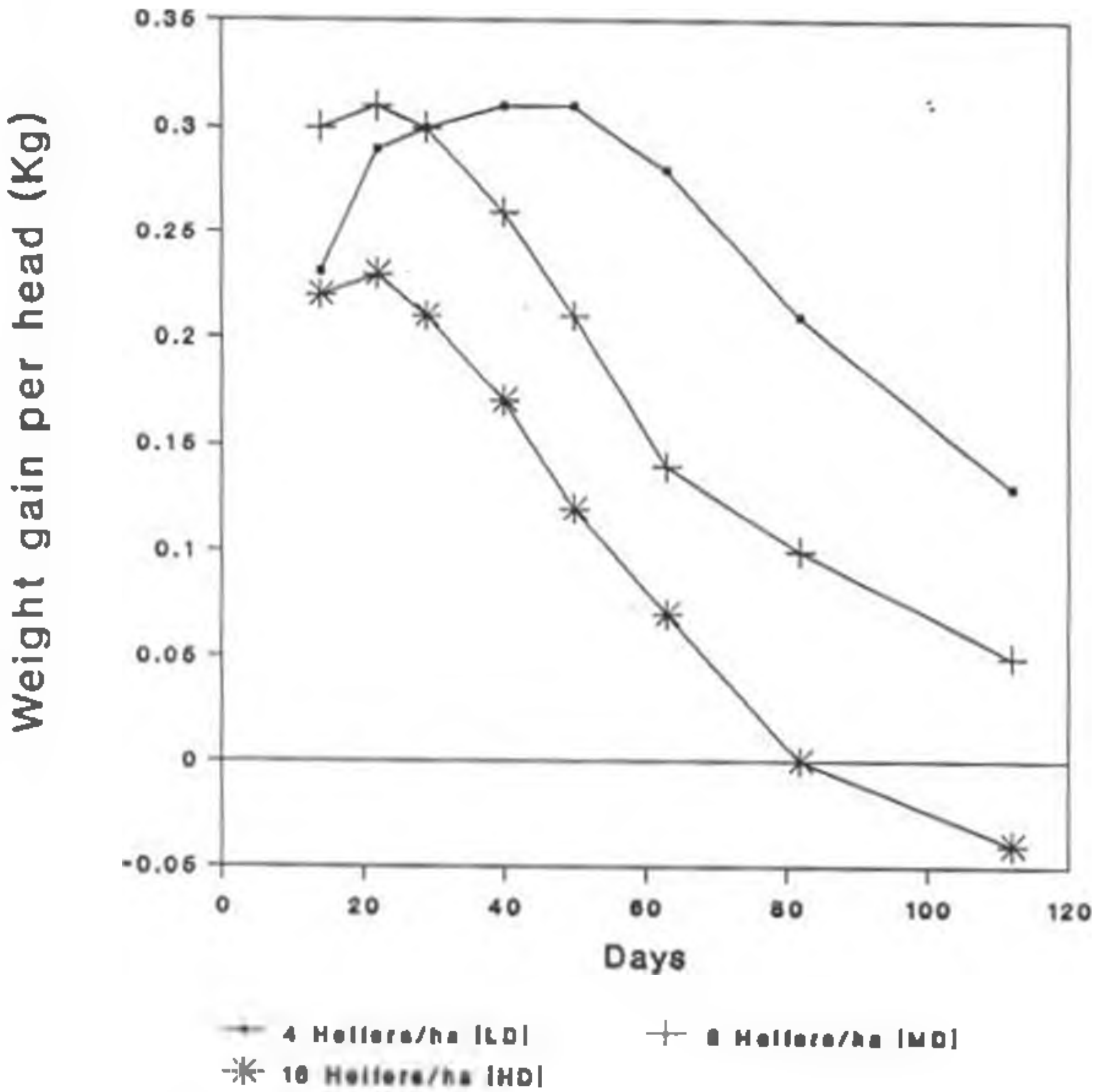

Figure 3. The average weight gains per head of heifers in the various grazing treatments.

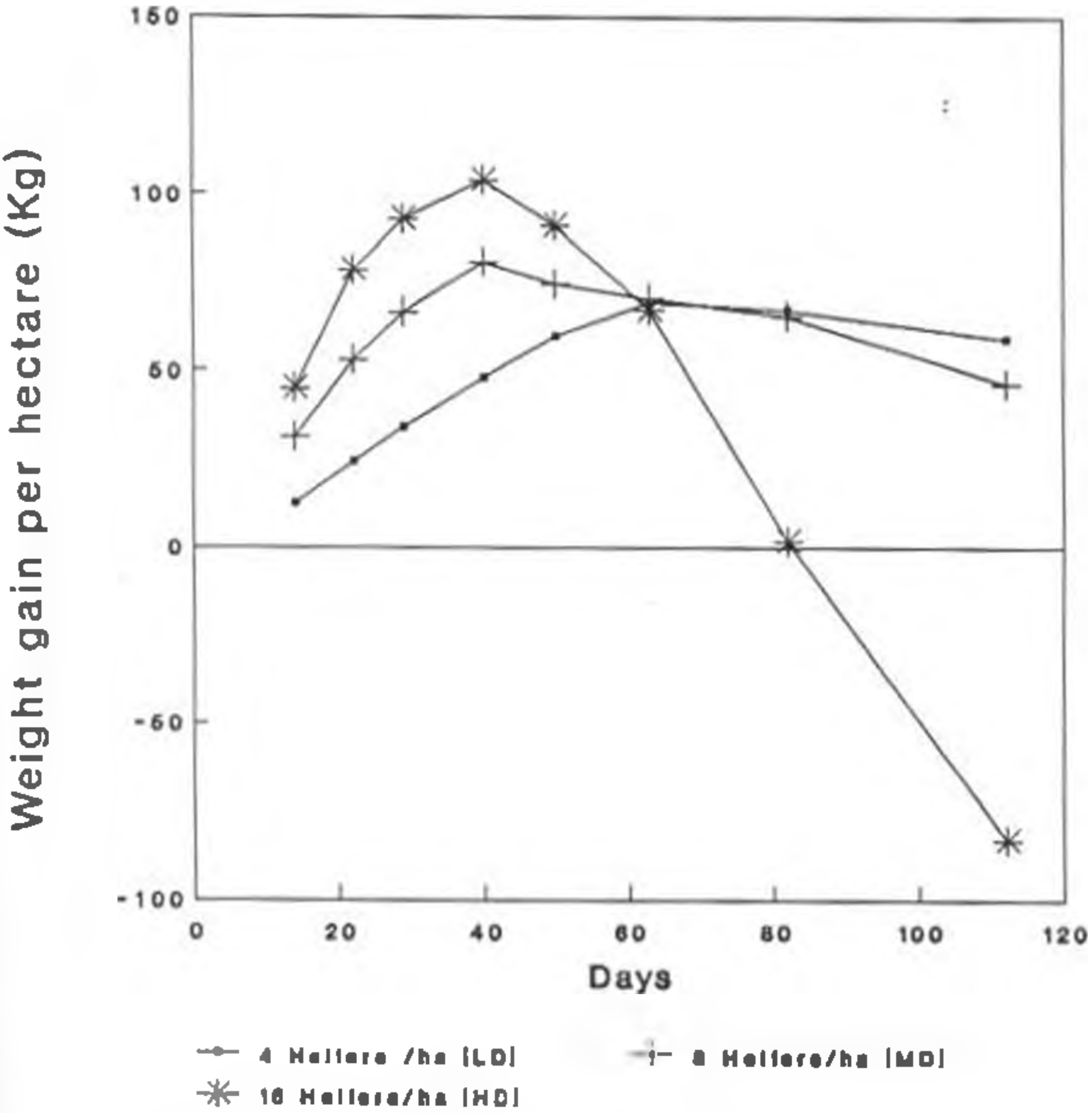

Figure 4. Animal liveweight gain per hectare in the various grazing treatments.

Regression analysis showed the relation of weight per head and stocking rate to be of negative linear type, with the equation $\underline{Ya}=0.416-0.011\underline{x}$ ($\underline{r}^2=0.828$ $p<0.001$) where $\underline{Ya}$ is the weight per head and $\underline{x}$ the stocking density.

4.2 VEGETATION RESPONSES

A large number of forbs were observed to have emerged during the short rains prior to stocking the plots; the major forbs included; Commelina bengalensis, Helitropeum steuderi, Astripomea hysoscyamoides, Vernonia aemulas and Ocimum americanum. The main grasses in terms of density were Digitaria macroblephara, Chloris roxburghiana, Bothriochloa insculpta, and Eragrostis caespitosa. At the commencement of the experiment the grasses in the study area were tall and stemy; because the area was under utilized. Initial trampling in January, in the HD treatment left the grasses lying prostrate. During the months January and February high regrowth of defoliated grasses especially Digitaria macroblephera was observed.

Phenological differences of some grasses and shrub species in different treatments in relation to flowering was noted. It was observed that most Chloris roxburghiana in the CL and a large number in the LD treatment flowered a second time in early February, having flowered first in late November. To a lesser degree Digitaria macroblephera displayed the same phenomena. No grass species in the MD and HD flowered in the duration of the study. Similarly, in March, Solanum incanum in the HD treatments had no flowers, few leaves, and yellowing fruits from the previous flowering, while the plants in the CL and LD treatment were in flower. Solanum incanum was mainly found around the ant hills.

Some annual plants such as the Cassia mimosidea completely failed to establish in the MD and HD treatment, yet in the CL and outside the treatment plots it grew in large numbers flowered and seeded heavily. In the MD treatment only a few scattered heavily defoliated Cassia mimosidea plants were observed. Generally by the end of the experiment the number of different species of forbs was higher in the CL plots than any other treatment.

Towards the end of the experiment, shrubs mainly in the HD treatment were observed to have been heavily defoliated. This included Solanum incanum. Hermania allensis. Grewia bicolor. Grewia similis and also on trees such as Cordia ovalis a definite browse line was evident. This was due heifers consuming more browse as the grass reduced in amount.

It was also observed that once grazed to the level of approximately 2cm, some grasses tended be pulled off the soil, Chloris roxburghiana was especially susceptible and to lesser degree Digitaria macroblephara.

4.2.1 STANDING CROP AND LITTER

Sampling for herbaceous standing crop was done once every month from December to May, with an exception of April.
In December prior to the application of grazing treatments the overall mean biomass was 3.0 tons/ha (Table 2). On subjecting the data to the analysis of variance the level of stocking density was found to have produced significant difference ($p < 0.01$) differences in herbage standing crop. The date of sampling also had significant ($p<0.05$) effect on herbage standing crop.

Table 2. Mean herbage standing crop (Tons/Ha) shown by treatment and date of sampling.

Treatment Heifers/ha	Date of sampling					Average
	Dec	Jan	Feb	Mar	May	
0 [CL]	3.0^{a}	3.6^{a}	3.8^{a}	4.2^{a}	4.2^{a}	3.8^{a}
4 [LD]	3.0^{a}	3.3^{a}	3.7^{a}	3.2^{ba}	2.1^{b}	3.1^{b}
8 [MD]	3.1^{a}	3.7^{a}	3.5^{a}	2.3^{bc}	1.2^{c}	2.7^{b}
16 [HD]	2.9^{a}	2.8^{a}	2.0^{b}	1.2^{c}	0.4^{d}	1.8^{c}

^{abcd} column means with different superscript letters differ significantly ($p<0.05$)

(p<0.01) on the amount of herbage standing crop. The interaction of stocking density and the date of sampling was significant (p<0.01).

In the first month after implementation of treatments, there were no significant differences (p>0.05) between treatments in standing crop. In subsequent sampling dates after the January the standing crop declined with increasing stocking density. Eventually by the month of May the means of standing crop for all treatments differed significantly (p<0.05), with 4.2 Tons/ha and 0.4 Tons/ha for CL and HD treatments being the extremes.

In the CL paddocks, standing crop increased throughout the experiment even though the increase after March was very small due to the onset of the dry season. In the LD treatment standing crop increased through January and February after which it started to decline, while in the MD treatment the increase was only in January.

In the HD treatment the standing crop declined significantly (p<0.01) throughout the experiment from 2.9 to 0.4 tons/ha in December and May respectively.

In all grazed plots (LD, MD, and HD) the decline in mean standing crop was significant (p<0.05). When analysis with dates of sampling taken as blocks was done to get the average treatment effect, the average amount of standing crop in the

CL was significantly higher ($p<0.05$) than all other treatments, while the HD was significantly ($p<0.05$) lower than the rest of the treatments.

Sampling for litter accumulation was done in December March and May and is shown table 3. The level of stocking produced a significant ($p<0.01$) response in the amount of litter accumulated in the plots.

The date of sampling after the commencement of the treatments also led to significant ($p<0.01$) response in litter accumulation. In December the means of litter dry weight (table 3) did not differ significantly ($p>0.05$) and the overall mean was 0.49 Tons/ha. In March the mean litter dry weight for the HD treatment, of 2.2 tons/ha, was significantly higher ($p<0.05$) than all the other means of litter dry weight. By the month of May an order of increasing litter with increasing stocking was evident, with HD plots having 1.1 Tons/ha of litter more than CL plots.

In all treatments, except the HD, the mean litter dry weight increased through the three sampling dates of December, March and May. The change in litter dry weight across sampling dates was significant ($p<0.01$) in the MD and HD treatments. It will be noted that the mean litter dry weight in the HD increased initially upto March and then started to decline. Analysis of variance to determine average treatment effect showed that only the mean litter dry weight for HD differed significantly ($p<0.05$) from the rest.

Table 3. Litter dry weight(tons/Ha) shown by treatment and date of sampling.

Treatment Heifers/ha	Date of sampling			Average
	December	March	May	
0 [CL]	0.4^{a}	0.7^{a}	0.7^{a}	0.6^{a}
4 [LD]	0.5^{a}	1.0^{a}	1.1^{ba}	0.9^{a}
8 [MD]	0.5^{a}	1.0^{a}	1.3^{b}	1.0^{a}
16 [HD]	0.5^{a}	2.2^{b}	1.8^{c}	1.6^{b}

^{abcd} column means with different superscript letters differ significantly ($p<0.05$)

4.2.2 HERBAGE FOLIAR COVER

Determination of herbaceous foliar cover was done in December and March. In December the mean herbaceous cover across all plots was 61% with perennial grasses constituting 51% (Table 4). The most abundant perennial grasses were Chloris roxburghiana, Digitaria macroblephara, Cenchrus ciliaris, and Bothriochloa insculpta. Relative herbaceous cover in CL and LD treatments increased by 13.5% and 3.1% respectively between December and March; whereas that of MD and HD treatments declined by 17.0 % and 17.3 % respectively. In all treatment plots, in both December and March Digitaria macroblephera and Chloris roxburghiana had the highest relative cover. However by March an order of declining herbaceous foliar cover with increasing stocking density was evident, with the difference between CL and HD being 30.4%.

Table 4. Herbage foliar cover (%) shown by treatment and date of sampling.

DECEMBER	Treatment (Heifers/ha)			
Species	0 [CL]	4 [LD]	8 [MD]	16 [HD]
Digitaria macroblephera	33.1	31.8	37.8	22.9
Chloris roxburghiana	9.7	5.3	5.5	13.1
Cymbogon posichilli	0.0	3.6	0.0	1.8
Eragrostis caespistosa	1.4	2.2	2.6	4.6
Cenchrus ciliaris	0.4	5.4	1.3	1.4
Bothrichloa insculta	3.6	3.7	4.4	2.7
Solanum incanum	5.3	0.8	0.6	1.2
Hermania alhensis	0.0	1.0	1.3	3.9
Panicum maximum	0.5	0.0	0.0	0.1
Tehrosia villosa	0.3	0.2	0.0	0.3
Sehima nervosum	0.0	3.9	0.7	0.0
Commelina bengalensis	4.1	5.2	1.5	2.0
Sporobulus pellucidus	1.1	2.0	2.9	1.4
Total Herbage cover %	**59.8**	**65.1**	**58.6**	**60.2**
MARCH				
Digitaria macroblephera	40.4	34.3	34.6	17.3
Chloris roxburghiana	10.3	5.1	3.6	12.7
Cymbogon posichilli	0.4	6.4	0.0	1.1
Eragrostis caespistosa	1.2	3.7	1.6	3.6
Cenchrus ciliaris	1.0	4.5	1.1	0.8
Bothrichloa insculta	3.7	5.4	4.4	3.1
Solanum incanum	7.9	0.8	0.8	0.3
Tehrosia villosa	0.2	0.0	0.0	0.0
Sehima nervosum	0.0	5.1	0.3	0.0
Commelina bengalensis	1.3	0.4	0.4	0.0
Sporobulus pellucidus	2.0	0.9	3.9	1.4
Cassia mimosides	1.2	0.0	0.0	0.0
Hermania allensis	0.9	0.6	0.0	0.0
Panicum maximum	1.2	0.0	0.0	0.0
Total Herbage cover %	**73.3**	**68.6**	**50.7**	**42.9**

4.3 WATERSHED RESPONSES

4.3.1 INFILTRATION RATE.

The rate of water infiltration into the soil was estimated through measurements taken in December, March and May. The means of infiltration rate (cm/hr) taken at all sampling dates and all time intervals is shown in Table 5. Only infiltration rate after 30 minutes was subjected to statistical analysis, due to two observations. Firstly, there was a similarity in trend of infiltration data collected at the time intervals of 5, 10, 15, 20, 25, and 30 minutes across treatments. Secondly, after 30 minutes an almost steady state infiltration had been achieved. It was noticed that during all simulated rainfall events, irrespective of the treatment or date, infiltration rate was high in the first 5 minutes and declined with time approaching a steady state infiltration after 30 minutes.

The mean infiltration rate (cm/hr) after 30 minutes of all treatments and at all sampling dates after statistical analysis is presented in Table 6. Prior to application of the grazing treatments there were no significant differences ($p<0.05$) in the mean infiltration rates of the various plots and the overall mean for December was 7.4 cm/hr. The level of stocking produced a significant ($p<0.01$) response in the rate of water infiltration in the study plots. The date of sampling also produced a significant ($p<0.05$) response in infiltration rate.

Table 5. The means of infiltration rate (cm/hr) by treatment, at all time intervals and date of sampling.

1. December

Treatment	Time interval (minutes)					
Heifers/ha	5	10	15	20	25	30
0 [CL]	9.1	8.1	8.0	7.6	6.7	7.4
4 [LD]	9.0	7.3	7.9	7.9	7.6	7.8
8 [MD]	8.0	7.9	7.1	7.0	7.2	7.1
16 [HD]	8.2	7.5	7.5	7.6	7.3	7.2

2. March

Treatment	Time interval (minutes)					
Heifers/ha	5	10	15	20	25	30
0 [CL]	7.7	7.5	7.2	7.1	7.3	7.2
4 [LD]	7.2	7.1	6.1	5.7	5.5	5.6
8 [MD]	7.1	6.1	5.7	5.8	5.8	5.6
16 [HD]	5.5	4.5	4.6	4.1	4.1	4.3

3. May

Treatment	Time interval (minutes)					
Heifers/ha	5	10	15	20	25	30
0 [CL]	8.3	7.6	7.5	7.4	7.0	6.9
4 [LD]	7.6	6.9	6.6	5.9	5.4	5.2
8 [MD]	7.2	6.1	5.5	5.2	4.3	4.5
16 [HD]	7.5	6.7	5.4	4.8	3.9	3.8

Table 6. Mean infiltration rate (cm/hr) after 30 minutes of simulated rainfall by treatment and date of sampling.

Treatment Heifers/Ha	Date of sampling			Average
	December	March	May	
0 [CL]	7.4^{a}	7.2^{a}	6.9^{a}	7.1^{a}
4 [LD]	7.8^{a}	5.6^{ba}	5.2^{b}	6.0^{b}
8 [MD]	7.1^{a}	5.6[illegible]	4.5^{cb}	5.6^{cb}
16 [HD]	7.3^{a}	4.3^{b}	3.8^{c}	4.9^{c}

[abcd] column means with different superscript letters differ significantly ($p<0.05$).

In the sampling dates of March and May when the grazing treatments were implemented, infiltration rates decreased with increasing stocking density. Also in all grazed plots (LD, MD, and HD) infiltration rate declined with time, thus in each treatment infiltration rate in March was higher than May. The decline in infiltration rate in the December to March period was higher than the decline in March to May period. In march the mean infiltration rate of the CL treatment, 7.2 cm/hr, was significantly higher than that of HD treatment. However, the infiltration rates of CL, LD and MD treatments did not differ significantly ($p<0.05$).

During may the infiltration rate of the CL treatment, 6.9 cm/hr, was significantly higher than 5.1, 4.5 and 3.8 cm/hr for the LD, MD and HD treatments respectively. Also the infiltration rate of the HD treatment was significantly lower than 5.2 cm/hr for the LD treatment. The average water infiltration rate in the CL plots was significantly higher ($p<0.05$) than all other treatments. Conversely, the mean infiltration rate in the HD was the lowest, but not significantly lower ($p<0.05$) than MD (table 6).

Infiltration rates for bare ground measurement plots on all sampling dates were generally lower than those with grass cover irrespective of the treatment (Table 7). Infiltration rates of all types of plot cover declined with increasing stocking density.

Table 7. Mean infiltration rate (cm/hr) after 30 minutes of simulated rainfall by treatment and type of plot cover.

Treatments Heifers/Ha	Type of plot cover		
	Bare ground	*Chloris roxburghiana*	*Digitaria macroblephera*
Before grazing	$(4.0)^{a}$	$(8.8)^{a}$	$(8.0)^{a}$
0 [CL]	5.2^{ba}	8.4^{a}	8.3^{a}
4 [LD]	3.2^{b}	6.2^{b}	7.1^{ab}
8 [MD]	3.0^{b}	6.1^{b}	6.0^{b}
16 [HD]	2.6^{b}	5.1^{c}	4.4^{c}

Mean of data taken before grazing is shown in parathensis.
^{abcd} column means with different superscript letters differ significantly ($p<0.05$).

Simple correlation analysis showed the variable with the greatest correlation to infiltration after 30 minutes was the amount of herbage standing crop (r=0.72).Other variables were initial soil moisture(r=0.32), and bulk density 0-5cm (r=-0.175).

4.3.2 SEDIMENT PRODUCTION.

Sediment production measurements were taken on three sampling dates, December, March and May. Prior to the application of grazing treatments there was no significant difference ($p<0.05$) in the means of sediment production of the various plots and the overall mean for December was 320 kg/ha (Table 8). The level of stocking density was found to produce a significant ($p<0.01$) response in the amount of soil lost from the measuring plots. The date of sampling after the commencement of the treatments also significantly ($p<0.05$) influenced soil loss. There was also a significant ($p<0.05$) stocking density to date of sampling interaction.

On the sampling dates of March and May sediment production increased with increasing stocking density. Soil loss from all grazed plots (LD, MD and HD) increased with time of grazing, thus in all these plots the amount of soil lost was higher in May than March, while the least was lost in December. The amount soil of lost with time of grazing from the HD and MD was significant ($p<0.01$). The change in soil loss increased with time was but not significant ($p<0.05$) in the CL treatment. In the LD plots soil loss increased with time but the increase was not significant ($p>0.05$).

In march the extremes of sediment production were 277 kg/Ha and 660 kg/Ha for CL and HD respectively, were significantly

Table 8. Sediment production (kg/ha) by treatment and date ofsampling.

Treatment Heifers/ha	Date of sampling			Average
	December	March	May	
0 [CL]	267[a]	277[a]	226[a]	256[a]
4 [LD]	379[a]	396[ba]	518[a]	437[a]
8 [MD]	377[a]	533[ba]	876[b]	668[b]
16 [HD]	250[a]	660[b]	1115[b]	724[b]

[abcd] column means with different superscript letters differ significantly ($p<0.05$).

different ($p<0.05$). In May 1115 Kg/ha of sediment was produced from HD, this is significantly different ($p<0.05$) from 226 and 518 kg/ha for the CL and LD respectively.

Average sediment production from the CL and LD plots were significantly different ($p<0.05$), however the two differed from the sediment yield of MD and HD plots.

Simple correlation analysis showed that the variable with the greatest influence on soil loss was herbage standing crop($r=-0.44$). Thus soil loss from the plots increased as the amount of herbage was reduced by the grazing animals.Other variables influencing sediment production were bulk density($r=0.34$) and initial soil moisture($r=-0.27$).

4.3.3 SOIL BULK DENSITY

Sampling for soil bulk density was done in December, March and May. Prior to grazing treatments there was no significant differences ($p<0.05$) in the means of soil bulk density (Table 9) and the overall mean of all plots was 1.03 gm/cm^3. The level of stocking density produced significant ($p<0.01$) differences in bulk density. The date of sampling after commencement of grazing treatments also significantly ($p<0.05$) influenced bulk density.

On all sampling dates after application of the grazing treatments the mean bulk density increased with increasing stocking density. In March the mean bulk density within HD treatment of 1.25 gm/cm^3 was significantly higher ($p<0.05$)

than the mean bulk densities of CL and LD treatments which were 1.08 gm/cm^3 and 1.13 gm/cm^3 respectively.

In May the mean of bulk density of MD and HD were not significantly different ($p<0.05$), both were significantly higher than those of CL and LD treatments. The mean bulk density of CL and LD treatments did not differ significantly ($p<0.05$).

Mean bulk density in grazed plots increased with time, the increase was significant ($p<0.05$) in the MD and HD treatments whereas in the CL and LD treatments the change was not significant ($p<0.05$). In all treatments the increase in means of bulk density was higher for the December to March period than March to May period. It will be noted that the rains were received in December to March period (Figure 2).

Soil texture analysis of samples collected at 0-5cm depth was done by use of the hydrometer method. On average the soil was found to consist of 71.5% sand, 25% clay and 3.5% silt. The texture class of the soil is therefore, sandy clay loam, according to USDA classification (Fitzpatrick, 1974).

Table 9. Mean soil bulk density (gm/cm^3) shown by treatment and date of sampling.

Treatments Heifers/Ha	Date of sampling			Average
	December	March	May	
0 [CL]	1.05^{a}	1.08^{a}	1.09^{a}	1.08^{a}
4 [LD]	1.01^{a}	1.13^{ba}	1.12^{a}	1.09^{a}
8 [MD]	1.08^{a}	1.2^{cb}	1.24^{b}	1.15^{b}
16 [HD]	1.09^{a}	1.25^{c}	1.26^{b}	1.21^{b}

^{abcd} column means with different superscript differ significantly ($p<0.05$).

Chapter 5

DISCUSSION

5.1 ANIMAL RESPONSE TO DIFFERENT STOCKING RATES.

From the results of this study the relationship between weight gain per head (Ya)and stocking density (x) was found to follow a negative linear trend, with equation $Ya=0.416-0.011x$ ($r^2=0.828$, $p<0.001$). The relationship between declining animal production and increasing stocking density has been reported in several grazing studies involving cattle and sheep. Jones and Sandland (1974) used results from an experiment conducted on tropical grass-legume pastures to demonstrate the relationship and obtained r values ranging -0.973 to -0.999. Wilson and Macleod (1991) having reviewed several experiments showed that despite relationships being true for certain range of stocking rates it will not hold at low stocking rates when forage available becomes non-limiting. Also at high stocking rates, pasture deterioration occurs and an accelerated decline in production per head follows (Wilson, 1986). A similar situation was observed to have occurred in the heavily stocked pastures where the gain per head fell rapidly after about 40 days.

In terms of production per hectare, the highest stocking rate (HD) yielded the highest weight gain per hectare reaching a maximum of 104 kg/Ha on day 40. This was followed by a sharp drop. This could be attributed to depletion of fodder which was falling rapidly after 30 days of grazing as shown non Table 2.

By the end of the experiment the lightest stocked paddock gave the highest cumulative output per hectare of 59.2 kg, closely followed by MD treatment at 46.4 kg. Similarly, at the end of the experiment animals in the LD treatment had the highest average daily weight gain of 0.13 kg/head/day followed by those of MD. In this study, the results in gain per head and the average weight of heifers in the LD and MD were rather close as compared to those in HD treatment which were very low. If the relationship of stocking density to animal product output is developed over a long time, it can be used to determine when overgrazing occurs. Overgrazing is considered to have occurred when pasture productivity declines leading to a loss of linearity between animal product output and stocking rate (Wilson and Macleod, 1991). The need to develop the relationship over a long period of time arises because animal performance in rangelands fluctuates depending on forage availability and season. The results of this study also have implications on the management objéctives of rangelands. For example, if the objective is to produce quality beef for a specified market the lower stocking densities which maximize output per animal would be appropriate. This would be the case for private ranches, however considerations of marginal costs and revenue would still be necessary. If the objective is to maximize output of animal products per unit of land then higher stocking densities would be appropriate. This could be combined with herd mobility or rest rotation. Maximization of animal output per hectare is generally the objective of pastoralist, hence their use of high stocking densities (Cossins, 1985).

However, it should be noted that the study was conducted over a period of 2 seasons which is inadequate to draw a definite relationship and further experimentation is necessary.

5.2 VEGETATION RESPONSES

The two most abundant perennial grasses in the study plots, Digitaria macroblephera and Chloris roxburghiana failed to flower in the MD and HD treatments. This could be attributed to the high grazing pressure applied during the early phenological stages, thus retarding maturity. Delay of maturity of perennial grasses as result of early grazing pressure has been reported by several workers (Heady, 1975). The perennial grass tufts once grazed to 2cm stubble height in the HD treatment tended to be easily uprooted from the soil by grazing animals. The uprooting of perennial grasses coupled with the fact that they failed to produce seeds could lead to changes in grass relative densities in the subsequent seasons, favoring annual grasses which matured and seeded very fast. Based on these results it would be advisable for livestock managers in rangelands which are dominated by perennial grasses such as Chloris roxburghiana and Digitaria macroblephera to avoid intensive grazing during the establishment phase. Similarly, grazing to a level of 2cm stubble height would lead not only to uprooting of the tufts but also destabilization of the soil rendering it more prone to erosion. Changes in relative abundance of species are common in grasslands as a result of year to year variations in climatic or environmental factors. These are fluctuations rather than successional changes (Miles, 1971). The seasonal forb Cassia mimosidea completely failed to establish and seed in the MD and HD plots, yet it seeded heavily in the CL plots. If this causes differences in the seed bank then a reduction in relative forb densities in the subsequent seasons would be expected if the treatments continued. Harper (1977) noted that the flux of seed into a habitat determines the potential population of that habitat. The time period over which the experiment was conducted was not long enough to draw conclusions on vegetational changes.

Data collected on herbage biomass and cover in the LD, MD, and HD plots can be regarded as responses to the simultaneous effects of defoliation by grazing and environmental factors especially rainfall. In the CL the effect of defoliation by grazing livestock is removed and the responses can be attributed to environmental factors.

At the start of the experiment herbage standing crop among plots was not significantly different and the mean was 3.0 tons/Ha. In the period of December to February herbage standing crop increased in the CL, LD and MD plots despite application of grazing treatments in LD and MD (Table 2). The increase in herbage standing crop was 0.8, 0.7 and 0.4 tons/Ha for the CL, LD, and MD treatments respectively. These increases could be explained by the continuing rains (Figure 2), which allowed high growth and regrowth of herbage surpassing animal consumption. During this period ocular observations of high regrowth of defoliated grasses in the MD and HD treatments were made. Similar results obtained on responses of grasses to defoliation include, stimulation of new growth (Heady, 1975), decline in above ground grass biomass (Belsky, 1986), reduced vegetation cover (Wood and Blackburn, 1984).

In the period of March to May herbage standing crop declined in all treatments except in the CL where it remained constant. This could be explained by the onset of the dry spell (see Figure 2). Thus in the LD, MD and HD growth and regrowth was surpassed by animal consumption. The significant (p<0.05) interaction between stocking density and date of sampling for herbage standing crop indicated that the two factors were not independent of each other.

In the period of December to March, all grazed plots (LD, MD and HD) showed an initial high increase in litter accumulation with HD having the highest. This could be attributed to initial trampling on tall and stemy grasses, since the study plots were set in a relatively under utilized area. Hence the amount of litter generated was proportional to the amount of trampling. However, as time progressed and standing crop declined in the grazed plots less litter was generated, as is seen in the March to May period. During the period of March to May litter accumulated in the HD plots declined. This can be attributed to the fall in standing crop, hence less litter being generated and consumption by termites. Other researchers have found litter accumulation to decline with increasing stocking rate in the long term (Naeth et al. 1990b; Johnstone et al.1971; Orodho et al. 1990). The same result would have eventually arisen in this experiment since the HD plots which had the least standing crop would have the least litter being generated, and consumption by livestock would be high.

Vegetation cover declined with increasing stocking density, as expected. The increasing land bareness with high stocking densities reflects what would be the outcome of long term heavy utilization of South Kenya rangelands. High stocking rates were associated with increase in annual grasses as compared to perennial grasses. Also the increasing land bareness would lead to soil loss and thus a decline in productivity.

5.3 WATERSHED RESPONSES

5.3.1 INFILTRATION RATE

Infiltration rate at all sampling dates in all treatments was initially high and declined with time of application of simulated rainfall. Thus in all cases infiltration rate after 5 minutes was highest and tended to be steady in the last 25-30 minutes. This conforms to the general infiltration curve derived from a wide range of studies (Branson et al. 1981), whereby infiltration is initially high at the start of water application, but declines with time to approach a steady state. Since the soils in this study were initially at field capacity having been pre-wet 24 hours earlier infiltrations quickly approached the steady state.

It was observed that prior to the application of grazing treatments there were no significant differences in infiltration rate after 30 minutes as shown in Table 4.
On all sampling dates following application of grazing treatments infiltration after 30 declined significantly ($p<0.05$) with increasing stocking density. The same trend to a large extent was also observed at time intervals 5-25 minutes. Lack of significant interaction between stocking density and date of sampling for infiltration rate indicated the two factors were independent. Seasonality had no appreciable effect as is shown by lack of a significant

($p<0.05$) change in infiltration between dates within the CL, which was ungrazed. Similar trends have been obtained by other workers, for example, Warren (1986) using heifers to trample small plots at the rates of 8.1, 4.1 and 2.7 Ha/Au/yr found infiltration to decline with increasing trampling rate, irrespective of whether the plot was wetted or not. Similar results were reported by Abdel-magid et al (1987a) who simulated trampling using artificial hoofs and sods, and found infiltration to decline with increasing trampling intensity.

The fall in infiltration with increasing stocking density in this study could be due to several factors. Simple correlation analysis showed herbage standing crop to be the one most strongly influencing infiltration rate ($r=0.72$). Herbage standing crop declined with increasing stocking density and was accompanied by declining infiltration rate. In other rangeland infiltration studies standing herbage biomass, vegetation cover, and bulk density have been shown to be major factors influencing the rate of infiltration. Pluhar et al (1987) while conducting an experiment to quantify the effects of rotational grazing on rangeland hydrologic properties in Texas concluded that the total vegetation standing crop and the percentage bare ground were the factors most strongly correlated to infiltration rate. In this study, in all treatments and at all sampling dates infiltration rate on bare ground plots was lower than on vegetated plots. Infiltration in bare plots declined with increasing stocking density, thus there was less water in infiltration on bare ground in HD plots than on bare ground in any other treatment. This indicates that the more intensive the trampling on bare ground the greater the reduction in infiltration rate. This has practical implications to the livestock manager. It indicates that once vegetation cover falls as a result of over utilization or drought, the stocking level should be reduced not only in response to reduced forage, but also to avoid accelerated soil loss and compaction.

The primary role of vegetation is to decrease the kinetic energy of raindrops before they strike the soil. This reduces the potential impact velocity, and the pores are less likely to be clogged by deaggregated soil particles. The results indicate the importance of avoiding depletion of vegetation cover by over stocking on the Kenya rangelands since this would lead to severe drop in infiltration and increased runoff. In this experiment variation in infiltration rate was only weakly correlated to bulk density ($r=-0.175$).

5.3.2 SEDIMENT PRODUCTION

Sediment production(kg/Ha) was used as an index of soil loss resulting from the grazing treatments. Sediment production from the plots before application of grazing treatments was not significantly different and the overall mean was 320 kg/Ha. In the following two sampling dates after initiation of grazing treatments a clear trend of increasing soil loss with increasing stocking density was evident. Even though the interaction of stocking density and date of sampling was significant ($p<0.05$), it was much smaller than the main effects ($p<0.05$). Therefore the interaction may have been due to minor variation in the effects of stocking density across sampling dates. In all treatments except CL, the sediment production in May was higher than in March with 1115 kg/Ha for HD treatment being the highest. This indicates that livestock grazing has cumulative effect on sediment production. Thus if a pasture is stocked at levels that cause a soil loss problem,it will only get worse with time unless corrections are taken. This could include reducing the stocking level, reseeding the pasture or simply resting it. In this study sediment production increased by 36%, 132% and 346% for the LD, MD and HD treatments respectively. In other studies in Kenya rangelands, Dunne (1977) working in Amboseli and Athi Kapiti in Kajiado district simulated trampling at levels of 0, 10, 100 and 1000 hoofprints/m^2 and found soil loss to increase from 910 kg/Ha to 3800 kg/ha in the 0 and 1000 hoofprints/m^2 respectively. This he attributed to the mechanical disturbance of the soil and reduction in vegetative cover.

In this study correlation analysis across all dates and treatments showed herbage standing crop to be the variable most highly correlated to soil loss (r=0.55). It will also be noted that percent herbage cover was least in the treatments that had the highest soil loss. Sediment production also increased with increasing bulk density (r=0.34). This shows that grazing livestock not only influences soil loss by removal of protective vegetation cover but also by physical manipulation of the soil aggregates through trampling, rendering the soil more susceptible to erosion.

5.3.3 BULK DENSITY

Soil bulk density taken at 0-5cm, prior to the application of grazing treatments was not significantly different across the plots and the overall mean was 1.05 gm/cm^3. On all sampling dates after the initiation of the grazing treatments soil bulk density increased with increasing stocking density. The lack significant interaction ($p<0.05$) between stocking density and date of sampling for bulk density indicated the factors were independent. Seasonality had no appreciable effect on soil bulk density as is shown by lack of a significant ($p<0.05$) change in between dates in the CL, which was ungrazed. Soil compaction as measured by taking soil bulk density has been reported to increase with livestock trampling in several rangeland studies (Naeth et al. 1990a, Abdel-Magid et al. 1987b, Laycock and Conrad, 1967). Stephson and Veigel (1987) reported that from a study using 3 stocking levels namely; 0, 10, and 40 cattle/ha the bulk densities were

1.36, 1.49, and 1.61 respectively before the recovery phase. This represents an increase of 18% in bulk density between the lowest and the highest stocking rate.

In this study bulk density in each treatment increased with time except in the CL treatment. In all grazed plots (LD, MD and HD) the increase in bulk density the period of January to February was higher than the increase in the March to May period. This could be due to the application of the compacting force, that is; the grazing livestock, during the rainy season. At this time the soils were wet and higher compaction could be attained as compared to the March to May period when it was dry (Figure 2). The increase in bulk density was 10% for the lowest stocking level and 16% for the stocking level. Increases in bulk density of upto 21% have been obtained as a result of livestock grazing (Orr, 1960). The increase in bulk density as a result of grazing could be attributed to loads exerted by the heifers when standing and moving. Soil compaction impedes movement of water and air through the soil by reducing the number of large pores. This will affect root growth and infiltration, in turn affecting productivity of the land (Hillel, 1982).

SUMMARY AND CONCLUSIONS

The HD treatment, which was the highest stocked pasture attained the highest output per hectare, a live weight gain of 104 kg/Ha after 40 days. However this treatment had the most deleterious effects on the pasture's hydrologic and vegetation characteristics. In the HD plots rapid decline in standing biomass and herbage cover was accompanied by reduced infiltration rate, increased soil loss and bulk density. The deterioration of the HD pasture led to a collapse of output on both per hectare and per head basis. On the other hand both LD and MD maintained positive weight gains per head with LD giving the highest output per head by the end the study. It can therefore be concluded that higher stocking densities maximize output per hectare. If such high stocking densities are to be used then suitable grazing management plans which allow herd mobility or rest rotation must be integrated. This would allow recovery in the pasture's infiltration rates, bulk density, sediment production and vegetation cover.

All parameters taken to assess the hydrologic condition of the plots generally deteriorated with increasing stocking density at each sampling date and time over which the grazing treatment was sustained. Infiltration rate other than declining with increasing stocking rate was found to be most strongly correlated (r= 0.72) to the amount of standing crop. A comparison of bare ground plots in all treatments showed that infiltration rate was least on bare ground plots in the HD treatment. This indicated that when the confounding effects of vegetation cover and standing crop have been removed, the intensity of trampling is still important in determining the site's hydrologic condition. Soil loss increased with increasing stocking density, however by the last sampling date loss in the MD and HD did not differ significantly ($p<0.05$). Soil loss in HD increased by four times to 1115 kg/Ha and which was about double that lost in the LD treatment. Bulk density, 0-5cm depth, on all sampling dates after the start grazing treatments increased with increasing stocking density. The bulk densities of MD and HD treatments were significantly higher ($p<0.5$) than those of CL and LD treatments. Bulk density ranged from 1.09 gm/cm^3 to 1.26 gm/cm^3 for the CL and HD treatments respectively. Increased bulk density is a reflection of increased soil compaction as result of greater livestock trampling.

In the treatments MD and HD, Chloris roxburghiana and Digitaria macroblephera the two most abundant perennial grasses, did not flower. This disruption in their phenology could be attributed to early defoliation stress which caused retardation of maturity. Once grazed to 2cm stubble height perennial grasses tended to be uprooted. Uprooting of perennial grass tufts coupled with failure to seed could cause changes in relative abundance of grasses in subsequent seasons. This in the long term will lead to denuded and eroded rangeland. Other forbs such as Cassia mimosidea failed to establish in the HD plots yet they were abundant in CL, this look have implications on the future botanical composition.

Herbage standing crop declined with increasing stocking rate, with extremes of 4.2 tons/Ha and 0.4 tons/Ha for the CL and HD treatments respectively. Litter accumulation in the plots increased initially as result of trampling, but the amount generated declined due to declined standing crop and termite consumption.

It can be concluded from this study that the effects of high stocking densities on the range from were, increased land bareness, reduced infiltration rates, increased soil loss, and increased soil compaction. Also it was found that the HD treatment maximized output per hectare in the short term but had the most adverse effects on infiltration rate, soil loss, and vegetation cover. The low stocking density on the other hand, gave the highest output per animal and had the least negative effects on the plots hydrologic condition and vegetation cover. The linear relationship of stocking density to output per head developed in this study could vary from year to year due climatic and other environmental variations. Further studies are necessary to develop long-term relationships.

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Appendix A. Heifer weights on various weighing dates.

Tag No.	Number of days after start of experiment										
	Tr	Rp	0	14	22	29	40	50	63	82	112
1	LD	A	130	137	139	142	147	150	151	151	149
2	LD	A	173	175	178	181	186	190	192	192	191
3	MD	A	155	157	159	160	161	155	155	153	150
4	MD	A	152	154	159	160	162	164	163	164	163
5	MD	A	178	186	190	191	192	194	193	190	188
6	MD	A	185	190	193	192	195	196	195	194	192
7	HD	A	126	130	131	132	135	136	134	128	124
8	HD	A	185	189	190	186	185	183	178	174	170
9	HD	A	155	156	158	161	162	162	160	168	158
10	HD	A	181	183	186	187	187	186	182	178	175
11	HD	A	165	170	172	174	166	164	162	152	150
12	HD	A	145	149	158	159	158	157	154	150	145
13	HD	A	115	118	122	125	128	129	126	120	115
14	HD	A	155	159	160	158	155	155	150	145	139
15	LD	B	170	172	176	178	180	182	185	185	184
16	LD	B	186	190	193	195	197	200	203	202	197
17	MD	B	183	185	186	188	192	183	182	183	183
18	MD	B	171	175	178	181	181	182	181	181	176
19	MD	B	170	176	180	182	183	182	182	182	179
20	MD	B	153	155	157	159	162	165	166	165	162
21	HD	B	120	123	125	127	128	125	128	125	120
22	HD	B	125	128	130	130	132	129	128	124	120
23	HD	B	166	170	174	175	176	177	168	160	150
24	HD	B	173	174	175	176	177	176	176	171	165
25	HD	B	155	158	160	162	164	165	166	165	159
26	HD	B	175	176	178	177	179	175	182	177	173
27	HD	B	145	150	145	148	150	149	148	145	142
28	HD	B	140	143	146	148	153	154	156	151	144

Where Tag No.= Ear tag number Tr= Treatment Rp= Replicate

Appendix 8: Analysis of variance tables for herbage standing crop

Source of variation	DF	Mean Square	F Value
Stocking Density (S.D)	3	37899.63	27.9**
Date	4	13365.38	9.8**
S.D x Date	12	5843.82	4.3**
Residual	326	1357.97	
Corrected total	345		
Treatment comparisons			
Between dates within CL	4	2805.89	1.26ns
Between dates within LD	4	4014.44	2.23ns
Between dates within MD	4	11320.98	11.87**
Between dates within HD	4	12755.53	25.12**
Between S.Ds within Dec	3	125.24	0.09ns
Between S.Ds within Jan	3	1074.97	0.69ns
Between S.Ds within Feb	3	9388.87	5.76**
Between S.Ds within Mar	3	17678.78	11.28**
Between S.Ds within May	3	31740.95	39.94**

*(p<0.05) **(p<0.01) ns not significant

Dec = December Jan = January Feb = February
Mar = March

Appendix C: Analysis of variance table for infiltration rate after 30 minutes of simulated rainfall

Source variation	DF	Mean Square	F Value
Stocking Density (S.D)	3	26.658	7.19**
Date	2	52.105	14.06**
S.D x Date	6	4.687	1.26ns
Residual	108	3.68	
Corrected total	119		
Treatment comparisons			
Between dates within CL	2	0.7301	0.23ns
Between dates within LD	2	16.934	4.21ns
Between dates within MD	2	15.696	3.59**
Between dates within HD	2	32.807	9.96**
Between S.Ds within Dec	3	0.4821	0.1ns
Between S.Ds within Mar	3	15.3273	3.16*
Between S.Ds within May	3	20.066	11.66**

*(p<0.05) **(p<0.01) ns not significant

Dec = December Mar = March

Appendix D. Analysis of variance table for sediment production.

Source variation	DF	Mean Square	F Value
Stocking Density (S.D)	3	1398751.57	10.03**
Date	2	1571290.79	11.26**
S.D x Date	6	366171.17	2.26ns
Residual	107	139497.83	
Corrected total	118		
Treatment comparisons			
Between dates within CL	2	26532.57	1.13ns
Between dates within LD	2	57581.34	0.34ns
Between dates within MD	2	345932.43	4.59**
Between dates within HD	2	1848973.3	9.14**
Between S.Ds within Dec	3	65610.23	0.41ns
Between S.Ds within Mar	3	2855750.05	2.95*
Between S.Ds within May	3	1806638.5	10.94**

*(p<0.05) **(p<0.01) ns not significant

Dec = December Mar = March

Appendix E. Analysis of variance table for soil bulk density.

Source variation	DF	Mean Square	F Value
Stocking Density (S.D)	3	0.1603	8.98**
Date	2	0.3411	19.11**
S.D x Date	6	0.03781	2.12ns
Residual	155	0.0178	
Corrected total	166		
Treatment comparisons			
Between dates within CL	2	0.0047	0.25ns
Between dates within LD	2	0.0526	1.96ns
Between dates within MD	2	0.2612	19.64**
Between dates within HD	2	0.1360	11.4**
Between S.Ds within Dec	3	0.0265	1.29ns
Between S.Ds within Mar	3	0.0682	9.26**
Between S.Ds within May	3	0.1435	6.27**

*(p<0.05) **(p<0.01) ns not significant

Dec = December Mar = March

Appendix F: Analysis of variance table for litter accumulation

Source variation	DF	Mean Square	F Value
Stocking Density (S.D)	3	1023.8	11**
Date	2	1192.36	12.8**
S.D x Date	6	189.9	2.0ns
Residual	107	93	
Corrected total	118		
Treatment comparisons			
Between dates within CL	2	44.5	0.63ns
Between dates within LD	2	154.21	1.96ns
Between dates within MD	2	254.04	3.77**
Between dates within HD	2	1309.35	10.6**
Between S.Ds within Dec	3	2.08	0.04ns
Between S.Ds within Mar	3	912.07	5.48**
Between S.Ds within May	3	452.41	7.99**

*(p<0.05) **(p<0.01) ns not significant

Dec = December Mar = March