ASPECTS OF CLIMATE, HERBAGE GROWTH AND ANIMAL PRODUCTION IN A SEMI-ARID AREA OF KENYA

BY

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DECLARATION

I declare that this thesis, entitled "Aspects of climate, herbage growth and animal production in a semi-arid area of Kenya" has not been submitted for a degree in any other University.

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25th March 1985

This thesis has been submitted for examination with my approval as University supervisor.

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SUMMARY

The results obtained from two major field experiments conducted on a natural rangeland sward in a semi-arid area of Kenya are presented and discussed in relation to other relevant work.

In the cutting trial 15 different combinations of cutting height and frequency were used to examine the effects of defoliation on the productivity and persistence of the natural sward. Over 10 growing seasons even the most severe of the treatments, in which the sward was cut every three weeks at 5cm height did not appear to cause irreversible decline in sward vigour in the absence of the grazing animal.

Highest overall herbage yields were obtained with the relatively severe defoliation treatment of six-weekly cutting at 5cm height. A multiple regression model relating the herbage production to rainfall in the present, previous and penultimate three-week periods before cutting accounted for 62% of the variation in yield. No advantage was found in using estimates of actual evapotranspiration rather than rainfall in the regression. The role of such a model in the prediction of long term forage productivity and potential animal performance is also discussed.

The grazing trial examined the performance of groups of beef steers under set stocking at two, three, four and five hectares per animal, over an eight year period. Performance per animal was relatively unaffected by stocking rate, with an overall growth rate of about 350g live-weight gain per day over the whole study period. Growth rate at any one time was found to be directly relatable to sward condition, which in itself was related to climatic season.
Evidence is presented that the crossbred animals used were very selective in their grazing, especially in the dry season, so that provided adequate forage was available within which selection could be effective, reduction in grazing intensity did not lead to improvement in diet intake quality or quantity.

The difficulties of estimation of diet quality and intake levels are discussed in relation to the present and other relevant studies, particularly with reference to the use of internal markers for estimation of diet digestibility.

The role of mathematical models in the examination of the climate/vegetation/animal complex is discussed and some of the problems associated with their use are examined.

Suggestions are made for areas of work considered to be priorities for future attention to assist in improving the management and animal productivity of the semi-arid areas. Attention is given to the need for research information to support the change in land use in such areas from low population-density nomadism to a sedentarised production system, which is required to support a higher level of human population.

CHAPTER I

INTRODUCTION

1.1. Climatic Background.

Only 15% of the land area of Kenya can be considered as well-watered (Table 1 and Fig. 1.1.), receiving more than 750mm rainfall in at least four years out of five (Griffiths, 1962).

For the remainder of the country the variability of rainfall, not only in seasonal or in annual total, but also in distribution, has mitigated against crop production, so that livestock husbandry has become the main land use. These drier zones are here classified as very arid (receiving less than 250mm rainfall four years in five), arid (receiving between 250 and 500mm rainfall four years in five), or semi-arid (receiving between 500 and 750 rainfall four years in five). These zones correspond very closely to the ecological zones VI, V and IV as described by Pratt et al, (1966). The present work was conducted in the semi-arid region, ecological zone IV.

1.2. Pre-colonial Pastoralism.

In common with many similar areas in other parts of Africa, in the drier zones of Kenya a system of nomadic pastoralism has developed as a strategy to provide security of human food supply (FAO, 1960;

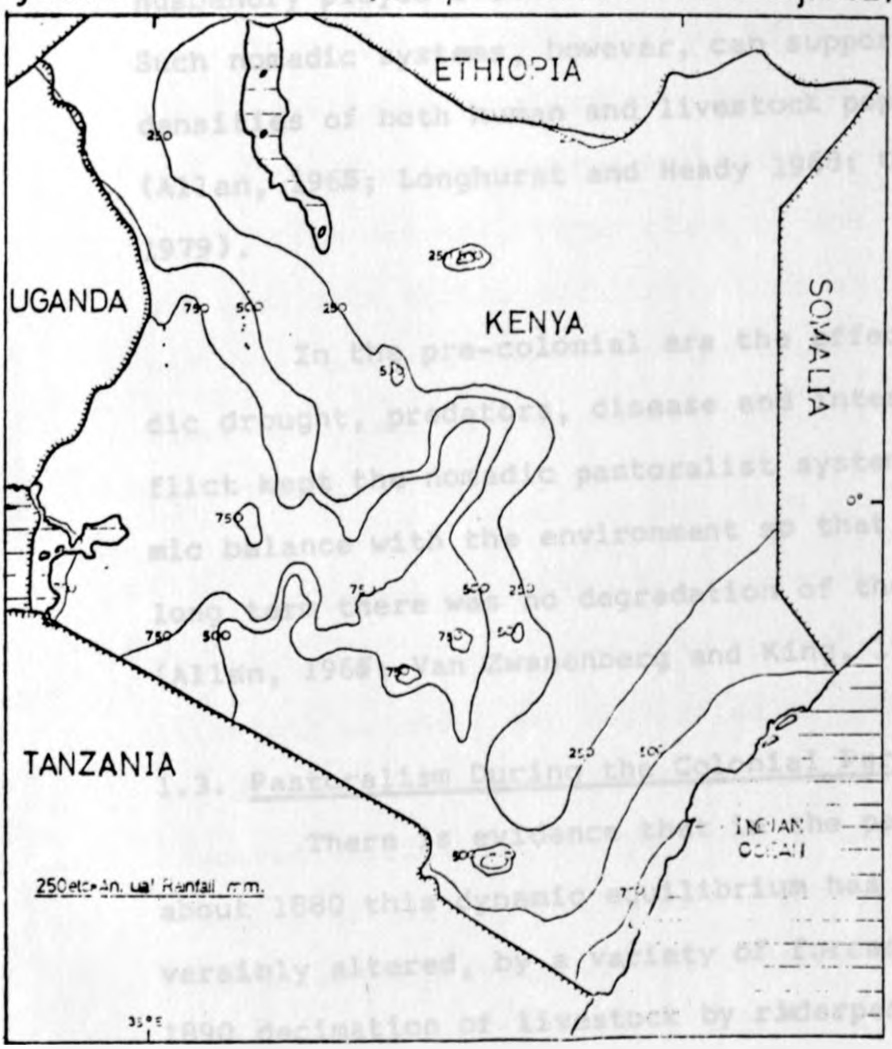
Table 1.1.

Percentage of Land Area of Kenya Receiving Selected Amounts of Annual Rainfall in Four Years out of Five.

Annual Rainfall mm	% of Area
Less than 500	72
500 - 750	13
750 - 1250	12
More than 1250	3

Fig.1.1. Rainfall Probability in Kenya

Annual Rainfall likely to be exceeded in four years out of five (adapted from Griffiths,1962)



Henning, 1960; Allan, 1965). The movement of family and livestock in response to changes in the local availability of grazing, water and minerals together with the occurrence of disease reduced the effects of the vagaries of the weather. The nomadic pastoralism became formalised by the development of quite complex socio-economic systems in which livestock and their husbandry played a central role (Campbell, 1979). Such nomadic systems, however, can support only low densities of both human and livestock populations (Allan, 1965; Longhurst and Heady 1968; Okoth-Ogendo, 1979).

In the pre-colonial era the effects of periodic drought, predators, disease and inter-tribal conflict kept the nomadic pastoralist system in a dynamic balance with the environment so that over the long term there was no degradation of the ecosystem (Allan, 1965; Van Zwanenberg and King, 1975).

1.3. Pastoralism During the Colonial Period.

There is evidence that in the period since about 1880 this dynamic equilibrium has been irreversibly altered, by a variety of forces. Around 1890 decimation of livestock by rinderpest and human population by cholera and smallpox reduced the ability of the nomads to resist the encroachment of cropproducing tribes into the semi-arid areas (Harlow, Chilver and Smith, 1965). Establishment of the British colonial administration immediately thereafter curtailed the expected reversal of this encroachment which would otherwise have occurred as the pastoralists regained their vigour (Low, 1965). Subsequent establishment, in the early years of the present century, of buffer zones of European settlement, particularly in Laikipia and Ukambani, where the settlers separated the pastoralists such as the Masai, from not only other clans of the same tribe, but also from agriculturalists, such as the Kikuyu and the Kamba, served to fix the boundaries of the areas available to the pastoralists (HuXley, 1935; Low, 1965).

Concern among the European settlers regarding the risks of disease spreading from the pastoralists livestock to their own cattle led to the establishment of a veterinary programme, which initially involved vaccination (Kenya, 1931). In spite of the droughts of 1929 and 1935 the reduction of losses to disease allowed stock numbers to rise rapidly so that by the end of the 1930's the authorities had become concerned with the apparent increase in overgrazing and soil erosion (Van Zwanenberg and King, 1975).

Compulsory purchase of cattle in the pastoral areas as part of war-time economic measures, together with a severe drought from 1943 to 1946 reduced stock numbers in the 1940's, particularly affecting the number of mature males (Kenya, 1944; Kenya, 1947; Meadows and White, 1979). However, the cultivation of crops in the pastoral areas had been increased during the war years and even though measures were introduced to control immigration of cultivators into the pastoral areas (Kenya, 1947) the loss of grazing area became more permanent as intermarriage reduced the effectiveness of influx control (Kenya, 1946).

Further inroads into the pastoral areas were also made by the reservation of certain areas for wildlife conservation as a result of the National Parks Ordinance of 1945. Such reserves were set up without full consideration of the role of these areas for dry season grazing use within the pastoral system. On occasions the pastoralists were, however, allowed to enter the gazetted park areas during droughts to reduce stock losses. This occurred for example in Tsavo in 1949 and in Amboseli up to 1977.

The low stock numbers in the pastoral areas at the end of the war could have provided a starting point for official attempts to encourage reduction of over-grazing in subsequent years, and the promotion of "improved" management methods, but it appears that this opportunity was not taken. Maintainance of very low prices to the producers by the Government purchasing bodies (The Meat Marketing Board, Kenya Meat Commission and the African Livestock Marketing Organisation) discouraged sellers even in drought years such as 1953 (Campbell, 1979). Closure of markets during the period of the Emergency between 1952 and 1959 further reduced the possibility of encouraging the retention of lower stock levels.

There is evidence, however, that where the necessary marketing facilities were available the grazing management and control of stock numbers recommended could be successfully implemented. Such a situation occurred at the Il Kissongo scheme near Loitokitok, where stock could be sold for highly attractive prices in Tanzania (Kenya, 1954).

1.4. <u>Land Registration</u>.

During the 1950's the lack of sale opportunities, generally favourable weather conditions, veterinary compaigns and control of influx of crop-producers all combined to allow stock numbers to rise rapidly. In Kajiado District, for example, the total cattle population rose from about 360,000 in 1948 to about 630,000 in 1960, the highest level this century (Meadows and White, 1979). Such stock numbers produced heavy grazing pressure. The drought of 1960-61 and the floods and armyworm plague of 1961-62 caused a catastrophic reduction of the stock numbers, as well as severe erosion of the denuded range areas. In Kajiado District the cattle population fell to about 208,000 by the end of 1962 (Meadows and White, 1979). The massive stock losses speeded up implementation of some of the recommendations in the survey of the situation in the range areas that had been carried out by Heady (1960). A new policy was initiated based on land adjudication and registration in the hope that the provision of land title would encourage development of a system of sustained output on a settled rather than on a nomadic basis. The land title would provide a source of collateral for financing of development infrastructure (Campbell, 1979).

1.5. <u>Group Ranches</u>:

Initial adjudications and registrations were made on the basis of individual claims, but by 1964 it became clear that pastoral areas could not easily be divided into individual holdings, and that in any case individual ownership could lead to the undesirable involvement of land speculators (Kenya, 1961;

McGillivray, 1967). The problem of allocations of individual grazing rights on particular blocks of land was approached by the development of the concept of a registration of ownership by a group rather than by an individual (Hedlund, 1971; Pratt and Gwynne, 1977). It was intended that this would provide a policy for land use on a holding by consensus of the group and in addition control influx and influence of immigrants from other areas. Land adjudication and registration has been a slow process due to the complexities of the past tribal land use, but it has been completed in Kajiado District and is nearing completion in Narok District.

Increased output on the Group Ranch or indeed on any other settled system may be generated by various factors of which the following are the most important:-

1. The land title may be used as collateral for the provision on the holding of development facilities such as water, tick control units and improved stock, which can raise livestock performance.

2. Settlement facilitates the provision of central services such as health, education,

communications, marketing and commerce. General living standards can be raised and the absolute dependance on livestock for food reduced, so that changes in animal husbandry may be made which release more animals for sale.

3. The settlement of the members of the Group Ranch within an area with which they are familiar allows for use of their accumulated knowledge of the area's environment and ensures continuity of social cohesion.

The performance of the Group Ranches has been well documented (Hedlund, 1971; Davis, 1971; Halderman 1972; Von Kaufmann, 1976; Helland, 1978; White and Meadows, 1981). There is a general consensus that the original objectives of the Group Ranch programme have only partially been fulfilled (Campbell, 1979).

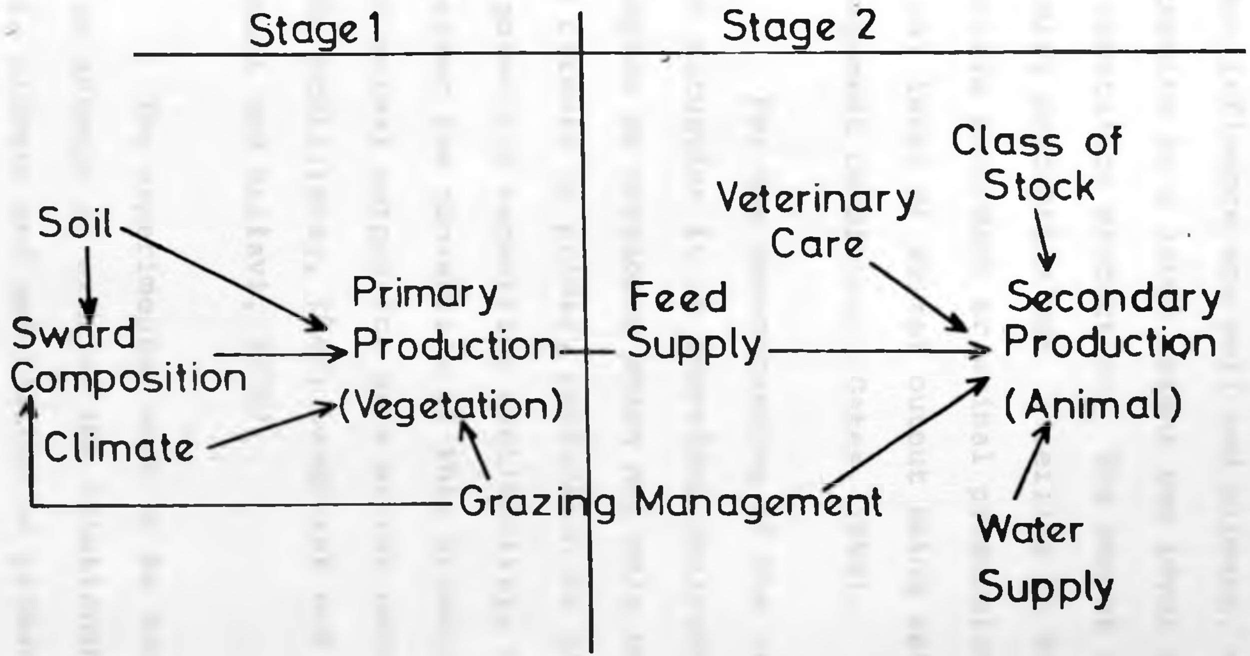
Some of the problems which have been encountered are amenable to solutions which can be provided by the development agencies. Provision of the important sectors of the physical infrastructure such as market and trading centres, water points, roads and veterinary services may be effectively promoted by either central government or the local administration. Experience in Kajiado District suggests that provision of this basic infrastructure can be associated with rapid modification of land use and animal husbandry practices (White and Meadows, 1981).

1.6. <u>Research Information Requirements</u>.

Efficient operations by the settled pastoralist depend not only on the "hardware" provision mentioned above but also on the availability of the appropriate "software" or operating system information. The past strategy of maintaining maximum stock numbers, especially of lactating cows, as an insurance against the effects of drought and disease on food supply together with the use of movement to avoid difficult environmental circumstances may be either irrelevant or effectively circumscribed in a settled situation. The effects of local drought, disease outbreak and water supply depletion are much more serious in a settled rather than a nomadic pastoral situation. Ecological knowledge accumulated by the pastoralists in their nomadic past may not be directly applicable to the new settled system.

To the pastoralist, whether nomadic or settled, subsistence or commercial, it is the animal output which is of value to the producer. This output is a consequence of the interaction of a whole series of factors, which can be represented as in Fig. 1.2.

Fig 1.2. Climate/Vegetation/Animal Interactions



(Potter, 1980). This diagram indicates that most factors may be under direct human control. The most important parameters not directly controllable by human influence are soil and climate, which together determine to a large extent the level of the primary or vegetation production. The amount and quality of primary production set a ceiling to the level of possible secondary or animal production, with the actual level of animal output being set by local management conditions (Gates, 1968).

For the understanding of the settled pastoralist situation it is therefore desirable that methodologies be developed which not only relate the soil and climate to primary production to give an estimate of potential vegetation availability, but also consider the conversion of this primary production into animal output for sale or for consumption (Heady, 1960; McGillivray, 1967; Longhurst and Heady, 1968; Gichohi and Kallavi, 1979).

The experimental work to be described below is an attempt to examine the relationship between soil, climate and defoliation on primary production and to examine the conversion of the primary production into animal output on a single rangeland site in Kenya. The results of these studies will be related to those of other relevant work and to the development of extension advice appropriate to the settled pastoralists in semi-arid areas.

CHAPTER 2

LITERATURE REVIEW

2.1. Assessment of Climatic Variability:

In the semi-arid regions (Ecozone IV) of Kenya the equatorial latitude results in warm, sunny conditions with little temperature variation through the year (Pratt and Gwynne, 1977). The reduction in temperature due to altitude is small as the maximum altitude is little over 1500m. The mean annual temperature lies between 22°C and 25°C (Griffiths, 1962). The solar radiation, temperature and wind conditions are suitable for plant growth, provided that water is available. Rainfall is therefore the major climatic factor affecting rangeland productivity (Woodhead, 1970; Pratt and Gwynne, 1977). Examination of the patterns of rainfall in the semi-arid region would therefore be useful for providing a basis for consideration of likely variation in rangeland productivity, whether primary (vegetation) or secondary (animal).

Compilations of available long-term records of rainfall within East Africa have been made since the 1950's (Sanson, 1954; Griffiths, 1962; Tomsett, 1975). By 1970 data for Kenya were available from more than 700 sites with over 10 years of records

(Woodhead, 1970). These data have been used for the construction of maps of rainfall or water balances at the scale of 1:3,000,000 (Atlas of Kenya, 1970). Examination of the geographical distribution of the recording sites by the present author indicated that the distribution in the semi-arid areas may not be fully representative of the region (cf. Norton-Griffiths, 1977). Recording sites were generally set up and well-maintained only near to sites of permanent settlement. These settlements may have been located because of specially favourable conditions, for example permanent water supply, availability of fuel wood, etcetera, some of which conditions may result from local climatic peculiarities. The rainfall data available have been subjected to analysis but the subsequent use of the results of the analysis has not usually taken into account the limitations of extrapolation from specific, possibly atypical sites to extensive areas of open rangeland (Woodhead, 1970; Clarke, 1973; Norton-Griffiths,1977).

Within the semi-arid areas of Kenya, only in Kajiado District has there been a detailed study of the rainfall patterns (Norton-Griffiths, 1977). Kajiado District is adjacent to the Machakos District in which the study area is situated and the field site is only 15km from the boundary between the two districts. The general climatic pattern and the topography of the rangeland in the two districts appear to be similar so that the conclusions from the Kajiado study may be applied to the study site. The frequency distribution of values for annual rainfall on any particular site indicate a skewed rather than a normal distribution, while mean annual value gives no indication of the variation around the mean. Probabilities of particular rainfall levels which have been based on the assumption of a normal type of distribution are not valid in the skewed distribution situation, or if there is any cyclical pattern to the rainfall (Brooks and Carruthers,1953). If there are "runs" of dry and wet years rather than simple cycles as indicated by the Kajiado district data (Norton-Griffiths, 1977) and by the data from the Serengeti ecosystem in a broadly similar area in Tanzania (Pennycuick and Norton-Griffiths, 1976) the normal distribution may again be inappropriate as a basis for probability analysis. Use of the Fourier-type spectral analysis, polynomial regression analysis (Pennycuick and Norton-Griffiths, 1976) and of recurrence interval analysis (Dury, 1964) have also proved to be inappropriate in the Kajiado data set due to the auto-correlation of consecutive year totals (Norton-Griffiths, 1977).

When seasonal or even shorter term periods of rainfall are considered the conventional use of standard deviation from the mean to generate the probability estimates may lead to meaningless negative values for rainfall as the lower confidence limit. For the development of a predictive model which has rainfall as the main climatic variable to generate an estimate of productivity it is necessary to have a probability function for rainfall, on either a seasonal or other time period basis (Clarke, 1973). Use of a cumulative probability curve may be more appropriate as a basis for the discussion of the frequency of the occurrence of a particular level of rainfall (TeChow, 1964).

2.2. Methodology of Forage Productivity Assessment:

As there is likely to be rather little use of hay and/or silage made from the natural vegetation in the area to which the present study relates, it would be desirable that the measurement of the productivity of the sward could be made using the grazing animal ('t Mannetje et al., 1976). Use of the animal ensures that factors such as dietary selection and the spoiling of herbage by excretion and/or trampling are taken into account. However, various practical limitations may prevent the exclusive use of grazing studies for sward evaluation, especially when a number of treatments are involved. As groups rather than a single animal are required to reduce the effects of inter-animal variation, the land, animal and other resources involved are not generally available. In addition it may not be possible to find an area for the study which has sufficient uniformity of soil, topography, vegetation or other characteristics to reduce non-treatment variation to acceptable levels (Grasslands Research Institute, 1961). Evaluation of herbage productivity therefore normally includes to a greater or lesser extent, non-grazing studies. These non-grazing studies may involve both non-destructive and/or destructive methodologies for assessment of sward yield or composition.

Non-destructive methodologies may be of considerable value for the determination of the seasonal variation in available standing forage under the prevailing cutting or grazing regime. Data collection does not normally have any effect on sward growth. Observation may be done very rapidly, over extensive areas, allowing for a very cost-effective accumulation of data ('t Mannetje et al., 1976). Instrumental techniques such as capacitance (Campbell et al., 1962), rising plate (Earle and McGowan,1979; Michell, 1982) and beta-ray absorption (Mitchell,1972) have been suggested to estimate yield. Such methods have limitations on accuracy or reproducibility when much of the herbage is dry as is the case for most of the year in the type of area under study (Shaw et al., 1976). Comparative spectral reflectance at two or more wavelengths has been widely used for estimation of standing forage at a reconaisance level (Duggin et al., 1975) from either aircraft or satellites. The method is, however, as with other non-destructive methods, subject to limitations of accuracy on small field plot scale, especially with a heterogeneous sward (Earle and McGowan, 1979) or with swards in which there is much dry material (McCloy, 1980). The use of an average of many observations to increase the accuracy of the estimate is precluded by the small size of the plot in field experiments.

Visual estimates have been proposed using trained observers to estimate standing forage quantity as this can allow for up to several hundred observations per day to be made per observer (Haydock and Shaw, 1975). Such methods have been based either on estimation followed by later calibration, for each of the observers, using cut quadrats (Morley et al., 1964) or by initial training involving a set of standard quadrats followed by field estimation (Haydock and Shaw, 1975).

All of the non-destructive methods which have been proposed require the use at some stage of harvested sample plots to establish calibration relationships so that instrument- or observer-based values can be converted into yield or, more correctly, available standing herbage figures. In general the herbage has been harvested by cutting at or very near to ground level to obtain an estimate of total above-ground biomass (Grassland Research Institute, 1961).

For long-term studies of the productivity of a particular sward in a semi-arid area practical difficulties will arise with non-destructive methods outlined above. Visual estimation requires continuity of the observer team, which may not be possible over some years. In addition the long term and seasonal changes in botanical composition of the sward and the seasonal variation in the proportions of dry and green material will make calibration very difficult. This will be particularly true if a number of different sward treatments are being examined simultaneously, whether observer- or instrument-derived methods are being used (Jensen at al., 1975).

Destructive or harvest methods of estimation of the standing herbage quantity involve the use of some cutting regime. The number and size of the sample areas required will depend on the heterogeneity of the sward, but the requirements can be readily determined with simple statistical methods involving uniformity trials (Grieg-Smith, 1964). Decisions as to the cutting technique to be employed are much more difficult to make and there is no general agreement (Milner and Hughes, 1968). Hand shears (Jones, 1973), powered sheep shears (Alder and Richards, 1962), motor scythes (Grassland Research Institute, 1961; Shaw et al., 1976) and flail harvesters (Allen et al., 1968) are among the cutting methods used.

Each of the above harvesting methods can be used to cut the sward at a range of heights above the ground. The height of cut used will greatly influence the quantity of the material harvested. This quantity will depend on the vertical distribution of plant material in the sward, itself a function of the species composition, time of year and the defoliation system (Alexander, Sullivan and McCloud, 1962; Voorthuizen, 1972; Humphreys, 1981). Unless the sward is cut at ground level some plant material will remain after harvest and this may introduce bias where the sward contains both prostrate and erect plants (Shaw et al., 1976).

This last point becomes of particular importance when attempts are made to relate the results of cutting studies to the grazing situation where dietary selection occurs ('t Mannetje, 1974). An additional complication arises in studies such as that to be described below, where height and frequency of cutting are used to crudely simulate the defoliation effects of various grazing systems ('t Mannetje et al. 1976). The predetermined heights of cutting treatments prevent the cutting of the sward for the different treatments at a common height. Repeated defoliation to a particular height may be expected to influence sward growth and composition. This effect has been noted for many years (Biswell and Weaver, 1933; Leukel et al., 1934; Lush, 1935). Any changes in the sward occurring below the predetermined cutting height cannot readily be assessed.

With regard to the frequency of cutting, in early work a single harvest at the end of the growing season was used (Wiegert and Evans, 1964). This system does not measure the losses during the growing season nor does it take account of differences in maturing rate of different species within the sward (Woodwell and Whittaker, 1968). Systematic harvesting followed by a summative analysis therefore has been suggested as a more useful technique for assessing seasonal productivity and for assesing available standing forage (Singh and Yadava, 1974).

The influence of harvesting methodology on "yield" recorded is therefore considerable. The comparison of results from different herbage production studies without consideration of the methodology of harvesting may therefore lead to invalid conclusions (Jones et al., 1982). Attempts to combine regional (Le Houerou and Hoste, 1977) or even world-wide (Rosenzweig, 1968) data into production models may therefore be of dubious value, where no common method of harvests of the herbage has been established. This point is discussed further below (Section 5.1.).

2.3. Relationships between Climate & Forage Production.

2.3.1. Background:

The review by Blackmann (1961) of early work on the effect of environment on plant growth indicated the complexity of the interactions between the various parameters. The work reported was mainly concerned with growth studies under controlled conditions and therefore in a somewhat artificial situation as in the field the environmental factors are generally not controllable, but must be accepted as found and measured. Compilation and analysis of large quantities of instrumental data on the environmental characteristics of an area for which yield data was also available became possible in the 1950's with the development of high-speed computing equipment. This led to two main areas of agroclimatological study.

2.3.2. Climatological Classification.

Classification of areas for production potential on the basis of climatic characteristics was carried out from local (for example in Taita district of Kenya by FAO, 1970) to regional (for example East Africa by Pratt et al., 1966) to global scales (for example by Papadakis, 1961). Such classifications have been found useful for various purposes. A typical example is that of examination of geographically separate areas for similar climate types ("homoclimes") and therefore similar growing conditions to assist in the search for possibly transferable plant introductions (Russell and Moore, 1970).

The earliest published review of East African climatic classification appears to be that of Moreau (1938), but this was a largely theoretical excercise as the climatic data available at that time were rather limited. The next major review was that of Edwards (1956). The formation of the East African Rangeland Committee in 1964 acted as a major stimulus towards the rationalisation of agro-climatological classification in East Africa. An important contribution derived from the work of this committee was the production of the now classic paper in which the major ecozones for the region were described and defined (Pratt et al., 1966). Table 2.1. outlines their classification. The original classification has been used with only minor amendments (Woodhead, 1970) up to the present time in Kenya, Uganda and Northern Tanzania. The climatic patterns in Southern Tanzania are more closely allied to those prevailing in Central and Southern Africa but attempts were later made to incorporate the area in the overall East African classification system (Pratt and Gwynne, 1977). The classification has been considered very useful in the drawing up of development stategies on an ecozonal basis (Pratt, 1968; Pratt and Gwynne, 1977; Gichohi and Kallavi, 1979.

2.3.3. Herbage Production Models.

The broad ecozonal classifications discussed above are of potential value for regional or national planning but their scale of detail may

Table 2.1. Agroecological Zone in East Africa

Zone[1] No.	Name of Zone	Cropping Potential	Hectare/[2] Livestock Unit	Climate Type
I	Afro-Alpine	(Forest)	-	Wet
II	Forest	High	0.8	Humid
III	Moist Woodland	Medium	1.6	Sub-humid
IV	Dry Woodland	Marginal	4.0	Semi-arid
V	Dry Thorn Bushland	Slight	12.0	Arid
VI	Semi-desert	Nil	42.0	Very arid
VII	Desert	Nil	?	Dry

Notes:- 1. Classification based on Pratt et al., (1966) as modified by Woodhead(1970).

2. Stocking rates based on Pratt (1968).

limit their usefulness at the level of the individual holding. A knowledge of potential herbage availability has been recognised as a very useful factor in assisting the settlement of previously nomadic pastoralists in Kenya (FAO, 1968; Potter, 1981).

Many attempts have been made to examine the relationships between climate, particularly rainfall, and herbage productivity in order to develop useful predictive models. Examples include, Trumble and Cornish (1934) in South Australia; Rogler and Haas (1947) in North Dakota U.S.A.; Walter (1954) in South Africa; Smoliak (1956) in Alberta, Canada; Stewart (1960) in Libya; Dahl (1963) in Colorado, U.S.A.; Le Houerou (1964) in North Africa; Rosenzweig (1968) in various countries of the world; Murphy (1970) in California, Khan (1971) in Pakistan; Breman (1973) in Mali; Cline and Rickard (1973) in Washington, U.S.A.; McCown et al.,(1974) in Queensland, Australia; Duncan and Woodmansee (1975) in California U.S.A.; Le Houerou and Hoste (1977) in the Mediterranean Basin and the Sudano-Sudano-Sahelian zones and Britten et al., (1978) in Texas, U.S.A. For the East African region the number of studies appears very limited (Braun,1973; Clarke, 1973; Cassaday, 1973; Lamprey, 1975). This reflects mainly the lack of production data as the climatic database, as already indicated, is relatively good for a developing region.

In all of the above and similar studies the available production data have been combined with the historical climatic information available in some form of correlation analysis. The usefulness of the analyses can be roughly judged by the overall coefficient of determination (R^2), rather than the statistical significance of the regression equation at any chosen probability level, for example P=0.05. For the studies examined by the present author the value of R^2 ranged from 0.2 (Khan, 1971) to 0.74 (Smoliak, 1956). In the former case little value can be placed upon the model as 80% of the variation in yield is not explained. The present author suggests that any model with an R^2 value of less than 0.5 has little practical value.

Most of the work discussed above was concerned with the relationship between rainfall and forage growth. Rainfall has been attractive as an independent variable in the regression models due to the relative ease with which values can be obtained directly from the instrumental records. However, it has been suggested that there may be other measures that can be more appropriate indicators of the availability of water for plant use. The simple rainfall values take no account of the drainage, run-off or evaporation from the uncovered areas of the soil. Soil moisture (Dahl,1963; Baier and Robertson, 1968; Britton et al., 1978) or estimated actual evapotranspiration (AE) derived from soil water balance models (Rosenzweig, 1968; McCown et al., 1974) have been suggested as more appropriate than rainfall as indicators for availability of water. In general terms the use of AE depends on the premise that gaseous exchange for photosynthesis is directly related to the transpiration of water through the effects of stomatal opening. A measurement of the conditions affecting transpiration may therefore be directly relatable to the rate of photosynthesis and hence plant growth (Major, 1963).

It is tacitly assumed in all the models so far examined that firstly, the mathematical relationships derived from the historical data will hold true in the future and secondly, that the climatic patterns of the future will be the same as in the past. With these assumptions various attempts have been made to generate probabilities of levels of production which could be of potential value for future management planning (Rosenzweig, 1968; Knops, 1971; Clarke, 1973; McCown et al., 1974; Le Houerou and Hoste, 1977).

Users of the models generated by the regressions analysis must be aware of their limitations. In the first case the assumptions mentioned in the previous paragraph may not be valid as there is at present no certain way of forecasting climatic trends. Secondly the difficulties associated with the methodology of yield or standing forage estimation mentioned above (Section 2.2.) may cast doubts as to the vegetational basis for the model. Thirdly, and perhaps most importantly of all, the models only normally consider the vegetation productivity, whereas for the producer on the land involved it is the animal output that will yield a living. The importance of the first two points will be discussed further in the light of the results from the present study in Chapter 5 and the third point in the next section (2.4.).

2.4. Factors affecting animal productivity on Rangeland

2.4.1. Primary versus Secondary Production

The models discussed in the previous section have all been concerned with the relationships between climate and vegetation, that is primary productivity. For the producer, however, it is the animal or secondary productivity that is of greatest importance (Pratt and Gwynne, 1977). The productivity of the animal will depend on, firstly, the composition and quantity of feed consumed and secondly, the conversion of the feed into animal tissue.

2.4.2. Vegetation factors affecting diet quality and quantity

A recent review (Hodgson, 1982) indicates the complexity of the interactions between the factors which affect the diet selected and quantity consumed by the grazing animal, so that the interactions indicated in Fig. 1.2. may represent a great oversimplification of the real situation. Vegetation factors which have been related to the quality and to the quantity of intake include leaf/stem ratio (Van Dyne , 1970; Poppi et al., 1981); green/dry matter ratio (Chacon and Stobbs, 1976; Low et al., 1981); herbage digestibility (Heaney et al., 1963); bulk density of herbage in the sward (Hodgson,1977); water content of the herbage (Davies, 1962; Yoelao et al., 1970); fibre content (Donefer et al., 1963); the presence of toxins (Underwood, 1966; Hegarty, 1982); spoilage by dung or urine (Marsh and Campling, 1970; Keogh, 1973) and sward botanical composition (Hunter, 1962). The climate/herbage productivity models discussed above are confined almost exclusively to consideration of total herbage dry matter, which is relatable to intake only through the bulk density function (Hodgson, 1977).

2.4.3. Animal factors affecting the feed conversion process

Whereas rainfall may be the major climatic factor directly influencing plant growth in rangelands, as indicated in Section 2.3., it is ambient temperature which most directly affects the animal (Findlay and Beakley, 1954). Control of body temperature under high ambient temperatures is effected by increased evaporative water loss through panting and sweating or by lowering of basal metabolic rate (Ragsdale et al., 1951; Brown and Hutchinson, 1973; Robertshaw and Finch, 1976). High ambient temperatures may therefore directly affect forage intake levels (Frisch and Vercoe, 1977).

The interactions between feed intake and the supply and intake of water are rather complex. Not only is water required for its role in the evaporative cooling process but also the ratio of water to solids in the total feed supply and hence stomach content is important for its effects on the efficiency of the digestive process (Payne, 1963; Van Soest, 1982). There is also very good evidence that the breed, age, sex and body condition of the animal can greatly influence not only the ability of the animal to deal with the effects of heat stress but also the levels of feed intake in a particular environment (Johnson et al., 1958; Langlands and Hamilton, 1969; Frisch and Vercoe, 1977; Frisch and Vercoe, 1978; Allden, 1979; Egan and Doyle, 1980; Forbes, 1970). Actual levels of intake in any particular situation are therefore very difficult to predict with any great precision.

2.4.4. Prediction of animal performance under rangeland conditions.

Sections 2.4.2. and 2.4.3. clearly indicate the problems associated with prediction of animal performance in rangeland. The considerable uncertainty regarding the relationship between the environment and the productivity of the vegetation are confounded with the interactions between the vegetation and the animal factors, which will affect intake and conversion efficiency in any situation. To overcome, or possibly to avoid, the complexities of the system attempts have been made to derive direct relationships between the animal and the environment. In such models the environment to vegetation and the vegetation to animal linkages may be considered as a "black box" (Buechner and Golley, 1967; Morley, 1972). The application of this approach to the present study area is discussed for a beef steer production system in Section 5.4.

CHAPTER 3

MATERIALS AND METHODS

3.1. Experimental Site Details

3.1.1. Location:

The field experiments were carried out at the Rohet Ranch Field Sub-station situated 15km. from Athi River Township, Machakos District. (Lat. $1^{o}20'$S Long. $37^{o}05$E). The site is at an altitude of 1500m (± 50m) above sea level.

3.1.2. Climate:

Table 3.1. indicates some of the major climatic parameters recorded by the meteorological station situated 100m from the site of the cutting trials and 1-2000m from the grazing paddocks. The site lies in the bimodal rainfall zone with rainfall Nov./Dec. and Mar./Apr./May, (Griffiths, 1962). Rainfall is highly variable both annually and seasonally, and its distribution is the major factor controlling plant growth. Evaporation potential is high, with less than one month in 20 in which rainfall exceeds potential evaporation. Where water is available the temperatures are always adequate to support plant growth.

The existing standard classification of East African Rangelands (Pratt et al.,1966) is based mainly on a climatic assessment. Under this classification

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Table 3.1.

MAJOR CLIMATIC PARAMETERS 1971 - 1981 ROHET RANCH ATHI RIVER

Month	Rainfall mm			Max. Temp. °C			Min. Temp. °C			Evaporation * mm	
	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Penman	Class A Pan
January	37.7	104.4	2.2	26.9	28.5	25.5	12.6	14.0	11.8	202	177
February	38.8	138.7	3.0	28.3	29.5	26.5	13.1	14.6	11.5	195	186
March	63.5	176.1	1.5	28.5	30.5	26.2	13.6	15.4	12.0	214	204
April	120.1	253.0	1.2	27.0	29.1	25.4	14.7	15.9	13.4	173	148
May	76.1	182.2	8.5	25.5	26.6	24.3	13.4	14.7	11.5	151	116
June	22.9	75.5	0.4	24.2	25.8	22.5	11.7	13.0	8.5	135	105
July	10.9	34.5	0.8	23.5	24.6	22.1	11.3	12.2	10.0	130	98
August	7.4	28.3	0.0	24.3	25.2	23.0	11.1	11.5	10.8	140	119
September	21.4	86.5	0.0	26.8	27.7	25.8	11.5	12.2	1.9	170	155
October	23.6	109.9	0.7	28.0	29.1	26.3	12.8	14.0	11.7	198	203
November	105.9	227.9	39.0	26.1	27.7	24.6	13.9	15.1	12.9	177	154
December	48.5	105.9	2.8	25.7	27.4	24.3	13.3	14.6	11.2	185	149
Annual Total	576.9	852.1	261.3	-	-	-	-	-	-	2070	1804
Years used	11	11	11	9	9	9	9	9	9	7	4

* Evaporation Measures - Penman Po. Calculated according to Penman (1948)

- Class A Pan. Observed evaporation from U.S. Weather Bureau Class A Land Plan.

the experimental site lies in Ecozone IV (Semi-arid).

3.1.3. Soils and Topography:

The soils at the experimental site are generally shallow (less than 100cm) grey-brown sandy clay loams. They are typical of the ridge-tops of the Athi-Kaputei plains of the region, and are probably derived from transported material (Scott, 1962).

Table 3.2. indicates some of the major soil analytical characteristics, as determined by the Soil Chemistry and Soil Physics Laboratories of the Kenya Agricultural Research Institute (KARI) at Muguga. Water contents were determined using a vacuum pump for $\frac{1}{3}$ atmosphere and a pressure plate for 15 atmosphere pressure levels. Nitrogen was determined according to the method of Bremner and Keeney (1965). The Ammonium lactate method described by Egner and Domingo (1960) was used for the determination of Phosphorus, Potassium, Calcium and Magnesium. P^H was measured using 1 Volume of soil in 2.5. volume of 0.01 Molar Calcium chloride solution. The Chromic oxide method of Walkley and Black (1934) was used for estimation of organic carbon.

The topography of the area is generally of a gently undulating mosaic of ridges and shallow valleys which indicate seasonal watercourses draining into

Table 3.2.

MAJOR SOIL PARAMETERS ROMET RANCH ATHI RIVER

Depth cm	Bulk Density	Water Content mm.			N	P	K	Ca	Mg	pH	Organic Carbon %
		¼ Bar	15 Bar	Avail.	%	ma %	mg %	mg %	mg %		
0.15	1.44	43.6	21.5	22.1	0.35	0.9	75	139	190	5.4	6.8
15-30	1.32	57.9	25.2	32.7	0.23	0.8	42	105	290	5.2	4.1
30-45	1.20	79.2	51.1	28.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
45-75	1.14	163.2	100.4	62.8	0.14	0.7	20	110	270	5.4	2.4
75-105	1.00	126	83.6	43.3	0.10	0.7	17	100	280	5.5	2.0

n.a. = Not available.

the Athi River Basin (Saggerson, 1962).

3.1.4. Vegetation:

A general description of the area is available (Ledger et al., 1969). The vegetation type is variously known as "Acacia-Savannah" (Trapnell and Langdale-Brown, 1962) or "Scattered-Tree grassland" Edwards, 1956). The main grass species present at the start of the trials were Themeda triandra. Forsk, Pennisetum mezianam. Leeke and Digitaria macroblephara. Stapf, with Sporobolus stapfianus. Gandoger, Sporobolus pellucidus. Hochst and Bothriochloa insculpta (A. Rich) A. Camus as important minor components.

3.2. Experimental Techniques

The field trial programme was based on two major experiments. One of the experiments used cutting treatments to assess herbage availability, while the second used both cutting and animal grazing techniques.

3.2.1. Experiment I. Effects of Cutting Height and Frequency on Herbage Availability.

The object of this trial was to simulate the effects of a variety of grazing treatments by means of mechanical harvesting techniques. Although selection of herbage, trampling, and spoilage by faeces and urine does not occur in a cutting experiment, the cutting treatments can yield information about the potential herbage availability in the absence of the animal, so setting an upper limit to sward production potential ('t Mannetje et al, 1978).

In this experiment a split-plot design was used (Cochran & Cox, 1950). Height of cutting, at 5, 10 and 15cm was the main plot treatment, with frecuency of cutting at 3, 6, 9, 12 and 15 weeks as the sub-plot treatment. There were 3 replications. An outline of the analysis of variance is indicated in table 3.3.

The gross sub-plot size was 4.5 x 4.5m. A 1 metre guard row or discard around the four sides resulted in a nett harvest area of 2.5m x 2.5m i.e. 1/1600 ha. The cutting was carried out by Allan motor scythe (Manufactured by Allan Power Equipment Ltd., Didcot, Berks; U.K.) using a 90cm cutter bar. The 5cm height of cut was the effective height of out of the standard machine. The 10cm and 15cm heights were achieved by metal skids designed by the author. These skids bolted on the underside of the cutter bar assembly as required.

At each harvest the discard area of each scheduled sub-plot was first cut and removed. The

Table 3.3.

Outline Analysis of Variance for
Experiment I Considered as a
Split - Plot Design.

Outline Analysis of Variance of Annual Yield

Component	d.f.
Replicates	2
Height (H)	2
Error (a)	4
Whole Plot	8
Frequency (F)	4
F x H	8
Error (b)	24
Years (Y)	3
Y x H	6
Y x F	12
H x F x H	24
Error (c)	82
Total	179

harvest area was then cut, raked together and weighed. A representative sample of about 400g fresh material, or the whole plot fresh harvest if less than 400g was then collected, placed in a polythene bag to reduce water loss and transported the 80km to the main station facilities at Muguga. The fresh sample was weighed and then dried at 65-75°C in a forced draught oven for 48 hours to ensure complete drying. After weighing of the dry matter, the sample was allowed to reach air dry condition (usually about 90% dry matter) as this reduced brittleness.

The air dry material was sorted into botanical components as far as possible, but the results and discussion are confined to the overall dry matter results. The material was then recombined and ground through a 1mm screen for proximate analysis. Analysis was carried out by the KARI Laboratories for Crude Protein and Ash (AOAC, 1970) and Detergent Fibre Components by the methods of Van Soest (1963).

Harvest data were related to a three-week time module by the use of 1, 2, 3, 4 and 5 series of plots for the 3, 6, 9, 12 and 15 week frequency treatments. This is indicated in the operational schedule in Table 3.4. It was considered desirable to use this multiple series approach for the following main reasons:-

Table 3.4.

Schedule of Harvest Operations for Experiment I

Frequency	No.	Harvest Dates (Every Three Weeks)																
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	etc.
3 weeks	1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
6 weeks	2	x	-	x	-	x	-	x	-	c	-	x	-	x	-	x	-	
"	3	-	x	-	x	-	x	-	x	-	x	-	x	-	x	-	x	
9 weeks	4	x	-	-	x	-	-	x	-	-	x	-	-	x	-	-	x	
"	5	-	x	-	-	y	-	-	x	-	-	x	-	-	x	-	-	
"	6	-	-	x	-	-	x	-	-	x	-	-	x	-	-	x	-	
12 weeks	7	x	-	-	.	x	-	-	-	x	-	-	-	x	-	-	-	
"	8	-	x	-	-	-	x	-	-	-	x	-	-	-	x	-	-	
"	9	-	-	x	-	-	-	x	-	-	-	x	-	-	-	x	-	
"	10	-	-	-	x	-	-	-	x	-	-	-	x	-	-	-	x	
15 weeks	11	x	-	-	-	-	x	-	-	-	-	x	-	-	-	-	x	
"	12	-	x	-	-	-	-	x	-	-	-	-	x	-	-	-	-	
"	13	-	-	x	-	-	-	-	x	-	-	-	-	x	-	-	-	
"	14	-	-	-	x	-	-	-	-	x	-	-	-	-	x	-	-	
"	15	-	-	-	-	x	-	-	-	-	x	-	-	-	-	x	-	

x = Cutting date (for each of the three Heights)

(i) A single series of plots for the 6, 9, 12 and 15 weeks frequency treatments might be expected to give different results depending on the relationship between the date of cut and the actual seasonal growth pattern of the sward. For example, a 15 week period covering the whole of the rainy season, followed by a 15 week period covering the subsequent dry season might give an estimate of herbage productivity quite different from that derived from a cut in the middle of the rains, followed by a cut in the middle of the following dry season.

(ii) In a grazing situation, to which the results of the cutting trials must be finally related, defoliation of the sward by the grazing animal does not occur at discrete time intervals, but rather the sward is grazed in a more haphazard manner. In the sward at any one time there will be plants which have had a variety of periods of regrowth since their last grazing. This argument applies whatever the grazing intensity (equivalent to cutting height and frequency) that is employed.

(iii) Insect removal and/or microbial decay of herbage have been considered to quite significantly affect the standing forage quantity in local studies (Cassaday, 1973); Karue, 1975). The seasonal variation in rate of these non-grazing defoliation processes cannot at this stage be considered to be uniform throughout the year.

For these reasons the analysis of the seasonal variation in available herbage under the different treatments has been based on the use of a moving arithmetical average estimate of the yield on the 1, 2, 3, 4 and 5 series of plots for the respective 3, 6, 9, 12 and 15 week frequency treatments, with all results being related to a three week time module. The moving average results were derived for the 82 three week periods between April 1974 and December 1978.

3.2.2. Experiment 2. Grazing Trial:

This trial was established as an unreplicated observation using a single paddock containing four steers for each of the four stocking rates used. The stocking rates chosen were two, three, four and five hectares per animal. The choice of these particular rates was made following discussion with local ranchers and extension personnel, and it agrees with the estimates made for Ecozone IV by Pratt (1968), and for estimates based on rainfall distribution by Jahnke (1982).

Set stocking was practised with the animals, rather than any rotational grazing system. This is in line with current local practice. It was also considered that the results from a set stocking study would provide base-line data from which subsequent studies could be developed to evaluate more resource-demanding rotational grazing possibilities. The relatively limited data available for tropical pastures also indicate that continuous grazing under set stocking gives results on a performance per animal basis as good as under rotational grazing ('t Mannetje et al., 1976).

The experimental paddocks were grazed from 6.30 a.m. until 6.30 p.m. each day as for security against wildlife predators and stock theft it was necessary to confine the animals in guarded enclosures at night. The animals were sprayed on a 5 day cycle using approved acaricides to eliminate tick-borne disease problems and were routinely inoculated against foot and mouth disease and anthrax.

The steers used were first generation crosses between Bos indicus (Boran Type) as maternal parent, and Bos taurus (Hereford Type) as paternal parent, such crosses being very commonly used in the ranching areas of Kenya.

The experimental paddocks were grazed continually from June 1974. Animals were introduced at approximately 15-18 months of age, and removed for slaughter at 30-36 months. The results presented in Chapter 4 are derived from the first 6 series of animals, up to July 1982. Average ages and weights for the 6 series of animals at the start and end of each grazing period are presented in Table 3.5.

Weekly records of liveweight, after overnight fasting and withdrawal of water were collected by weighing between 8 a.m. and 9 a.m. for all 96 animals used in the experiment.

On 6 occasions during the course of the study additional animal data was collected as indicated in Table 3.6.

The faecal output samples were obtained by feeding of 10g per day of Chromic oxide as an inert tracer in four gelatin capsules containing 2.5g each. The capsules were administered to the animals by hand in the handling unit attached to night enclosures. Practical difficulties limited administration to a

Table 3.5.

Animal Weights and Ages at the Start and end of Each Grazing Series in Experiment 2

Series No.	Date	Stocking Rate ha/hd 2	3	4	5	Mean	
1	June 1974	24	24	21	23	23	Starting Age (Months)
	"	302	301	300	300	301	" Weight (kg.)
	Jan. 1975	32	32	29	31	31	Ending Age (Months)
	"	381	375	415	395	392	" Weight (Kg.)
2	Feb. 1975	16	16	16	16	16	Starting Age (Months)
	"	223	216	225	213	219	" Weight (kg.)
	Aug. 1976	34	34	34	34	34	Ending Age (Months)
	"	406	422	418	446	423	" Weight (kg.)
3	Sept. 1976	18	18	18	18	18	Starting Age (Months)
	"	271	278	276	280	276	" Weight (kg.)
	July 1977	28	28	28	28	28	Ending Age (Months)
	"	401	426	421	432	420	" Weight (kg.)
4	Sept. 1977	17	17	17	17	17	Starting Age (Months)
	"	247	255	251	255	252	" Weight (kg)
	Jan. 1979	34	34	34	34	34	Ending Age (Months)
	"	406	456	429	432	431	" Weight (kg.)
5	Jan. 1979	12	12	12	12	12	Starting Age (Months)
	"	185	184	186	185	185	" Weight (kg.)
	Feb. 1981	37	37	37	37	37	Ending Age (Months)
	"	451	500	445	454	463	" Weight (kg.)
6	Mar. 1981	25	24	24	25	25	Starting Age (Months)
	"	263	258	261	269	263	" Weight (kg.)
	Jun. 1982	40	39	39	40	40	Ending Age (Months)
	"	403	440	403	426	418	" Weight (kg.)

Table 3.6. Schedule of Faecal and Fistula Sampling for Experiment 2.

A. Faecal Sampling (Using Chromic Oxide).

1.	17/06/74	-	29/06/74	3 ha and 4 ha stocking rates
2.	07/10/74	-	19/10/74	"
3.	12/05/75	-	25/05/75	"
4.	16/08/75	-	28/08/75	"
5.	05/09/75	-	14/09/76	"
6	18/05/77	-	25/05/77	"

B. Oesophageal Fistula Sampling.

1.	26/06/74	-	28/06/74	3 ha and 4 ha stocking rates (6x3)
	01/07/74	-	04/07/74	2 ha and 5 ha stocking rates (6x3)
2.	15/10/74	-	16/10/74	3 ha and 4 ha stocking rates (4x2)
	22/10/74	-	23/10/74	2 ha and 5 ha stocking rates (4x2)
3.	14/05/75	-	16/05/75	3 ha and 4 ha stocking rates (3x4)
	19/05/75	-	22/05/75	2 ha and 5 ha stocking rates (3x4)
4.	20/08/75	-	22/08/75	3 ha and 4 ha stocking rates (3x4)
5.	26/08/75	-	28/08/75	2 ha and 5 ha stocking rates (3x4)
5.	07/09/76	-	09/09/76	3 ha and 4 ha stocking rates (3x4)
	01/09/76	-	03/09/76	2 ha and 4 ha stocking rates (3x4)
6.	06/06/77	-	12/06/77	3 ha and 4 ha stocking rates (6x3)
	13/06/77	-	18/06/77	2 ha and 5 ha stocking rates (6x3)

Numbers in brackets refer to the number of sampling times and the number of fistulated animals used respectively for each period.

once daily event, even though this has been recorded to give greater diurnal variation in faecal Chromic oxide content than a twice-daily dosing (Putman et al., 1957; Hopper et al.,1978). The capsules were fed for four days prior to faecal sample collection to allow for equilibration throughout the digestive tract. Following this, grab samples of about 1kg were collected from the rectum of the animals morning and evening, immediately prior to departure from the night enclosure in the morning and after return in the evening (Minson et al, 1976). The faecal samples were frozen immediately after collection and transported to Muguga for further analysis. Drying and chemical analysis of the samples was carried out using the methods described for the herbage from Experiment I. Chromic oxide content was analysed colo rimetrically against prepared standards (Kimura and Miller, 1957).

Samples for estimation of dietary composition were obtained by the use of Oesophageal fistulated animals of breed and size similar to those used for the grazing studies. Fistulation was carried out at the Faculty of Veterinary Medicine of the University of Nairobi. The plug type was as described as type C by Van Dyne and Torell (1964), made of a section of rigid polyethylene pipe inside the Oesophagus and an external wooden plug. On each occasion sampling was carried out for approximately 30 minutes. No foam plug was used to close off the lower Oesophagus during sampling (Minson et al.,1976). Water-proof canvas bags were used for collection of both solid and liquid material. At the end of the collection period most of the saliva was removed from the sample by wringing the wet material in muslin cloth. The volume of saliva expressed and the total weight of wet solids were recorded following which a sample of the solids of about 250g of wet material was then frozen for further analysis at Muguga.

Attempts to assess botanical composition of the fistula material by means of the microscope point-hit method (Harker et al.,1964) were abandoned after it proved impossible to obtain reasonably reproducible results with such a complex sward mixture, using the limited available laboratory resources. Analysis of the fistula samples was, therefore confined to the chemical methods as outlined above for Experiment I. To reduce the effect of salivary contamination results of the chemical analysis were calculated on an ash-free basis (Marshall et al.,1967).

At the end of each grazing period all 16 animals were slaughtered and carcass composition analysis was carried out at the Meat Research Unit at

Muguga. The Right side of each carcass was fully dissected, while the 10th rib was used as a sample joint for the Left side (Ledger et al., 1973).

3.3. Data analysis methods

3.3.1. Equipment used:

Statistical analyses of results was carried out by the author using either a Wang MVP2000 series minicomputer, with standard Wang software, or with a Sinclair ZX Spectrum microcomputer using programmes developed by the author.

3.3.2. Statistical analysis of Experiment I.

3.3.2.1. Yield:

For the reasons outlined in section 3.2.1. above, one, two, three, four and five series of plots respectively were used for the 3, 6, 9, 12 and 15 week cutting frequency treatments.

Initial analysis of yield was carried out by analysis of Variance of the mean yields for each treatment on a yearly basis. As 1974 results were not for a complete year only the results for 1975 to 1978 were used. The experiment was considered to be a split-split plot design for this analysis with height of cut as the main plot, frequency as the sub-plot and year as the sub-sub-plot. The outline analysis of variance is presented in Table 3.3.

The multiple series of plots provided the data for calculation of the moving average estimate for each cutting frequency for each three week time period. The moving averages were derived using equal weighting of the one, two, three, four or five separate estimates of mean three week production for the 3, 6, 9, 12 and 15 week frequency treatments.

3.3.2.2. Rainfall and Yield.

In an initial attempt to relate herbage productivity with climate, a multiple regression analysis of yield estimated by the moving average technique against rainfall was carried out. A multiple regression model was examined as it was considered that rainfall occurring in the period immediately prior to a harvest could be likely to have a variable effect on growth of the herbage depending on whether the rainfall had been preceeded by a period of other rainfall or not. Initial testing of the data by the backward method of deletion of redundant variables (Kendall, 1976) indicated that the inclusion of periods earlier than nine weeks before harvest (i.e. two three-week periods before the one terminated by the harvest) was not justified as their contribution to the regression was negligible. The analysis was therefore continued on the basis of a model of the form:-

$$\text{Yield} = K + a X_1 + b X_2 + c X_3$$

where K, a, b and c were constants and X_1, X_2 and X_3 were the rainfall totals for the present (0-3 weeks before harvest), previous (3-6 weeks before harvest) and penultimate (6-9 weeks before harvest). This model assumes that there may be a direct relationship between water provided by rainfall and the yield of herbage (Martin and Cable., 1974).

3.3.2.3. Yield and Evapotranspiration

As discussed in the literature review (2.3.3.). evapotranspiration may be a measure of water relations of the herbage which reflects water availability to the plant more accurately than the simple rainfall figure. Using the Australian model described (McCown et al.,1974), estimates of Actual Evapotranspiration (A.E.) have been calculated for the 82 three weekly periods for which the moving averages of yield in Experiment I were derived. The initial AE calculation was based on the average of potential evaporation and total rainfall for the whole of each 21 day period. However such an approach may be criticised as it assumes that both rainfall and evaporation are occurring continuously throughout the 21 days. In reality the rainfall occurs in more or less discrete showers, whereas the evaporation is a more continuous process. For this reason the A.E. estimate was additionally calculated on a daily basis.

A further factor complicating the calculation of the A.E. estimate is the crop factor to be used to convert the potential evaporation derived from the Penman (1948) calculations to a potential transpiration estimate. Derivation of this crop factor depends on the use of a technique such as the hydraulic lysimeter (Glover and Forsgate.,1962). In East Africa the crop factors have been determined for relatively few agricultural situations. The only published value for a grass sward is that for a Pennisetum clandestinum sward at Muguga, where the sward and the climatic conditions are markedly different from the present site (Pereira and McCulloch.,1962). In the absence of any alternative value, however, the value of 0.86 for the crop factor has been used, together with 1.00 as suggested by McCulloch (1965) for full ground cover, in the A.E. calculations.

Final factor considered in the derivation of the A.E. figures was the actual soil water holding capacity. Due to the uncertain relevance of the $\frac{1}{3}$ bar and 15 bar pressure limits for field capacity to the sward under consideration and the lack of knowledge regarding the actual soil volume from which water is used by the sward the true soil water holding capacity value for use in A.E. calculation cannot be accurately specified. For this reason calculations were carried out using both 150mm and 200mm values for soil water holding capacity. A total of 8 A.E. values were therefore derived (150/200mm, 0.86/1.00 and Daily/three-weekly). These values were incorporated into a multiple regression analysis with yield of type similar to that described above for rainfall and yield.

3.3.3. Statistical Analysis of the Results of Experiment 2.

3.3.3.1. Liveweight Gains:

Analysis of variance of stocking rate effects on liveweight gains was carried out for each of the six series of animals. In addition the regression of daily liveweight gain against rainfall in the present (0-3 weeks), previous (3-6 weeks) and penultimate (6-9 weeks) periods before weighing were calculated, using the three week periods closest to those used in Experiment I.

3.3.3.2. Dietary Composition:

The chemical composition of the faecal, fistula and standing forage samples for each sampling occasion were compared using a standard multiple range test (Duncan, 1955).

CHAPTER 4

RESULTS

4.1. Experiment I.

Effects of Cutting Height and Frecuency on Herbage Availability.

4.1.1. Analysis of Variance of Dry Matter Yield as an Annual Basis.

Table 4.1. indicates the analysis of the annual dry matter yields over the years 1975 to 1978 for the 15 height and frequency treatment combinations. Table 4.2. gives the yield in kg dry matter per hectare, together with standard errors and least significant differences for the treatments and interactions which were found to be statistically significant at a level of probability less than 0.05, according to the analysis of variance.

Growth occurring below the height of cut was not assessed in this trial. The increase in yield noted with reduction of height of cut requires some caution in interpretation. Even if the growth of herbage was uniform for each of the three heights of cutting, it would be expected that whatever the vertical distribution of the plant canopy, a lower cutting height would result in higher yield collection. The statistically significant effect of height indicated in Table 4.1. may therefore be largely a

Table 4.1 Experiment I

Analysis of Variance of Total Annual Dry Matter Yield for the Complete Years 1975 to 1978.

Component	Degrees of Freedom	Sum of Squares	Mean Square	Variance ratio	
Replicates	2	5.00	2.50	2.41	n.s.
Height (H)	2	39.50	19.75	10.04	+
Error (a)	4	4.15	1.04		
Whole Plot Total	8	48.65			
Frequency (F)	4	8.12	2.03	3.44	+
F x H	8	6.32	0.79	1.34	n.s.
Error (b)	24	14.12	0.59		
Sub Plot Total	44	77.22			
Years (Y)	3	289.73	96.58	218.22	+++
Y x H	6	54.48	9.08	20.35	+++
Y x F	12	10.50	0.87	1.97	+
Y x F x H	24	9.08	0.38	0.86	
Error (c)	90	39.83	0.44		
Total	179	480.83			

N.B. All calculations were based on kg/ha values multiplied by 10^{-6} for ease of handling.

Standard Error (Whole Plots) = 1018kg/ha Coefficient of Variation =65.3%

" " (Sub Plots) = 767kg/ha " " " =49.2%

" " (Sub-Sub-Plots) = 665kg/ha " " " =42.7%

\+ = Significant at P=0.05

++ = Significant at P=0.01

+++ = Significant at P=0.001

Table 4.2. Experiment I

Treatment Yields in Kg. dry Matter per Hectare (1975 to 1978)

Height cm	Frequency Weeks	Year				
		1975	1976	1977	1978	Mean
5	3	848	160	1177	4191	1594
	6	961	192	2913	5707	2443
	9	769	215	2665	5926	2394
	12	830	284	1825	5411	2088
	15	1064	358	2255	5558	2309
	Mean	894	242	2167	5359	2165
10	3	643	346	1086	1785	965
	6	918	211	1508	3927	1616
	9	649	267	1160	3016	1273
	12	841	289	2064	4899	2023
	15	826	256	1614	3494	1546
	Mean	756	274	1486	3424	1485
15	3	667	293	746	1561	687
	6	687	264	1014	1464	857
	9	537	263	1636	2355	1198
	12	592	219	1623	2023	1114
	15	561	253	1057	2488	1090
	Mean	649	258	1215	1978	1025
Mean	3	786	267	1003	2512	1142
	6	822	222	1811	3700	1639
	9	652	248	1620	3766	1622
	12	754	264	1837	4111	1742
	15	817	289	1642	3847	1649
	Mean	766	258	1623	3587	1559

Item	Standard Error	Least Significant Difference (P=0.05)
Heights	186	516
Frequencies	181	374
Years	140	278
Years at same Height	242	482
Heights in same year	280	655

Total Annual Rainfall in mm.

1975 - 572 1976 - 385
1977 - 766 1978 - 852

reflection of the harvesting technique alone, rather than an effect of the cutting treatment on plant vigour. The reduction in yield at the greater height of cutting was more marked the higher the level of overall annual yield, this effect being indicated by the statistical significance of the year x height interaction. This may be explained by the concentration of biomass production in the lower levels of the sward, resulting from the characteristic growth habit of the sward being studied.

The effect on yield level of years was much greater than that of either height or frequency. The probable origin of these large inter-year differences is indicated by the annual rainfall totals at the bottom of Table 4.2.

4.1.2. Analysis of Yield in Relation to Rainfall.

Tables 4.3., 4.4. and 4.5. show the moving average yield estimates for the three heights of cutting, 5, 10 and 15cm for each of the 82 three-week periods examined. The tables indicate the mean yield of the three replicates for each of the 3,6,9, 12 and 15 week frecuencies of cutting. Very distinct periodsof low and high yield are apparent, and the pattern is consistent for all the defoliation treatments.

Table 4.3. Experiment 1. Moving averages of dry matter yield over three-week period and cumulative total of yield for 5cm cutting height.

Yield - Units - kg/ha

Harvest		3 weeks		6 weeks		9 weeks		12 weeks		15 weeks		Mean	
No.	Date	Period Value	Run. Total	Period Value	Run. Total	Period Value	Run. Total	Period Value	Run. Total	Period Value	Run. Total	Period Value	Run. Total
1	23.4.74	183	183	536	536	337	337	284	284	281	281	324	324
2	14.5.74	412	595	479	1015	338	675	303	587	281	562	363	687
3	4.6.74	57	652	119	1134	189	864	238	825	211	773	163	850
4	25.6.74	113	765	77	1211	106	970	176	1001	161	934	127	977
5	16.7.74	48	813	59	1270	75	1045	87	1088	116	1050	77	1054
6	6.8.74	53	866	62	1332	59	1104	47	1135	58	1108	56	1110
7	27.8.74	73	939	63	1395	44	1148	39	1174	43	1151	52	1162
8	17.9.74	39	978	76	1471	37	1185	34	1208	37	1188	45	1207
9	8.10.74	61	1039	87	1558	46	1231	36	1244	37	1225	53	1260
10	29.10.74	21	1060	56	1614	39	1270	38	1282	38	1263	38	1298
11	19.11.74	30	1090	44	1658	49	1319	41	1323	43	1306	41	1339
12	10.12.74	28	1118	65	1723	43	1362	49	1372	39	1345	45	1384
13	31.12.74	32	1150	50	1773	51	1413	44	1416	41	1386	44	1428
14	21.1.75	23	1173	40	1813	33	1446	37	1453	36	1422	34	1462
15	11.2.75	68	1241	30	1843	28	1474	28	1481	30	1452	37	1499
16	4.3.75	4	1245	14	1857	13	1487	31	1512	28	1480	18	1517
17	25.3.75	20	1265	19	1876	17	1504	15	1527	71	1551	28	1545
18	15.4.75	17	1282	16	1892	34	1538	81	1608	104	1655	50	1595
19	6.5.75	37	1319	79	1971	129	1667	107	1715	131	1786	97	1692
20	27.5.75	108	1427	266	2237	159	1826	124	1839	146	1932	161	1853
21	17.6.75	432	1769	220	2457	141	1967	113	1952	137	2069	191	2044
22	8.7.75	103	1872	26	2483	45	2012	62	2014	91	2160	65	2109
23	29.7.75	8	1880	18	2501	13	2025	37	2051	56	2216	26	2135
24	19.8.75	0	1880	23	2524	8	2033	18	2069	31	2247	16	2151
25	9.9.75	12	1892	10	2534	10	2043	12	2081	21	2268	13	2164
26	30.9.75	3	1895	5	2539	8	2051	17	2098	25	2293	12	2176
27	21.10.75	6	1901	6	2545	19	2070	24	2122	39	2332	19	2195
28	11.11.75	1	1902	42	2587	28	2098	48	2170	58	2390	35	2230
29	2.12.75	130	2032	87	2674	54	2152	60	2230	71	2461	80	2310
30	23.12.75	69	2101	68	2742	50	2202	56	2286	63	2524	61	2371
31	13.1.76	28	2129	42	2784	45	2247	47	2333	53	2577	43	2414
32	3.2.76	22	2151	35	2819	21	2268	22	2355	44	2621	29	2443
33	24.2.76	48	2199	17	2836	16	2284	9	2364	22	2643	22	2465
34	16.3.76	10	2209	9	2845	8	2292	9	2373	7	2650	9	2474
35	6.4.76	5	2214	11	2856	6	2298	7	2380	7	2657	7	2481
36	27.4.76	7	2221	8	2864	3	2301	6	2386	8	2665	6	2487
37	18.5.76	5	2226	4	2868	4	2305	6	2392	12	2677	6	2493
38	8.6.76	1	2227	5	2873	4	2309	7	2399	10	2687	5	2498
39	29.6.76	12	2239	7	2880	8	2317	7	2406	12	2699	9	2507
40	20.7.76	9	2248	11	2891	10	2327	9	2415	13	2712	10	2517
41	10.8.76	3	2251	7	2898	20	2347	6	2421	10	2722	9	2526
42	31.8.76	0	2251	2	2900	5	2352	5	2426	7	2729	4	2530
43	21.9.76	2	2253	3	2903	3	2355	4	2430	6	2736	4	2534
44	12.10.76	0	2253	2	2905	2	2357	3	2433	10	2745	3	2537
45	2.11.76	0	2253	2	2907	3	2360	5	2438	6	2751	3	2540
46	23.11.76	1	2254	3	2910	6	2366	6	2444	8	2759	5	2545
47	14.12.76	8	2262	9	2919	8	2374	9	2453	11	2770	9	2554
48	4.1.77	17	2279	12	2931	9	2383	11	2464	12	2782	12	2566
49	25.1.77	0	2279	8	2939	8	2391	8	2472	13	2795	7	2573
50	15.2.77	1	2280	5	2944	6	2397	8	2480	40	2835	12	2585
51	8.3.77	0	2280	3	2947	11	2408	78	2558	112	2947	41	2626
52	29.3.77	1	2281	17	2964	167	2575	193	2751	224	3171	120	2746
53	19.4.77	46	2327	357	3321	297	2872	326	3077	342	3513	274	3020
54	10.5.77	579	2906	911	4232	511	3383	432	3509	428	3941	572	3592
55	31.5.77	193	3099	632	4864	377	3760	373	3882	401	4342	395	3987
56	21.6.77	57	3154	81	4945	253	4013	258	4140	323	4665	194	4181
57	12.7.77	45	3201	31	4976	36	4049	127	4267	208	4873	89	4270
58	2.8.77	14	3215	18	4994	17	4066	20	4287	89	4962	32	4302
59	23.8.77	9	3224	10	5004	12	4078	6	4293	7	4969	9	4311
60	13.9.77	4	3228	9	5013	16	4094	6	4299	5	4974	8	4319
61	4.10.77	4	3232	6	5019	19	4113	6	4305	75	5049	22	4341
62	25.10.77	0	3232	11	5030	22	4135	86	4391	147	5196	53	4394
63	15.11.77	5	3237	19	5049	28	4163	261	4652	152	5348	93	4487
64	6.12.77	39	3276	393	5442	670	4833	267	4919	150	5496	304	4791
65	27.12.77	165	3441	498	5940	670	5503	294	5213	224	5732	372	5163
66	17.1.78	357	3798	152	6092	511	6014	323	5536	266	5998	322	5485
67	7.2.78	61	3859	112	6204	117	6131	197	5733	413	6411	180	5665
68	28.2.78	86	3945	486	6690	433	6564	502	6235	509	6920	403	6068
69	21.3.78	838	4783	1149	7839	1183	7747	740	6975	735	7655	929	6997
70	11.4.78	747	5530	1520	9359	1651	9398	732	7707	682	8337	1066	8063
71	2.5.78	878	6408	1356	10715	693	10091	757	8464	745	9082	886	8949
72	23.5.78	60	6468	146	10861	249	10340	604	9068	559	9641	324	9273
73	10.6.78	35	6503	129	10990	217	10557	319	9387	498	10139	240	9513
74	4.7.78	23	6526	95	11085	308	10865	230	9617	309	10448	193	9706
75	25.7.78	9	6535	21	11106	280	11145	213	9830	277	10725	160	9866
76	15.8.78	6	6541	9	11115	154	11299	200	10030	263	10988	126	9992
77	5.9.78	0	6541	7	11122	16	11315	13	10043	254	11242	58	10050
78	26.9.78	0	6541	4	11126	29	11344	14	10057	60	11302	21	10071
79	17.10.78	0	6541	2	11128	8	11352	52	10110	91	11393	31	10102
80	7.11.78	0	6541	5	11133	72	11424	141	10251	120	11513	68	10170
81	28.11.78	18	6559	321	11454	169	11593	225	10476	252	11765	197	10367
82	19.12.78	1073	7632	627	12081	331	11924	297	10773	259	12024	517	10884

Table 4.4. Experiment 1. Moving averages of dry matter yield over three-week period and cumulative total of yield for each cutting height

Yield - Units - kg/ha

Harvest		3 weeks		6 weeks		9 weeks		12 weeks		15 weeks		Mean	
No.	Date	Period Value	Run. Total	Period Value	Run. Total	Period Value	Run. Total	Period Value	Run. Total	Period Value	Run. Total	Period Value	Run. Total
1.	23.4.74	130	130	217	217	172	172	172	172	162	162	171	171
2.	14.5.74	279	409	240	457	191	363	167	339	159	321	207	378
3.	4.6.74	66	475	111	568	134	497	122	461	129	450	112	490
4.	25.6.74	198	673	80	648	78	575	97	558	90	540	109	599
5.	16.7.74	139	810	81	729	61	636	57	615	60	600	79	678
6.	6.8.74	114	924	74	803	56	692	53	668	35	635	66	744
7.	27.8.74	229	1153	50	853	60	752	43	711	31	666	83	827
8.	17.9.74	43	1196	74	927	36	788	31	742	34	700	44	871
9.	8.10.74	82	1278	63	990	37	825	38	780	39	739	52	923
10.	29.10.74	15	1293	32	1022	36	861	30	810	38	777	30	953
11.	19.11.74	48	1341	59	1081	59	920	35	845	46	823	49	1002
12.	10.12.74	71	1412	61	1142	59	979	41	886	42	865	55	1057
13.	31.12.74	31	1443	44	1186	52	1031	32	918	34	899	39	1096
14.	21.1.75	41	1484	45	1231	35	1066	25	943	32	931	36	1132
15.	11.2.75	75	1559	50	1281	27	1093	27	970	29	960	42	1174
16.	4.3.75	27	1586	11	1292	16	1109	19	989	24	984	19	1193
17.	25.3.75	1	1587	16	1308	10	1119	25	1014	57	1041	22	1215
18.	15.4.75	19	1606	20	1328	24	1143	67	1081	77	1118	41	1256
19.	6.5.75	16	1622	39	1367	85	1228	97	1178	83	1201	64	1320
20.	27.5.75	63	1685	137	1504	125	1353	110	1288	94	1295	106	1426
21.	17.6.75	206	1891	170	1674	116	1469	121	1409	90	1385	141	1567
22.	8.7.75	22	1913	72	1746	61	1530	79	1488	54	1439	58	1625
23.	29.7.75	12	1925	29	1775	22	1552	40	1528	33	1472	27	1652
24.	19.8.75	36	1961	31	1806	15	1567	25	1553	22	1494	26	1678
25.	9.9.75	8	1969	9	1815	6	1573	7	1560	14	1508	9	1687
26.	30.9.75	1	1970	6	1821	3	1576	12	1572	25	1533	9	1696
27.	21.10.75	4	1974	7	1828	12	1588	25	1597	38	1571	17	1713
28.	11.11.75	10	1984	22	1850	25	1613	45	1642	43	1614	29	1742
29.	2.12.75	41	2025	79	1929	57	1670	57	1699	51	1665	57	1799
30.	23.12.75	61	2086	79	2008	55	1725	58	1757	44	1709	59	1858
31.	13.1.76	62	2148	31	2039	30	1755	45	1802	49	1758	43	1901
32.	3.2.76	21	2169	38	2077	29	1784	26	1828	21	1779	27	1928
33.	24.2.76	90	2259	29	2106	24	1808	12	1840	15	1794	34	1962
34.	16.3.76	25	2284	10	2116	6	1814	10	1850	6	1800	11	1973
35.	6.4.76	13	2297	10	2126	8	1822	9	1859	7	1807	9	1982
36.	27.4.76	5	2302	9	2135	7	1829	12	1871	8	1815	8	1990
37.	18.5.76	8	2310	9	2144	10	1839	11	1882	8	1823	9	1999
38.	8.6.76	2	2312	11	2155	9	1848	12	1894	9	1832	9	2008
39.	29.6.76	30	2342	12	2167	12	1860	14	1908	11	1843	16	2024
40.	20.7.76	9	2351	11	2178	9	1869	11	1919	11	1854	10	2034
41.	10.8.76	13	2364	9	2187	6	1875	9	1928	10	1864	9	2043
42.	31.8.76	0	2364	6	2193	2	1877	5	1933	7	1871	4	2047
43.	21.9.76	7	2371	4	2197	1	1878	4	1937	7	1878	5	2052
44.	12.10.76	0	2371	3	2200	2	1880	4	1941	8	1886	3	2055
45.	2.11.76	7	2378	5	2205	4	1882	8	1949	7	1893	6	2061
46.	23.11.76	0	2378	5	2210	7	1889	9	1958	9	1902	6	2067
47.	14.12.76	11	2389	11	2221	13	1904	13	1971	11	1913	12	2079
48.	4.1.77	13	2402	17	2238	15	1919	14	1985	13	1926	14	2093
49.	25.1.77	7	2409	13	2251	14	1933	11	1996	12	1938	11	2104
50.	15.2.77	19	2428	10	2261	8	1941	10	2006	37	1975	17	2121
51.	8.3.77	1	2429	4	2265	5	1946	47	2053	79	2054	27	2148
52.	29.3.77	2	2431	4	2269	54	2000	121	2174	162	2216	69	2217
53.	19.4.77	12	2443	172	2441	139	2139	291	2465	208	2424	164	2381
54.	10.5.77	279	2722	354	2795	233	2372	388	2853	272	2696	305	2686
55.	31.5.77	88	2810	287	3082	199	2571	365	3218	246	2942	237	2923
56.	21.6.77	27	2837	120	3202	116	2687	291	3509	203	3145	151	3074
57.	12.7.77	19	2856	64	3266	25	2712	127	3636	119	3264	71	3145
58.	2.8.77	25	2881	49	3315	14	2726	28	3664	71	3335	37	3182
59.	23.8.77	23	2904	13	3328	10	2736	10	3674	7	3342	13	3195
60.	13.9.77	41	2945	14	3342	8	2744	11	3685	7	3349	16	3211
61.	4.10.77	6	2951	4	3346	4	2748	5	3690	53	3402	14	3225
62.	25.10.77	0	2951	0	3346	9	2757	126	3816	125	3527	52	3277
63.	15.11.77	2	2953	20	3366	153	2910	317	4133	136	3663	126	3403
64.	6.12.77	40	2993	220	3586	215	3125	250	4383	120	3733	169	3572
65.	27.12.77	486	3479	517	4103	221	3346	290	4673	212	3995	345	3917
66.	17.1.78	107	3586	314	4417	137	3483	264	4937	216	4211	208	4125
67.	7.2.78	31	3617	53	4470	92	3575	270	5207	342	4553	158	4283
68.	28.2.78	53	3670	462	4932	369	3947	548	5755	420	4973	370	4653
69.	21.3.78	202	3872	857	5819	673	4617	674	6429	532	5505	594	5247
70.	11.4.78	168	4040	787	6606	907	5524	726	7153	437	5942	605	5852
71.	2.5.78	680	4720	701	7307	399	5923	592	7745	406	6343	556	6408
72.	23.5.78	148	4868	260	7567	155	6078	332	8077	233	6581	226	6634
73.	13.6.78	74	4942	234	7801	128	6206	304	8381	240	6821	196	6830
74.	4.7.78	30	4972	35	7836	76	6282	212	8593	103	6934	73	6903
75.	25.7.78	13	4985	23	7859	68	6350	142	8735	73	7007	64	6967
76.	15.8.78	35	5020	24	7883	13	6363	140	8875	73	7080	51	7018
77.	5.9.78	0	5020	8	7891	10	6373	15	8890	68	7148	20	7038
78.	26.9.78	14	5034	4	7895	9	6382	15	8905	42	7190	17	7055
79.	17.10.78	0	5034	2	7897	4	6386	40	8945	83	7273	26	7081
80.	7.11.78	3	5037	5	7902	32	6418	62	9007	97	7370	40	7121
81.	28.11.78	10	5047	142	8044	61	6479	158	9165	131	7501	100	7221
82.	19.12.78	217	5264	199	8243	118	6597	272	9437	139	7640	189	7410

Table 4.5. Experiment I. Moving averages of dry matter yield over three-week period and cumulative total of yield for 15cm cutting height.

Units - kg/ha

Harvest		3 weeks		6 weeks		9 weeks		12 weeks		15 weeks		Mean	
No.	Date	Period Value	Run. Total	Period Value	Run. Total	Period Value	Run. Total	Period Value	Run. Total	Period Value	Run. Total	Period Value	Run. Total
1	23.4.74	276	276	171	171	134	134	135	135	117	117	167	167
2	14.5.74	176	452	119	290	142	276	116	251	110	227	133	300
3	4.6.74	44	496	82	372	110	386	91	342	90	317	83	383
4	25.6.74	152	648	70	442	93	479	84	426	67	384	93	476
5	16.7.74	91	739	51	493	75	554	63	489	58	442	68	544
6	6.8.74	140	879	66	559	65	619	65	554	49	491	77	621
7	27.8.74	146	1025	51	610	59	678	66	620	51	542	75	696
8	17.9.74	54	1079	65	675	64	742	56	676	42	584	56	752
9	8.10.74	120	1199	14	789	72	814	50	726	45	629	80	832
10	29.10.74	161	1360	97	886	52	866	46	772	40	669	79	911
11	19.11.74	72	1432	45	931	35	901	32	804	34	703	44	955
12	10.12.74	14	1446	49	980	23	924	30	834	27	730	29	894
13	31.12.74	34	1480	52	1032	37	961	27	861	27	757	35	1019
14	21.1.75	20	1500	32	1064	26	987	21	882	25	782	25	1044
15	11.2.75	57	1557	27	1091	21	1008	28	910	22	804	31	1075
16	4.3.75	12	1569	16	1107	16	1026	23	933	17	821	17	1092
17	25.3.75	30	1599	27	1134	16	1040	29	962	29	859	26	1118
18	15.4.75	113	1712	24	1158	22	1062	54	1016	48	898	52	1170
19	6.5.75	48	1760	24	1182	47	1109	64	1080	54	952	47	1217
20	27.5.75	27	1787	98	1280	73	1182	72	1152	63	1015	67	1284
21	17.6.75	209	1996	141	1421	71	1253	74	1226	66	1081	112	1396
22	8.7.75	104	2160	68	1489	47	1300	50	1276	50	1131	76	1472
23	29.7.75	15	2175	44	1533	26	1326	29	1305	31	1262	29	1501
24	19.8.75	21	2196	43	1576	20	1346	18	1323	22	1184	25	1526
25	9.9.75	53	2249	9	1585	13	1359	10	1333	15	1199	20	1546
26	30.9.75	4	2253	5	1590	8	1367	11	1344	8	1207	7	1553
27	21.10.75	9	2262	2	1592	17	1384	23	1367	26	1233	15	1568
28	11.11.75	7	2269	15	1607	34	1418	34	1401	28	1261	24	1592
29	2.12.75	42	2311	59	1666	52	1470	37	1438	31	1292	44	1636
30	23.12.75	37	2348	61	1727	49	1519	34	1472	28	1320	42	1678
31	13.1.76	33	2381	27	1754	32	1551	23	1495	24	1344	28	1706
32	3.2.76	32	2413	21	1775	14	1565	12	1507	16	1360	19	1725
33	24.2.76	23	2436	19	1794	11	1576	12	1519	18	1378	17	1742
34	16.3.76	22	2459	15	1809	12	1588	14	1533	17	1395	16	1758
35	6.4.76	18	2476	16	1825	22	1810	17	1550	16	1411	18	1776
36	27.4.76	13	2489	23	1853	27	1637	17	1567	15	1426	20	1796
37	18.5.76	42	2631	43	1896	23	1660	13	1580	15	1441	27	1823
38	8.6.76	23	2554	29	1925	11	1671	11	1591	10	1451	17	1840
39	29.6.76	0	2554	7	1932	9	1680	7	1598	8	1459	6	1846
40	20.7.76	10	2564	9	1941	9	1689	7	1605	7	1466	8	1854
41	10.8.76	5	2569	8	1949	9	1698	6	1611	6	1472	7	1861
42	31.8.76	0	2569	4	1953	5	1703	4	1615	8	1480	4	1865
43	21.9.76	27	2576	3	1956	4	1707	8	1623	8	1488	10	1875
44	12.10.76	0	2596	3	1959	8	1715	8	1631	10	1498	6	1881
45	2.11.76	1	2597	12	1971	9	1724	12	1643	12	1510	9	1890
46	23.11.76	33	2630	12	1983	17	1741	14	1657	16	1526	16	1908
47	14.12.76	12	2642	8	1991	15	1756	14	1671	13	1539	12	1920
48	4.1.77	16	2658	12	2003	21	1777	15	1686	14	1553	16	1936
49	25.1.77	3	2661	11	2014	14	1791	11	1697	11	1564	10	1946
50	15.2.77	11	2672	6	2020	11	1802	9	1705	8	1572	9	1955
51	8.3.77	3	2675	3	2023	5	1807	44	1750	48	1620	21	1976
52	29.3.77	3	2678	3	2026	63	1870	68	1818	102	1722	48	2025
53	19.4.77	2	2680	146	2172	242	2112	100	1918	140	1862	126	2150
54	10.5.77	179	2859	242	2414	185	2297	117	2035	141	2003	173	2323
55	31.5.77	48	2907	112	2526	214	2511	91	2126	122	2125	117	2440
56	11.6.77	10	2917	24	2550	173	2684	66	2191	31	2206	71	2511
57	12.7.77	11	2928	19	2569	80	2764	398	2599	28	2234	107	2618
58	2.8.77	23	2951	14	2583	29	2793	48	2628	19	2253	27	2645
59	23.8.77	20	2971	11	2594	18	2811	9	2647	9	2262	13	2658
60	13.9.77	32	3003	12	2606	11	2823	7	2654	48	2310	22	2680
61	4.10.77	2	3005	5	2611	3	2825	8	2662	97	2407	23	2703
62	25.10.77	0	3005	0	2611	8	2833	211	2873	147	2554	73	2776
63	15.11.77	0	3005	0	2611	294	3127	283	3156	151	2705	146	2922
64	6.12.77	45	3050	195	2806	409	3536	228	3384	151	2856	206	3128
65	27.12.77	346	3396	224	3030	412	3948	247	3631	255	3111	297	3425
66	17.1.78	31	3427	74	3104	239	4187	113	3744	118	3229	115	3540
67	7.2.78	33	3460	66	3170	66	4253	164	3908	183	3412	102	3642
68	28.2.78	18	3259	89	3259	205	4458	359	4267	242	3654	183	3825
69	21.3.78	147	3625	278	3537	305	4763	450	4717	282	3926	292	4117
70	11.4.78	511	4136	456	3993	397	5160	497	5214	253	4189	422	4540
71	2.5.78	220	4356	285	4278	239	5399	366	5590	217	4406	266	4805
72	23.5.78	76	4422	94	4372	97	5496	199	5680	146	4552	108	4908
73	13.6.78	88	4520	24	4466	97	5593	100	5780	133	4685	102	5010
74	4.7.78	10	4530	35	4591	69	5662	32	5812	77	4762	45	5055
75	25.7.78	112	4642	31	4532	43	5705	26	5838	81	4843	59	5114
76	15.8.78	57	4699	20	4552	41	5766	17	5855	77	4920	92	5156
77	5.9.78	29	4728	13	4565	25	5771	18	5873	75	4995	22	5184
78	26.9.78	20	4748	18	4583	20	5791	22	5895	24	5019	21	5209
79	17.10.78	32	4780	15	4598	14	5805	34	5929	29	5048	25	5234
80	7.11.78	11	4791	8	4606	47	5852	50	5979	50	5098	33	5267
81	28.11.78	13	4804	90	4696	76	5928	88	6067	67	5165	67	5374
82	19.12.78	150	4954	150	4846	89	6017	104	5171	75	5240	114	5446

Table 4.6. indicates the distribution of rainfall in the 82 three-week periods and even without statistical analysis a general coincidence of high herbage yield with high rainfall is apparent if Table 4.6. is compared with Table 4.3.4.4. and 4.5.

The regressions of yield against rainfall for the 15 cutting treatment combinations as described in section 3.3.2.2. are presented in Table 4.7. This table indicates that the model used accounts for between 40% and 60% of the variation in measured yield for all but the 15cm x 3 week cutting treatment combination. All of the regressions are statistically significant at the 5% probability level. The possible value of the regression equations for prediction of estimated yield in relation to rainfall is discussed in more detail in section 5.1.

4.1.3. Analysis of Yield in Relation to the Actual Evapotranspiration Estimates.

Tables 4.8. and 4.9. indicate the estimates of Actual Evapotranspiration (AE) for the 150 and 200mm soil water holding capacities. For the reasons discussed in section 3.3.2.3. there are four AE values in each table derived from both the 0.86 and 1.00 crop factors and the daily and three-weekly basis for calculation. The rainfall value for the relevant three week period is included for comparison.

Table 4.5: Experiment I.

Rainfall for the three week periods 1974 - 78

Units mm/21 days

Period No.	Rate Ending	Rain-fall	Period No.	Date Ending	Rain-fall
1	12.2.74	44.9	41	10.8.76	0
0	2.4.74	69.3	42	31.8.76	5.8
1	23.4.74	83.4	43	21.9.76	16.9
2	14.5.74	41.6	44	12.10.76	6.0
3	4.6.74	24.6	45	2.11.76	0.3
4	25.6.74	25.0	46	23.11.76	22.7
5	10.7.74	41.3	47	14.12.76	79.1
6	6.8.74	5.7	48	4.1.77	56.0
7	22.8.74	6.0	49	25.1.77	0.6
8	17.9.74	6.5	50	15.2.77	19.7
9	8.10.74	9.1	51	8.3.77	44.4
10	29.10.74	2.1	52	29.3.77	13.8
11	19.11.74	90.5	53	19.4.77	192.7
12	10.12.74	83.4	54	10.5.77	121.1
13	31.12.74	7.7	55	31.5.77	27.5
14	21.1.75	3.1	56	21.6.77	13.5
15	11.2.75	0	57	12.7.77	12.5
16	4.3.75	4.6	58	2.8.77	2.5
17	25.3.75	63.4	59	23.8.77	12.0
18	15.4.75	3.6	60	13.9.77	0
19	6.5.75	75.2	61	4.10.77	2.2
20	27.5.75	85.3	62	25.10.77	3.4
21	17.6.75	41.4	63	15.11.77	125.6
22	28.7.75	0.7	64	6.12.77	110.8
23	29.7.75	13.9	65	27.12.77	55.0
24	19.8.75	4.8	66	17.1.78	9.9
25	9.9.75	0	67	7.2.78	53.0
26	30.9.75	40.5	68	28.2.78	119.4
27	21.10.75	48.6	69	21.3.78	50.2
28	11.11.75	15.8	70	11.4.78	193.4
29	2.12.75	123.1	71	2.5.78	94.5
30	23.12.75	48.3	72	23.5.78	30.0
31	13.1.76	11.8	73	13.6.78	0
32	3.2.76	0	74	4.7.78	0.9
33	24.2.76	5.0	75	25.7.78	0.3
34	16.3.76	2.4	76	15.8.78	8.0
35	6.4.76	2.7	77	5.9.78	1.8
36	27.4.76	53.2	78	26.9.78	9.5
37	18.5.76	25.5	79	17.10.78	1.8
38	8.6.76	3.0	80	7.11.78	42.6
39	29.6.76	72.0	81	28.11.78	95.7
40	20.7.76	30.0	82	19.12.78	106.6

Table 4.7. Experiment I

Regressions of herbage dry matter yield against rainfall for the present, previous and penultimate three - week period up to harvest, 1974 - 1978.

Height of cutting cm	Frequency of cutting weeks	Regression Equations	Coefficient of determination R^2	Mean Yield kg/ha 21 days
5	3	$Y = -50.74+1.20x_1 + 2.37x_2 + 0.47x_3$	0.451	93.0
	6	$Y = -107.70+2.77x_1 + 3.37x_2 + 1.19x_3$	0.616	153.9
	9	$Y = -92.02+2.83x_1 + 2.34x_2 + 1.49x_3$	0.541	145.9
	12	$Y = -23.31+1.75x_1 + 1.26x_2 + 0.99x_3$	0.604	114.8
	15	$Y = -9.59+1.53x_1 + 1.06x_2 + 1.32x_3$	0.541	139.0
10	3	$Y = -3.93+0.11x_1 + 1.50x_2 + 0.31x_3$	0.453	64.1
	6	$Y = -39.06+1.34x_1 + 1.61x_2 + 0.83x_3$	0.523	96.2
	9	$Y = -35.89+1.56x_1 + 0.86x_2 + 0.79x_3$	0.503	78.8
	12	$Y = -27.82+1.74x_1 + 1.00x_2 + 1.00x_3$	0.585	105.4
	15	$Y = -0.29+1.00x_1 + 0.75x_2 + 0.28x_3$	0.472	90.7
15	3	$Y = +7.71+0.49x_1 + 0.46x_2 + 0.51x_3$	0.277	59.6
	6	$Y = -8.04+0.79x_1 + 0.71x_2 + 0.39x_3$	0.602	59.4
	9	$Y = -9.14+0.89x_1 + 0.73x_2 + 0.73x_3$	0.535	74.5
	12	$Y = -0.67+0.97x_1 + 0.55x_2 + 0.51x_3$	0.411	73.1
	15	$Y = -12.10+0.62x_1 + 0.38x_2 + 0.37x_3$	0.407	62.7

Y = Yield in kg/ha/3-week period
X_1 = Rainfall in current period (0-3 weeks before harvest)
X_2 = Rainfall in previous period (3-6 weeks before harvest)
X_3 = Rainfall in penultimate period(6-9 weeks before harvest).

Table 4.8. Experiment I.

Rainfall and actual evapotranspiration estimates in mm/21 days period for 150mm soil water holding capacity. ([illegible] Ranch Athi River 1974/78).

No.	Period Date Ending	Rain(mm) 3 Week Total	Actual Evapotranspiration 3 - Week Basis 0.85 Factor		Daily Basis 0.85 Factor	
			0.85 Factor	1.00 Factor	0.85 Factor	1.00 Factor
1	12.3.74	44.9	44.9	44.9	25.3	27.4
0	2.4.74	69.3	65.3	69.3	24.3	24.1
1	23.4.74	83.4	83.4	83.4	101.9	110.0
2	14.5.74	41.6	41.6	41.6	65.3	61.0
3	4.6.74	24.6	24.6	24.6	24.8	21.6
4	25.6.74	25.0	24.9	25.0	25.2	25.2
5	16.7.74	41.3	37.6	41.3	32.2	31.0
6	6.8.74	5.7	8.8	9.7	25.2	26.8
7	27.8.74	6.0	6.7	6.0	12.1	11.5
8	17.9.74	6.5	6.5	6.5	10.8	10.7
9	8.10.74	9.1	9.1	9.1	6.1	5.4
10	29.10.74	2.1	2.1	2.1	7.4	7.2
11	18.11.74	90.5	90.5	90.5	46.6	50.5
12	10.12.74	83.4	83.4	83.4	63.6	66.1
13	31.12.74	7.7	7.7	7.7	57.3	52.7
14	21.1.75	3.1	3.1	3.1	16.9	19.7
15	11.2.75	0	0	0	3.3	2.2
16	4.3.75	4.6	4.6	4.6	3.8	3.8
17	25.3.75	63.4	63.4	63.4	43.7	46.7
18	15.4.75	3.6	3.6	3.6	16.9	15.2
19	6.5.75	75.2	75.2	75.2	54.3	64.4
20	27.5.75	85.3	85.3	85.3	62.1	67.1
21	17.6.75	41.4	41.4	41.4	63.2	61.6
22	8.7.75	0.7	0.7	0.7	19.4	17.0
23	29.7.75	13.9	13.9	13.9	12.6	11.0
24	19.8.75	4.8	4.4	4.8	10.7	10.3
25	9.9.75	0	0.4	0	4.6	3.8
26	30.9.75	40.5	40.5	40.5	9.9	10.3
27	21.10.75	48.6	48.6	48.6	60.4	63.5
28	11.11.75	15.8	15.8	15.8	25.6	24.0
29	2.12.75	113.1	95.2	110.8	66.4	62.7
30	23.12.75	48.3	66.4	50.6	76.0	78.9
31	13.1.76	11.8	11.8	11.8	31.0	27.7
32	3.2.76	0	0	0	24.8	6.7
33	24.2.76	5.0	5.0	5.0	9.2	5.3
34	16.3.76	2.4	2.4	2.4	3.6	2.9
35	6.4.76	2.7	2.7	2.7	2.4	2.2
36	27.4.76	53.2	53.2	53.2	31.1	33.9
37	18.5.76	25.5	25.5	25.5	32.3	32.3
38	8.6.76	3.0	3.0	3.0	13.6	12.4
39	29.6.76	72.0	72.0	72.0	27.5	29.7
40	20.7.76	30.0	18.9	21.9	31.4	33.1
41	10.8.76	0	5.7	4.8	19.9	19.6
42	31.8.76	5.8	6.7	6.4	15.1	13.9
43	21.9.76	16.9	21.4	19.6	26.7	25.5
44	12.10.76	6.0	6.0	6.0	12.3	10.6
45	2.11.76	0.3	0	0.3	3.0	2.3
46	23.11.76	22.7	22.7	22.7	10.7	11.5
47	14.12.76	79.1	79.1	79.1	58.6	63.0
48	4.1.77	56.0	56.0	56.0	48.5	46.3
49	25.1.77	0.6	0.6	0.6	30.2	28.3
50	15.2.77	19.7	19.7	19.7	24.4	23.2
51	8.3.77	44.4	44.4	44.4	31.7	32.7
52	29.3.77	13.8	13.8	13.8	21.8	20.8
53	19.4.77	192.7	102.2	118.9	62.3	14.6
54	10.5.77	121.1	84.1	97.9	84.1	98.1
55	31.5.77	27.5	86.2	79.6	86.2	100.7
56	21.6.77	13.5	20.7	13.5	59.8	52.3
57	12.7.77	12.5	12.5	12.5	24.8	20.9
58	2.8.77	2.5	2.2	2.5	13.8	11.8
59	23.8.77	12.0	12.3	12.0	16.1	14.6
60	13.9.77	0	0	0	5.9	4.9
61	4.10.77	2.2	2.2	2.2	2.9	2.6
62	25.10.77	5.4	5.4	5.4	1.3	1.2
63	15.11.77	125.6	96.9	112.8	47.9	55.1
64	6.12.77	118.8	87.6	101.7	87.5	100.5
65	27.12.77	55.0	92.7	76.9	91.7	89.1
66	17.1.78	9.9	14.1	9.9	54.4	43.2
67	7.2.78	53.0	53.0	53.0	53.7	52.9
68	28.2.78	119.4	50.2	56.6	28.0	30.0
69	21.3.78	50.2	101.3	117.9	100.9	109.0
70	11.4.78	193.4	100.7	117.0	100.0	114.0
71	2.5.78	94.5	98.2	114.2	98.2	114.3
72	23.5.78	30.0	75.6	43.5	75.8	85.1
73	23.5.78	0	0	0	56.3	38.0
74	4.7.78	0.9	0.7	0.8	16.7	9.6
75	25.7.78	0.3	0.4	0.4	7.9	4.1
76	15.8.78	8.0	7.2	8.0	6.5	5.0
77	5.9.78	1.8	2.7	1.8	6.5	5.0
78	26.9.78	9.5	9.5	9.5	3.4	3.1
79	17.10.78	1.8	1.8	1.8	8.1	8.0
80	28.11.78	42.6	42.6	42.6	20.5	22.2
81	28.11.78	95.7	95.7	95.7	57.3	61.4
82.	19.12.78	106.6	87.0	101.3	84.4	96.7

Table 4.9. Experiment I.
Rainfall and estimated actual evapotranspiration for 200mm soil water holding capacity 1974-78.

Units mm/21 days

No.	Period Date Ending	Rainfall 3 Week Total	Actual Evapotranspiration: 3 - Week Basis, 0.86 Factor	3 - Week Basis, 1.00 Factor	Daily Basis, 0.86 Factor	Daily Basis, 1.00 Factor
1	13.3.74	44.9	44.9	44.9	21.6	23.4
0	2.4.74	69.3	69.3	69.3	23.6	24.0
1	23.4.74	83.4	83.4	83.4	94.0	100.4
2	14.5.74	41.6	41.2	41.6	64.2	63.6
3	4.6.74	24.6	21.6	24.6	29.4	26.6
4	25.6.74	25.0	21.2	25.6	26.2	25.6
5	16.7.74	41.3	33.7	35.9	31.3	31.4
6	6.8.74	5.7	14.8	12.2	26.4	27.6
7	27.8.74	6.0	10.8	8.9	16.2	8.9
8	17.9.74	6.5	7.4	6.6	12.5	11.7
9	8.10.74	9.1	9.3	9.1	7.5	6.4
10	29.10.74	2.1	2.9	2.1	8.1	7.5
11	18.11.74	90.5	90.5	90.5	39.2	42.3
12	10.12.74	83.4	82.2	83.4	59.6	62.3
13	31.12.74	7.7	8.9	7.7	58.4	58.4
14	21.1.75	3.1	3.1	3.1	23.2	19.6
15	11.2.75	0	0	0	7.0	4.7
16	4.3.75	4.6	4.6	4.6	4.8	4.3
17	25.3.75	63.4	63.4	63.4	37.8	41.1
18	15.4.75	3.6	3.6	3.6	19.4	18.1
19	6.5.75	75.2	67.1	75.2	48.2	51.3
20	27.5.75	85.3	80.8	85.3	58.5	61.2
21	17.6.75	41.4	47.4	41.4	60.5	61.1
22	8.7.75	0.7	6.2	0.7	25.5	22.4
23	29.7.75	13.9	12.1	13.9	16.1	14.4
24	19.8.75	4.8	6.0	4.8	12.6	11.4
25	9.9.75	0	2.2	0	7.1	5.8
26	30.9.75	40.5	36.7	40.5	9.6	9.6
27	21.10.75	48.6	52.9	48.6	53.9	57.2
28	11.11.75	15.8	15.8	15.8	28.1	27.0
29	2.12.75	113.1	95.2	110.9	59.7	63.4
30	23.12.75	48.3	66.4	50.5	73.8	75.6
31	31.1.76	11.8	11.8	11.8	37.7	33.8
32	3.2.76	0	0	0	14.6	11.2
33	24.2.76	5.0	5.0	5.0	7.7	6.7
34	16.3.76	2.4	2.4	2.4	4.0	3.5
35	6.4.76	2.7	2.7	2.7	2.7	7.3
36	27.4.76	53.2	53.2	53.2	25.7	28.6
37	18.5.76	25.5	24.3	25.5	31.0	31.7
38	8.6.76	3.0	3.9	3.0	16.0	14.9
39	29.6.76	72.0	62.3	72.0	24.6	25.9
40	20.7.76	30.0	18.9	16.4	28.0	29.9
41	10.8.76	0	8.1	6.1	19.3	19.7
42	31.8.76	5.8	5.8	7.0	8.4	15.6
43	21.9.76	16.9	25.3	23.2	20.8	20.0
44	12.10.76	6.0	6.0	6.0	12.8	14.2
45	2.11.76	0.3	0.3	0.3	4.4	3.9
46	23.11.76	32.7	22.7	22.7	9.9	10.4
47	14.12.76	79.1	79.1	79.1	50.2	54.7
48	4.1.77	56.0	53.6	56.0	47.5	40.3
49	25.1.77	0.6	2.9	0.6	33.0	31.6
50	15.2.77	19.7	19.8	19.7	27.3	25.5
51	8.3.77	44.4	44.4	44.4	30.3	27.9
52	29.3.77	13.8	13.8	13.8	23.8	20.8
53	19.4.77	192.7	102.2	118.9	61.2	69.1
54	10.5.77	121.1	84.1	97.9	84.1	96.1
55	31.5.77	27.5	86.2	100.6	86.2	99.9
56	21.6.77	13.5	62.3	37.4	75.0	58.7
57	21.6.77	12.5	15.7	10.9	36.1	26.8
58	2.8.77	2.5	5.1	4.1	20.2	15.3
59	23.8.77	12.0	14.6	12.0	21.0	17.1
60	13.9.77	0	0	0	9.4	6.8
61	4.10.77	2.2	2.2	2.2	4.4	3.4
62	25.10.77	5.4	5.4	5.4	2.4	1.9
63	15.11.77	125.6	96.9	112.2	42.6	48.0
64	6.12.77	110.8	87.6	101.6	85.3	97.9
65	27.12.77	55.0	92.7	77.6	85.3	82.5
66	17.1.78	9.9	24.1	9.9	56.4	50.0
67	7.2.78	53.0	48.2	53.0	52.7	51.7
68	28.2.78	118.4	50.2	58.6	29.9	31.6
69	21.3.78	50.2	101.3	111.0	97.4	101.9
70	11.4.78	193.4	100.7	117.0	99.4	110.1
71	2.5.78	94.5	98.2	114.2	98.2	114.3
72	23.5.78	30.0	75.8	96.4	75.8	84.7
73	13.6.78	0	39.1	9.5	67.0	45.1
74	4.7.78	0.9	6.8	1.2	26.0	15.0
75	25.7.78	0.3	3.1	0.6	15.1	7.8
76	15.8.78	8.0	6.7	6.4	10.8	6.6
77	5.9.78	1.8	4.1	3.5	9.2	6.7
78	26.9.78	9.5	10.0	9.7	6.3	3.5
79	17.10.78	1.8	2.3	1.8	8.1	8.3
80	7.11.78	42.6	42.1	42.6	18.0	19.0
81	28.11.78	95.7	95.4	95.7	42.8	54.2
82	19.12.78	106.6	27.0	101.1	82.8	94.4

The AE values were used in the computation of the regressions shown in Tables 4.10., 4.11. and 4.12. for the 5cm, 10cm and 15cm height of cutting respectively.

Table 4.13 tabulates the coefficient of determination (R^2) for each of the regressions for the 15 cutting treatments with each of the eight values for AE. The R^2 values for yield against rainfall are presented in the table for comparison.

In general the R^2 values for the daily basis AE calculations are slightly higher than those from the three-weekly based AE values. However, when the amount of computation required is considered there appears to be relatively little advantage as indicated by the R^2 in using AE values in preference to the much more easily derivable rainfall values. In 11 of the 15 treatments the R^2 for the regression with yield is highest with rainfall rather than with any of the AE values. This point is discussed further below in section 5.1.

Table 4.10. Experiment 1

Regressions of dry matter yield against estimated actual evapotranspiration for 5cm cutting height

Units A.E. - mm/21 days Y - kg/ha/21 days

Frequency of cutting in weeks	Time Basis	Crop Factor	Soil Water Holding Capacity mm	Regression Equation	Coefficient of Determination
3	3 wk	0.86	200	$Y = -66.28 + 1.87x_1 + 2.10x_2 + 0.30x_3$	0.367
	"	0.86	150	$Y = -64.96 + 1.84x_1 + 2.02x_2 + 0.78x_3$	0.377
	"	1.00	200	$Y = -62.14 + 1.88x_1 + 1.80x_2 + 0.66x_3$	0.398
	"	1.00	150	$Y = -68.51 + 1.98x_1 + 1.81x_2 + 0.86x_3$	[illegible]
	Daily	0.86	200	$Y = -83.16 + 4.66x_1 + 0.31x_2 + 0.01x_3$	0.410
	"	0.86	150	$Y = -81.50 + 3.85x_1 + 1.07x_2 + 0.04x_3$	[illegible]
	"	1.00	200	$Y = -81.00 + 4.26x_1 + 0.40x_2 + 0.20x_3$	0.454
	"	1.00	150	$Y = -73.34 + 3.51x_1 + 0.91x_2 + 0.20x_3$	[illegible]
6	3 wk	0.86	200	$Y = -122.61 + 4.02x_1 + 2.69x_2 + 1.12x_3$	0.470
	"	0.86	150	$Y = -117.08 + 3.92x_1 + 2.62x_2 + 1.41x_3$	0.496
	"	1.00	200	$Y = -116.34 + 3.79x_1 + 2.59x_2 + 1.18x_3$	0.547
	"	1.00	150	$Y = -121.68 + 3.78x_1 + 2.72x_2 + 1.43x_3$	0.570
	Daily	0.86	200	$Y = -142.57 + 7.43x_1 + 1.26x_2 + 0.31x_3$	0.541
	"	0.86	150	$Y = -139.46 + 6.60x_1 + 1.62x_2 + 0.11x_3$	[illegible]
	"	1.00	200	$Y = -140.50 + 7.03x_1 + 1.01x_2 + 0.17x_3$	0.594
	"	1.00	150	$Y = -126.67 + 5.99x_1 + 1.57x_2 + 0.24x_3$	0.570
9	3 wk	0.86	200	$Y = -103.67 + 3.69x_1 + 2.30x_2 + 1.07x_3$	0.453
	"	0.86	150	$Y = -97.24 + 3.46x_1 + 2.38x_2 + 1.30x_3$	0.454
	"	1.00	200	$Y = -97.00 + 3.37x_1 + 2.16x_2 + 1.23x_3$	0.493
	"	1.00	150	$Y = -104.78 + 3.44x_1 + 2.30x_2 + 1.40x_3$	[illegible]
	Daily	0.86	200	$Y = -122.65 + 6.67x_1 + 1.24x_2 + 0.33x_3$	0.508
	"	0.86	150	$Y = -118.25 + 5.86x_1 + 1.62x_2 + 0.03x_3$	0.494
	"	1.00	200	$Y = -117.40 + 6.13x_1 + 1.04x_2 + 0.19x_3$	0.534
	"	1.00	150	$Y = -104.98 + 5.19x_1 + 1.59x_2 + 0.19x_3$	0.515
12	3 wk	0.86	200	$Y = -39.26 + 2.36x_1 + 1.16x_2 + 0.81x_3$	0.520
	"	0.86	150	$Y = -33.67 + 2.16x_1 + 1.25x_2 + 0.95x_3$	0.517
	"	1.00	200	$Y = -32.95 + 2.16x_1 + 1.11x_2 + 0.96x_3$	0.564
	"	1.00	150	$Y = -35.06 + 2.17x_1 + 1.10x_2 + 1.05x_3$	0.578
	Daily	0.86	200	$Y = -54.45 + 4.13x_1 + 0.10x_2 + 0.56x_3$	0.555
	"	0.86	150	$Y = -50.48 + 3.55x_1 + 0.50x_2 + 0.64x_3$	0.536
	"	1.00	200	$Y = -49.44 + 3.74x_1 + 0.10x_2 + 0.75x_3$	0.578
	"	1.00	150	$Y = -39.89 + 3.12x_1 + 0.56x_2 + 0.63x_3$	0.553
15	3 wk	0.86	200	$Y = -31.79 + 2.23x_1 + 0.90x_2 + 1.44x_3$	0.526
	"	0.86	150	$Y = -21.94 + 1.97x_1 + 0.99x_2 + 1.49x_3$	0.496
	"	1.00	200	$Y = -21.52 + 1.98x_1 + 0.88x_2 + 1.36x_3$	0.549
	"	1.00	150	$Y = -19.58 + 1.94x_1 + 0.62x_2 + 1.53x_3$	0.533
	Daily	0.86	200	$Y = -60.49 + 3.93x_1 + 0.13x_2 + 1.69x_3$	0.506
	"	0.86	150	$Y = -52.35 + 3.34x_1 + 0.29x_2 + 1.55x_3$	0.560
	"	1.00	200	$Y = -51.10 + 3.48x_1 + 0.07x_2 + 1.65x_3$	0.496
	"	1.00	150	$Y = -38.55 + 2.89x_1 + 0.37x_2 + 1.43x_3$	0.564

Y = Yield of herbage in kg/ha/21 days

X_1 = A.E. estimate in Present (0-3 weeks) period before cutting

X_2 = A.E. estimate in Previous (3-6 weeks) period before cutting

X_3 = A.E. estimate in Penultimate (6-9 weeks) period before cutting

Table 4.11. Experiment I.

Regressions of dry matter yield against estimated actual evapotranspiration for 10cm cutting height.

Units A.E. = mm/21 days Y - kg/ha/21 days.

Frequency of Cutting in Weeks	Time Basis	Crop Factor	Soil Water Holding Capacity mm	Regression Equations	Coefficient of Determination
3	3 wk	0.86	200	$Y = -20.09 + 0.75x_1 + 0.91x_2 + 0.73x_3$	0.337
	"	0.86	150	$Y = -19.44 + 0.75x_1 + 0.90x_2 + 0.81x_3$	0.356
	"	1.00	200	$Y = -16.36 + 0.60x_1 + 0.94x_2 + 0.72x_3$	0.371
	"	1.00	150	$Y = -19.07 + 0.62x_1 + 0.93x_2 + 0.85x_3$	0.401
	Daily	0.86	200	$Y = -29.69 + 1.52x_1 + 1.04x_2 + 0.11x_3$	0.366
	"	0.86	150	$Y = -30.07 + 1.38x_1 + 1.01x_2 + 0.30x_3$	0.375
	"	1.00	200	$Y = -25.83 + 1.28x_1 + 1.17x_2 + 0.09x_3$	0.399
	"	1.00	150	$Y = -23.59 + 1.13x_1 + 1.05x_2 + 0.27x_3$	0.391
6	3 wk	0.86	200	$Y = -51.25 + 2.06x_1 + 1.26x_2 + 0.82x_3$	0.445
	"	0.86	150	$Y = -47.00 + 1.94x_1 + 1.34x_2 + 0.91x_3$	0.449
	"	1.00	200	$Y = -44.67 + 1.84x_1 + 1.29x_2 + 0.81x_3$	0.476
	"	1.00	150	$Y = -48.31 + 1.89x_1 + 1.32x_2 + 0.96x_3$	0.507
	Daily	0.86	200	$Y = -67.40 + 3.85x_1 + 0.51x_2 + 0.26x_3$	0.498
	"	0.86	150	$Y = -65.11 + 3.42x_1 + 0.73x_2 + 0.44x_3$	0.491
	"	1.00	200	$Y = -61.21 + 3.47x_1 + 0.50x_2 + 0.44x_3$	0.514
	"	1.00	150	$Y = -53.23 + 2.95x_1 + 0.82x_2 + 0.39x_3$	0.490
9	3 wk	0.86	200	$Y = -36.90 + 1.84x_1 + 0.92x_2 + 0.62x_3$	0.395
	"	0.86	150	$Y = -34.69 + 1.74x_1 + 0.97x_2 + 0.62x_3$	0.402
	"	1.00	200	$Y = -34.02 + 1.32x_1 + 0.91x_2 + 0.53x_3$	0.440
	"	1.00	150	$Y = -38.06 + 1.75x_1 + 0.96x_2 + 0.65x_3$	0.472
	Daily	0.86	200	$Y = -46.94 + 3.12x_1 + 0.53x_2 + 0.09x_3$	0.444
	"	0.86	150	$Y = -45.08 + 2.75x_1 + 0.70x_2 + 0.08x_3$	0.432
	"	1.00	200	$Y = -43.33 + 2.89x_1 + 0.41x_2 + 0.11x_3$	0.466
	"	1.00	150	$Y = -37.69 + 2.46x_1 + 0.67x_2 + 0.10x_3$	0.453
12	3 wk	0.86	200	$Y = -37.47 + 2.23x_1 + 0.93x_2 + 0.85x_3$	0.506
	"	0.86	150	$Y = -30.82 + 2.05x_1 + 1.03x_2 + 0.92x_3$	0.489
	"	1.00	200	$Y = -31.27 + 2.07x_1 + 0.92x_2 + 0.83x_3$	0.541
	"	1.00	150	$Y = -32.39 + 2.06x_1 + 0.91x_2 + 1.00x_3$	0.550
	Daily	0.86	200	$Y = -51.95 + 3.76x_1 + 0.06x_2 + 0.63x_3$	0.529
	"	0.86	150	$Y = -46.99 + 3.22x_1 + 0.44x_2 + 0.68x_3$	0.506
	"	1.00	200	$Y = -46.49 + 3.39x_1 + 0.11x_2 + 0.76x_3$	0.548
	"	1.00	150	$Y = -32.39 + 2.06x_1 + 0.91x_2 + 1.00x_3$	0.550
15	3 wk	0.86	200	$Y = -14.55 + 1.56x_1 + 0.47x_2 + 0.96x_3$	0.464
	"	0.86	150	$Y = -8.76 + 1.40x_1 + 0.54x_2 + 0.98x_3$	0.440
	"	1.00	200	$Y = -7.43 + 1.39x_1 + 0.48x_2 + 0.88x_3$	0.475
	"	1.00	150	$Y = -7.04 + 1.38x_1 + 0.45x_2 + 0.99x_3$	0.475
	Daily	0.86	200	$Y = -34.33 + 2.70x_1 + 0.32x_2 + 1.16x_3$	0.522
	"	0.86	150	$Y = -28.93 + 2.31x_1 - 0.13x_2 + 1.12x_3$	0.497
	"	1.00	200	$Y = -27.29 + 2.40x_1 - 0.26x_2 + 1.18x_3$	0.522
	"	1.00	150	$Y = -19.02 + 2.01x_1 + 0.06x_2 + 1.00x_3$	0.495

Y = Yield of herbage in kg/ha/21 days

X_1 = A.E. estimate in Present (0-3weeks) period before cutting

X_2 = A.E. estimate in Previous(3-6weeks) " " "

X_3 = A.E. estimate in Penultimate(6-9weeks) " " "

Table 4.12. Experiment I.

Regressions of dry matter yield against estimated actual evapotranspiration for 15cm cutting height.

Units A.E. = mm/21 days Y = kg/ha/21 days.

Frequency of cutting in weeks	Time Basis	Crop Factor	Soil Water Holding Capacity mm	Regression Equations	Coefficient of Determination
	3 wk	0.86	200	$Y = 6.77 + 0.49x_1 + 0.72x_2 + 0.30x_3$	0.229
	"	0.86	150	$Y = 7.79 + 0.46x_1 + 0.72x_2 + 0.34x_3$	0.232
	"	1.00	200	$Y = 9.55 + 0.38x_1 + 0.72x_2 + 0.30x_3$	0.246
	"	1.00	150	$Y = 7.44 + 0.39x_1 + 0.36x_2 + 0.35x_3$	0.272
3	Daily	0.86	200	$Y = 5.00 + 1.17x_1 + 0.88x_2 + 0.52x_3$	0.297
	"	0.86	150	$Y = 4.47 + 1.09x_1 + 0.79x_2 - 0.32x_3$	0.288
	"	1.00	200	$Y = 8.18 + 0.97x_1 + 0.92x_2 + 0.45x_3$	0.303
	"	1.00	150	$Y = 8.06 + 0.91x_1 + 0.78x_2 - 0.25x_3$	0.292
	3 wk	0.86	200	$Y = -9.59 + 0.97x_1 + 0.77x_2 + 0.21x_3$	0.493
	"	0.86	150	$Y = -8.53 + 0.93x_1 + 0.77x_2 + 0.29x_3$	0.501
	"	1.00	200	$Y = -7.33 + 0.87x_1 + 0.76x_2 + 0.23x_3$	0.536
	"	1.00	150	$Y = -9.22 + 0.88x_1 + 0.79x_2 + 0.31x_3$	0.567
6	Daily	0.86	200	$Y = -12.77 + 1.91x_1 + 0.38x_2 + 0.26x_3$	0.556
	"	0.86	150	$Y = -12.73 + 1.70x_1 + 0.46x_2 - 0.11x_3$	0.54[illegible]
	"	1.00	200	$Y = -11.62 + 1.74x_1 + 0.35x_2 - 0.11x_3$	0.566
	"	1.00	150	$Y = -9.34 + 1.49x_1 + 0.47x_2 - 0.05x_3$	0.567
	3 wk	0.86	200	$Y = -18.11 + 1.30x_1 + 0.85x_2 + 0.48x_3$	0.50[illegible]
	"	0.86	150	$Y = -12.82 + 1.16x_1 + 0.85x_2 + 0.56x_3$	0.478
	"	1.00	200	$Y = -13.87 + 1.10x_1 + 0.84x_2 + 0.54x_3$	0.524
	"	1.00	150	$Y = -12.93 + 1.08x_1 + 0.82x_2 + 0.62x_3$	0.525
9	Daily	0.86	200	$Y = -21.48 + 2.20x_1 + 0.68x_2 - 0.16x_3$	0.535
	"	0.86	150	$Y = -18.98 + 1.93x_1 + 0.71x_2 + 0.02x_3$	0.505
	"	1.00	200	$Y = -18.51 + 1.90x_1 + 0.63x_2 + 0.07x_3$	0.534
	"	1.00	150	$Y = -13.81 + 1.63x_1 + 0.72x_2 + 0.11x_3$	0.512
	3 wk	0.86	200	$Y = -7.36 + 1.32x_1 + 0.46x_2 + 0.49x_3$	0.379
	"	0.86	150	$Y = -1.27 + 1.20x_1 + 0.52x_2 + 0.45x_3$	0.358
	"	1.00	200	$Y = -3.63 + 1.16x_1 + 0.46x_2 + 0.48x_3$	0.417
	"	1.00	150	$Y = -4.57 + 1.21x_1 + 0.48x_2 + 0.55x_3$	0.415
12	Daily	0.86	200	$Y = -16.01 + 2.1$[illegible]$x_1 + 0.03x_2 + 0.36x_3$	0.297
	"	0.86	150	$Y = -12.65 + 1.80x_1 + 0.18x_2 + 0.40x_3$	0.374
	"	1.00	200	$Y = -12.29 + 1.93x_1 + 0.03x_2 + 0.43x_3$	0.406
	"	1.00	150	$Y = -7.02 + 1.65x_1 + 0.33x_2 + 0.35x_3$	0.39[illegible]
	3 wk	0.86	200	$Y = 7.17 + 0.93x_1 + 0.74x_2 + 0.40x_3$	0.364
	"	0.86	150	$Y = 10.67 + 0.84x_1 + 0.31x_2 + 0.37x_3$	0.352
	"	1.00	200	$Y = 10.47 + 0.84x_1 + 0.26x_2 + 0.32x_3$	0.276
	"	1.00	150	$Y = 9.40 + 0.85x_1 + 0.25x_2 + 0.44x_3$	0.392
15	Daily	0.86	200	$Y = 0.12 + 1.54x_1 + 0.20x_2 + 0.43x_3$	0.381
	"	0.86	150	$Y = 1.94 + 1.33x_1 - 0.02x_2 + 0.42x_3$	0.371
	"	1.00	200	$Y = 3.38 + 1.39x_1 - 0.15x_2 + 0.45x_3$	0.385
	"	1.00	150	$Y = 7.07 + 1.15x_1 + 0.03x_2 + 0.37x_3$	0.369

Y = Yield of herbage in kg/ha/21 days

x_1 = A.E. estimate in Present (0-3 weeks) period before cutting

x_2 = A.E. estimate in Previous (3-6 weeks) period before cutting

x_3 = A.E. estimate in Penultimate (6-9 weeks) period before cutting.

Table 4.13. Experiment I.

Coefficients of determination for the regressions of yield of forage dry matter against estimated actual evapotranspiration and rainfall.

Treatment		Water Holding Capacity	150mm			200mm				Rain-fall	Mean Yield
Height cm	Frequency wks	Crop Factor 0.86		1.00		0.86		1.00			kg/ha/21d.
		Daily	Three wk	Daily	Three wk	Daily	Three wk	Daily	Three wk		
5	3	0.412	0.377	0.433	0.431	0.420	0.367	0.454	0.398	0.451	93.05
	6	0.531	0.396	0.570	0.571	0.541	0.490	0.594	0.547	0.616	153.94
	9	0.494	0.454	0.515	0.528	0.508	0.453	0.534	0.493	0.541	145.85
	12	0.538	0.517	0.553	0.578	0.555	0.526	0.578	0.564	0.604	114.78
	15	0.560	0.498	0.564	0.533	0.588	0.528	0.595	0.544	0.541	129.05
10	3	0.375	0.356	0.391	0.401	0.368	0.337	0.399	0.344	0.453	64.07
	6	0.491	0.448	0.498	0.507	0.498	0.445	0.514	0.475	0.523	96.16
	9	0.432	0.402	0.453	0.472	0.444	0.395	0.466	0.440	0.503	78.78
	12	0.506	0.489	0.523	0.550	0.529	0.508	0.548	0.544	0.585	105.41
	15	0.497	0.440	0.495	0.475	0.522	0.464	0.522	0.475	0.472	90.73
15	3	0.288	0.237	0.293	0.272	0.297	0.229	0.303	0.246	0.277	59.62
	6	0.544	0.501	0.567	0.567	0.556	0.493	0.586	0.536	0.602	59.42
	9	0.505	0.478	0.512	0.525	0.535	0.510	0.534	0.534	0.535	74.55
	12	0.376	0.358	0.392	0.415	0.397	0.379	0.408	0.407	0.411	73.09
	15	0.371	0.352	0.369	0.392	0.383	0.364	0.385	0.378	0.407	62.72

4.2. Experiment 2.

Grazing Trial

4.2.1. Liveweight Changes

The weight changes for all the animals used in this experiment are presented on the basis of three-week periods between weighings. The actual three-week periods used were chosen to be as close as possible for the first four series of animals, to the periods used in Experiment I. As the weighings were conducted on Mondays and the harvests in Experiment 2 were made on Tuesdays the coincidence of the three-week periods was almost exact. For the series 5 and 6 animals the three-week periods used were a continuation of the pattern established in the previous four series.

For all six series of animals a cyclical variation in animal performance was observed (Tables 4.14., 4.17., 4.20., 4.23., 4.26. and 4.29.). The cycles were not regular but were associated with the pattern of rainfall as indicated in the last column of each table. Confirmation of this is given in the six tables of analysis of variance (Tables 4.15., 4.18., 4.21., 4.24., 4.27. and 4.30), where the effect of period on the liveweight changes was highly significant.

The overall effect of stocking rate on liveweight change was not significant at the P=0.05 level by the F or variance ratio test. The Duncan (1955) multiple range test also did not reveal any consistent pattern in the effects of stocking rate on per animal performance. For four out of the six series the stocking rate x period interaction was significant at P= 0.05, while for the other two series the interaction was significant at P= 0.1. Possible reasons for the lack of a consistent stocking rate effect are suggested in Sections 4.2.2. and 4.2.3. while a comparison with results from other similar studies is discussed in Chapter 5 (Section 5.2.). A notable feature was that even at the highest stocking rate (2ha/hd) a liveweight gain of 337g/hd/day was recorded over the whole of the six series of animals, compared with 382g/hd/day for the lowest stocking rate (5ha/hd). The actual level of average daily gain for each series of animals was not directly relatable to the overall average rainfall. This point is discussed further in Section 5.2.

For each series of animals, regressions of liveweight change against rainfall were calculated as outlined in Section 3.3.3.1. These regressions are presented in Tables 4.16., 4.19., 4.22., 4.25., 4.28.

Table 4.14. Experiment 2.

Liveweight gains of the animals under the four different stocking rates for the three week observation periods for Series I. Animals.

Units Liveweight gain-g/animal/day Rainfall mm/21 days

Observation Number	Date	Stocking Rate ha.hd 2	3	4	5	Mean	Rain-fall
1	24.6.74	+ 881	+ 524	+ 881	+ 881	+ 791	29.7
2	15.7.74	+ 238	+ 524	+ 619	+ 548	+ 494	41.3
3	5.8.74	+ 857	+ 90	+ 952	+ 500	+ 756	5.7
4	26.8.74	- 286	- 48	+ 190	+ 167	+ 6	6.0
5	16.9.74	- 24	- 500	- 857	- 500	- 494	6.5
6	7.10.74	- 143	+ 95	+ 952	+ 48	+ 238	9.1
7	28.10.74	+1671	+ 95	+ 48	+ 190	+ 125	2.1
8	18.11.74	- 714	- 690	- 833	- 476	- 679	80.0
9	9.12.74	+1333	+1095	+1500	+1310	+1310	93.9
10	30.12.74	+ 619	+ 929	+1071	+ 786	+ 851	9.9
11	20.1.75	+ 429	+ 452	+ 619	+ 619	+ 566	3.1
Mean		+ 305	+ 288	+ 468	+ 392	+ 363	26.1

+ Results are means of 4 animals per group.

Table 4.15. Experiment 2.

Analysis of variance for liveweight gains of Series I animals.

Component	Degrees of Freedom	Sum of Squares	Mean Square		F Ratio
Animals within group	12	156.64	13.05		n.a.
Stocking Rate	3	402.43	134.14		n.s.
Periods	10	24536.00	2453.6		35.02
Periods x Stocking Rate	30	2715.82	90.53		n.s.
Error	117	8198.26	70.07	S.E.=	8.37
Total	175	36019.25			

Overall mean = 7.625 S.E. = 8.37 C. of V. = 110%

Standard Error difference between Stocking Rate =1.26(LSD=P=0.05=2.37

Standard Error difference between Periods =2.09(LSD=P=0.05=4.10

Standard Error difference between Periods x Stocking Rate =4.19(LSD=P=0.05=8.20

Treatment effect Summary.

	Stocking Rate ha/head 2	3	4	5	L.S.D. P=0.05
Liveweight Gain kg/21 days/head	6.41	6.05	9.82	8.23	2.47
Liveweight Gain g/day/head	305	288	468	392	118
	a	a	a	a	

Means with the same subscript letter do not differ significantly at the P=0.05 level (Duncan, 1955).

Table 4.16. Experiment 2.

Regressions of Liveweight gain against rainfall for Series I animals.

Units liveweight gain - g/animal/day. Rainfall mm/21 days

Stocking Rate ha/animal		Coefficient Determination	Mean L.W.G.
2	L.W.G. = $-44.81 - 1.49x_1 + 14.05x_2 - 0.19x_3$	0.530	305
3	L.W.G. = $-150.57 - 1.57x_1 + 14.19x_2 + 2.62x_3$	0.702	288
4	L.W.G. = $7.90 - 2.43x_1 + 16.43x_2 + 2.00x_3$	0.477	468
5	L.W.G. = $-152.71 + 2.57x_1 + 10.81x_2 + 4.90x_3$	0.584	370
Mean	L.W.G. = $-85.24 - 1.29x_1 + 13.19x_2 + 3.00x_3$	0.594	350

X_1 = Rainfall in the present (0-3 wks) period up to

X_2 = Rainfall in the previous (3-6 wks) period up to weighing

X_3 = Rainfall in the penultimate (6-9 wks) period up to weighing.

Table 4.17. Experiment 2.

Liveweight gains * of the animals under the four stocking rates for the three week observation period for Series II animals.

Units Liveweight gains - g/animal/day Rainfall - mm/21 days

Observation Number	Date	Stocking Rate ha/hd 2	3	4	5	Mean	Rainfall
1	3.3.75	-24	+405	+119	+548	+262	4.6
2	24.3.75	+95	-24	-95	-167	-48	63.4
3	14.4.75	+452	+690	+357	+452	+500	0
4	5.5.75	+357	+214	+238	+286	+274	78.8
5	26.5.75	+738	+690	+595	+762	+697	85.3
6	16.6.75	+1119	+1119	+1190	+1262	+1173	41.4
7	7.7.75	+952	+976	+1143	+1143	+1054	0.7
8	28.7.75	+619	+190	+214	+214	+190	13.9
9	18.8.75	+476	+167	+214	+690	+387	0
10	8.9.75	-1595	-1214	-976	-1167	-1238	0
11	29.9.75	+738	+929	+452	+667	+792	40.5
12	20.10.75	+310	+500	+619	+381	+452	48.6
13	10.11.75	+810	+1167	+524	+833	+714	15.8
14	1.12.75	-333	-333	-119	-500	-321	113.1
15	27.12.75	+1810	+1286	+1381	+1738	+1744	48.3
16	12.1.76	+429	+786	+786	+786	+697	11.8
17	2.2.76	+214	+71	+95	-48	+83	0
18	25.2.76	+523	+357	+357	+667	+476	5.0
19	15.3.76	+143	+71	+238	+214	+167	2.4
20	5.4.76	+71	+310	-48	-286	+12	2.7
21	26.4.76	-1381	-833	-905	-714	-959	56.7
22	17.5.76	+1548	+1071	+1095	+1000	+1179	25.2
23	7.6.76	+786	+857	+833	+1048	+857	3.3
24	28.6.76	-929	-286	-357	-119	-423	27.0
25	19.7.76	+690	+571	+381	+333	+494	30.0
26	9.8.76	+595	+167	+476	+929	+542	0
27	30.8.76	+548	+143	+738	+500	+482	6.0
Mean		+344	+372	+354	+424	+373	28.5

* Results are means of 4 animals per group.

Table 4.18. Experiment 2.

Analysis of variance for liveweight gains of Series II animals.

Component	Degrees of Freedom	Sum Squares	Mean Square	F
Animals within groups	12	170.15	14.18	n.s.
Stocking Rate	3	159.63	53.21	n.s.
Periods	26	69939.02	2687.62	95.07 ***
Periods x Stocking Rate	73	5551.87	71.18	2.52 ***
Error	312	8825.85	28.29	S.E. = 5.32
Total	431	84646.52		

Overall Mean = 7.852 S.E. = 5.32 C.of V. = 68%

Standard Error difference between Stocking Rates = 0.51(L.S.D. P=0.05=1.0(

Standard Error difference between Periods = 1.33(L.S.D.P=0.05=2.61)

Standard Error difference between Periods x Stocking Rates = 2.66(L.S.D.P=0.05=5.21)

Treatment Effect Summary.

	Stocking Rate ha.hd 2	3	4	5	L.S.D. P=0.05
Liveweight gain kg/hd/21 day	7.22	7.81	7.43	8.90	1.00
Liveweight gain g/hd/day	344	372	354	424	48
	a	a	a	b	

Means with the same subscript letter do not differ significantly at the P=o.o5 level (Duncan, 1955).

Table 4.19. Experiment 2.

Regressions of liveweight gain against rainfall for Series II animals.

Units liveweight gain - g/animal/day Rainfall - mm/21 days

Stocking Rate ha/animal	Regression Equations	Coefficient of determination	Mean L.W.G.
2	$L.W.G. = 2.38 - 4.90x_1 + 15.43x_2 + 1.62x_3$	0.467	344
3	$L.W.G. = 72.67 - 3.81x_1 + 12.48x_2 + 1.95x_3$	0.497	372
4	$L.W.G. = .\ 7.57 - 3.52x_1 + 11.48x_2 + 4.29x_3$	0.551	354
5	$L.W.G. = 101.86 - 5.05x_1 + 12.71x_2 + 3.71x_3$	0.510	424
Mean	$L.W.G. = 43.71 - 4.14x_1 + 13.48x_2 + 2.57x_3$	0.528	379

X_1 = Rainfall in the present (0-3 wks) period up to weighing

X_2 = Rainfall in the previous (3-6 wks) period up to weighing

X_3 = Rainfall in the penultimate (6-9 wks) period up to weighing.

Table 4.20. Experiment 2.

Liveweight gains * of the animals under the four different stocking rates for the three week observation periods for Series III animal

Units Liveweight gain - g/animal/day Rainfall - mm/21 days.

Observation Number	Date	Stocking Rate ha/hd 2	3	4	5	Mean	Rainfall mm
1	11.10.76	+238	+500	+500	+524	+440	6.0
2	1.11.76	+190	+166	+214	+286	+214	0.3
3	22.11.76	-643	0	-571	-548	-429	22.7
4	13.12.76	-619	-119	-214	-548	-316	88.8
5	3.1.77	+1476	+1143	+1500	+1357	+1369	55.4
6	24.1.77	+1548	+1429	+1429	+1571	+1494	1.2
7	14.2.77	-190	+359	+316	+476	+238	19.7
8	7.3.77	-571	-95	-119	-190	-244	44.4
9	28.3.77	+524	+905	+929	+1286	+911	13.8
10	18.4.77	-1048	-1238	-1095	-1048	-1107	183.8
11	9.5.77	+1476	+643	+762	+786	+917	124.7
12	30.5.77	+1119	+333	+762	+905	+780	32.8
13	20.6.77	+1048	+1452	+1190	+738	+1107	13.5
14	11.7.77	+1214	+1071	+1119	+1190	+1149	12.5
Mean		+412	+468	+480	+502	+466	44.3

* Results are for the means of 4 animals per group.

Table 4.21. Experiment 2.

Analysis of variance for liveweight gains for Series III animals.

Component	Degrees of Freedom	Sum of Squares	Mean Squares	F Ratio
Animals within groups	12	463.14	38.60	n.s.
Stocking rate	3	112.79	37.60	n.s.
Periods	13	54346.86	4180.53	112.11 ***
Periods x Stocking rate	39	3995.71	102.45	2.75 ***
Error	153	5704.86	37.29	S.E. = 6.11
Total	223	64623.36		

Overall mean = 9.80 S.E. = 6.11 C. of V. = 62%

Standard Error difference between Stocking Rates = 0.82(LSD P=0.05=1.60
Standard Error difference between Periods = 1.53(LSD P=0.05=2.99)
Stamdadd Error difference between Periods x Stocking Rates= 3.05(LSD P=0.05=5.98)

Treatment Effect Summary.

	Stocking Rate ha/hd 2	3	4	5	LSD P=0.05
Liveweight gain kg/hd/21 days	8.65	9.83	10.08	10.54	0.71
Liveweight gain g/hd/day	412	468	480	502	34
	a	b	b	b	

Means with the same subscript letter do not differ significantly at the P= 0.05 level (Duncan, 1955).

Table 4.22. Experiment 2.

Regressions of liveweight gains against rainfall for Series III animals.

Units Liveweight gain - g/animal/day   Rainfall - mm/21 days

Stocking Rate ha/animal	Regressions Equations	Coefficient of determination	Mean LWG
2	L.W.G. = 153.76 - 9.14x_1 + 13.33x_2 + 1.57x_3	0.715	412
3	L.W.G. = 636.57 - 10.71x_1 + 7.00x_2 - 0.19x_3	0.640	468
4	L.W.G. = 490.90 - 10.05x_1 + 9.00x_2 - 0.67x_3	0.649	480
5	L.W.G. = 542.52 - 10.62x_1 + 9.48x_2 + 0.14x_3	0.673	502
Mean	L.W.G. = 457.90 - 10.14x_1 + 9.71x_2 + 0.57x_3	0.689	466

X_1 = Rainfall in the present (0-3 wks) period up to weighing

X_2 = Rainfall in the previous(3-6 wks) period up to weighing

X_3 = Rainfall in the penultimate(6-9 wks) period up to "

Table 4.23. Experiment 2.

Liveweight gains * of the animals under the four different stocking rates for the Series IV animals.

Units Liveweight gain - g/animal/day Rainfall mm/21 days

Observation No.	Date	Stocking Rate ha/head 2	3	4	5	Mean	Rainfall mm
1	22.8.77	+524	+667	+405	+524	+530	14.5
2	12.9.77	+48	+452	+262	+262	+256	3.8
3	3.10.77	+310	+429	-95	+167	+202	2.2
4	24.10.77	-167	0	-190	-71	-107	1.0
5	14.11.77	-810	-905	-881	-1000	-899	130.0
6	5.12.77	+1286	-1167	+1071	+1071	+1149	110.9
7	26.12.77	+786	+929	+1190	+1214	+1030	55.0
8	16.1.78	+119	+1429	+1286	+1095	+1232	28.0
9	6.2.78	+738	+738	+810	+714	+750	62.2
10	27.2.78	-310	-262	-357	-119	-262	119.4
11	20.3.78	+857	+976	+595	+667	+774	50.2
12	10.4.78	+405	+167	+833	+381	+446	115.8
13	1.5.78	+405	+667	+357	+476	+476	160.9
14	12.5.78	+690	+476	+429	+381	+494	41.5
15	12.6.78	+214	+71	-24	+405	+167	0
16	3.7.78	+548	+1167	+1000	+905	+905	0.9
17	24.7.78	+405	+524	+381	+238	+387	0.3
18	14.8.78	+310	+521	+357	+452	+411	6.0
19	4.9.78	+167	+500	+333	+286	+321	3.8
20	25.9.78	-405	-95	-190	-167	-214	1.8
21	16.10.78	+405	+24	+167	+119	+179	9.5
22	6.11.78	-1548	-952	-1167	-929	-1149	41.8
23	27.11.78	+781	+476	+357	+381	+500	85.2
24	18.12.78	+595	+405	+667	+405	+518	107.9
25	8.1.79	+833	+857	+1333	+952	+994	24.5
Mean		+327	+417	+357	+352	+364	47.0

*Results are for the means of 4 animals per group.

Table 4.24. Experiment 2.

Analysis of variance for liveweight gains of Series IV animals.

Component	Degrees of Freedom	Sum of Squares	Mean Square		F Ratio
Animals within groups	12	293.96	24.50		n.s.
Stocking rate	3	184.51	61.50		n.s.
Periods		56099.56	2337.48		62.82***
Periods x Stocking rate	72	3637.24	51.08		1.37*
Error	285	10605.04	37.21	S.E. =	6.10
Total	399	70820.31			

Overall Mean = 7.69 S.E. = 6.10 C. of V. = 79%

Standard Error difference between stocking rates =0.61(L.S.D. P=0.05=1.20)
Standard Error difference between periods =1.53(" " =2.99)
Standard Error difference between Periods x Stocking Rates =3.05(" " =5.98)

Treatment effects summary.

	Stocking rate ha/hd 2	3	4	5	LSD P=0.05
Liveweight gain kg/hd/21days	6.87	8.76	7.50	7.39	1.20
Liveweight gain g/hd/day	327	417	357	352	57
	a	b	a	a	

Table 4.25. Experiment 2.

Regressions of liveweight gains against rainfall for Series IV animals.

Units Liveweight gain - g/animal/day Rainfall - mm/21 days

Stocking Rate ha/animal	Regressions Equations	Coefficient of determination	Mean L.W.G.
2	$L.W.G. = 66.81-3.24x_1 + 7.62x_2 + 1.05x_3$	0.358	319
3	$L.W.G. = 291.33-4.86x_1 + 7.14x_2 + 0.14x_3$	0.326	407
4	$L.W.G. = 103.40-3.24x_1 + 6.10x_2 + 2.76x_3$	0.338	358
5	$L.W.G. = 149.71-4.38x_1 + 6.81x_2 + 2.33x_3$	0.446	365
Mean	$L.W.G. = 151.52-3.90x_1 + 6.86x_2 + 1.57x_3$	0.376	360

x_1 = Rainfall in the present(0.3 wks) period up to weighing

x_2 = Rainfall in the previous(3-6 wks) period up to "

x_3 = Rainfall in the penultimate(6-9 wks) period up to "

Table 4.26. Experiment 2.

Liveweight gains * of the animals under the four different stocking rates for the Series V animals.

Units Liveweight gain - g/animal/day Rainfall - mm/21days

Observation No.	Date	Stocking Rate ha/head 2	3	4	5	Means	Rainfall MM.
1	29.1.79	+643	+786	+524	+857	+826	18.5
2	19.2.79	+95	+238	+48	+95	+119	176.4
3	12.3.79	+857	+738	+714	+595	+726	7.0
4	2.4.79	+714	+762	+714	+810	+750	73.2
5	23.4.79	+429	+214	+429	+71	+286	93.2
6	14.5.79	+810	+952	+762	+595	+780	32.1
7	4.6.79	+667	+714	+548	+738	+667	26.0
8	25.6.79	+643	+595	+381	+429	+512	24.2
9	16.7.79	+429	+595	+524	+333	+470	5.5
10	6.8.79	+238	+310	+262	-214	+149	1.0
11	27.8.79	-214	+167	-357	-48	-113	2.1
12	17.9.79	-214	0	-95	0	-79	0
13	8.10.79	-714	-667	-643	-667	-673	0.5
14	29.10.79	+143	+286	+71	+357	+214	8.5
15	19.11.79	-952	-524	-500	-976	-738	102.3
16	10.12.79	+1786	+1500	+1524	+1857	+1667	2.0
17	31.12.79	+310	+571	+595	+571	+512	28.9
18	21.1.80	+738	+619	+762	+643	+690	0
19	11.2.80	-167	-143	-95	+167	-60	50.0
20	3.3.80	+619	+595	+524	+548	+571	28.6
21	24.3.80	+738	+571	+500	+643	+613	0.6
22	14.4.80	+452	+381	+476	+214	+381	48.6
23	5.5.80	-238	+71	-24	-214	-101	118.7
24	29.5.80	+1048	+405	+714	+595	+690	129.8
25	19.6.80	+1214	+1476	+1238	+1357	+1321	35.2
26	10.7.80	+905	+1190	+1095	+833	+1006	10.0
27	31.7.80	+619	+405	+357	+452	+459	0.5
28	18.8.80	-119	-143	+48	+24	-48	8.3
29	8.9.80	-214	+333	0	+190	+78	0.9
30	29.9.80	0	-48	-119	-95	-42	0
31	20.10.80	-595	-452	-405	-524	-494	9.7
32	10.11.80	-952	-429	-643	-619	-661	77.2
33	1.12.80	+1119	+1000	+1071	+1143	+1073	80.6
34	22.12.80	+1405	+1381	+1405	+1310	+1375	5.6
35	12.1.81	+690	+500	+452	+667	+578	4.2
36	2.2.81	-262	-238	-262	-286	-262	0
37	23.2.81	-48	+214	+214	+357	-77	0
Mean		+341	+405	+335	+345	+357	32.7

* Results are for the mean of 4 animals.

Table 4.27. Experiment 2.

Analysis of variance for liveweight gains of Series V animals.

Component	Degrees of Freedom	Sum of Squares	Mean Square		F Ratio
Animals within groups	12	94.54	7.88		n.s.
Stocking Rates	3	215.27	71.76		n.s.
Periods	36	81546.97	2265.19		74.76 ***
Periods x Stocking Rates	108	4052.73	37.53		n.s.
Error	433	13118.46	30.30	S.E. =	5.505
Total	591	99026.97			

Grand Mean = 7.49 S.E. 5.51 C. of V. = 74%

Standard Error difference between Periods = 1.38 (LSD P=0.05 = 270)

Standard Error difference between Stocking Rates = 0.45(LSD P=0.05=0.89

Standard Error difference between Periods x Stocking Rates = 2.75(" P=0.05=5.39)

Treatment effect summary.

	Stocking Rates ha/hd 2	3	4	5	L.S.D. P = 0.05
Liveweight gains kg/21day/hd	7.15	8.53	7.03	7.27	0.89
Liveweight gains g/day/hd	340	406	335	346	42
	a	b	a	a	

Means with the same subscript do not differ at P = 0.05 (Duncan, 1955).

Table 4.28. Experiment 2.

Regressions of liveweight gains against rainfall for Series V animals.

Units Liveweight gain - g/animal/day Rainfall - mm/21 days

Stocking Rate ha/animal	Regressions Equations	Coefficient of determination	Mean L.W.G.
2	L.W.G.= $-63.81-3.13x_1 + 9.10x_2 + 5.71x_3$	0.622	341
3	L.W.G.= $-62.67-3.01x_1 + 6.91x_2 + 5.81x_3$	0.656	406
4	L.W.G.= $-48.52-2.19x_2 + 7.71x_2 + 5.48x_3$	0.654	334
5	L.W.G.= $-10.24-3.54x_1 + 7.14x_2 + 5.95x_3$	0.576	346
Mean	L.W.G.= $-9.24-2.98x_1 + 7.67x_2 + 5.86x_3$	0.652	360

X_1 = Rainfall in the present (0-3 wks) period up to weighing
X_2 = Rainfall in the previous (3-6 wks) period up to weighing
X_3 = Rainfall in the penultimate (6-9 wks) period up to weighing.

Table 4.29. Experiment 2.

Liveweight gains * of the animals under the four different stocking rates for the Series VI animals.

Units Liveweight gain - g/animal/day Rainfall - mm/21 days

Observation No.	Date	Stocking Rate ha/hd 2	3	4	5	Mean	Rainfall
1	6.4.81	-762	-476	-524	-643	-601	221.9
2	27.4.81	+1214	+1143	+1262	+1071	+1173	110.9
3	18.5.81	+1167	+1095	+1190	+976	+1107	93.9
4	8.6.81	+1024	+762	+810	+905	+875	4.8
5	29.6.81	+929	+1167	+952	+1048	+1024	5.4
6	21.7.81	+738	+714	+619	+857	+732	0.7
7	10.8.81	+71	+286	-71	+500	+197	1.8
8	31.8.81	+381	+381	+929	+143	+340	0
9	21.9.81	-476	-452	-405	-262	-394	2.7
10	12.10.81	+48	-738	+119	+381	-48	28.2
11	2.11.81	-405	+1143	+24	+214	+244	14.2
12	23.11.81	0	+452	-214	-286	-12	49.6
13	14.12.81	+786	+476	+571	+429	+565	27.5
14	4.1.82	+667	+952	+857	+1119	+899	9.6
15	25.1.82	-286	-24	+48	+262	0	0
16	15.2.82	+262	+310	-48	-95	+107	4.5
17	5.3.82	-48	-143	+48	+143	0	0
18	29.3.82	-667	-95	-107	-48	-238	35.3
19	19.4.82	+71	-119	-643	-643	-333	42.1
20	10.5.82	+643	+667	+1119	+1190	+905	39.8
21	31.5.82	+1143	+357	+500	+48	+512	28.9
22	21.6.82	+167	+786	+238	+214	+351	0.9
Mean		+303	+393	+307	+342	+336	32.85

* Results are for the mean of 4 animals.

Table 4.30. Experiment 2.

Analysis of variance for liveweight gains of Series VI animals.

Component	Degrees of Freedom	Sum of Squares	Mean Square		F Ratio
Animals within groups	12	190.10	15.84		n.s.
Stocking Rates	3	200.41	66.80		1.61
Periods	21	40469.86	1927.14		46.58 ***
Periods x Stocking Rates	63	8152.59	123.41		2.98 ***
Error	252	10425.90	41.37	S.E.=	6.43
Total	351	59438.86			

Grand Mean = 7.06 S.E. = 6.43 C. of V. = 91%

Standard Error difference between periods =1.61 (LSD P=0.05 =3.15)

Standard Error difference between Stocking Rates =0.69 (LSD P=0.05 =1.34)

Standard Error difference between Stocking Rates x Periods =3.22 (LSD P=0.05 =6.30)

Treatment Effect Summary.

	Stocking Rate ha/hd				
	2	3	4	5	LSD P=0.05
Liveweight gain kg/21day/hd	6.36	8.25	6.45	7.16	1.34
Liveweight gain g/day/hd	303	393	307	341	64
	a	b	a	ab	

Means with the same subscript do not differ at P = 0.05 (Duncan, 1955).

Table 4.31. Experiment 2.

Regressions of liveweight gains against rainfall for Series VI animals.

Units Liveweight gain - g/animal/day - Rainfall - mm/21 day

Stocking Rate ha/Hd.	Regression Equations	Coefficient of determination	Mean L.W.G.
2	L.W.G. = 66.90 - $3.97x_1$ + $7.10x_2$ + $4.19x_3$	0.603	303
3	L.W.G. = 210.14 - $3.55x_1$ + $5.52x_2$ + $2.75x_3$	0.477	293
4	L.W.G. = 111.71 - $3.24x_1$ + $6.10x_2$ + $3.92x_3$	0.525	329
5	L.W.G. = 194.95 - $4.28x_1$ + $5.24x_2$ + $3.69x_3$	0.4757	342
Mean	L.W.G. = 136.67 - $3.710x_1$ + $6.00x_2$ + $3.94x_3$	0.6455	336

x_1 = Rainfall in the present (0-3wks) period up to weighing

x_2 = Rainfall in the previous (3-6wks) period up to weighing

x_3 = Rainfall in the penultimate (6-9wks) period up to weighing.

and 4.31. The coefficients for the equations vary considerably from series to series and also among the stocking rates. A feature common to all of the regressions is the negative coefficient associated with rainfall in the current period, that is from three weeks before the time of weighing. This contrasts with the results noted for the regression of rainfall against vegetative growth, where rainfall in the current period had a positive effect on herbage yield. The regression coefficient for rainfall in the previous three-week period, that is between three and six weeks prior to weighing is positive and this tallies with the results for the vegetation/rainfall regressions. The possible origins of the depressive effect on liveweight change of current rainfall are discussed in Section 5.2.

4.2.2. Dietary Composition

Tables 4.32., 4.33., 4.34., 4.35., 4.36. and 4.37 summarise the results obtained from the oesophageal fistula samples of diet actually selected. The results from the six series of animals are generally consistent and lead to two major conclusions. In the first place there is a marked difference in quality as indicated by crude protein content between the standing, or available herbage and the fistula samples. Dietary selection appeared to raise the

Table 4.32. Experiment 2.

Composition of dietary intake from oesophageal fistula samples, June/July 1974.

Component (Ash Free Basis)	Stocking Rate ha/hd					S.E.
	2	3	4	5	Mean	
Crude Protein % Fistula	8.0 a	8.2 a	8.5 b	8.1 a	8.2	0.1
% Sward	5.8 a	6.0 a	6.0 a	5.9 a	5.9	0.1
% Increase	37.9	36.7	41.7	37.3	37.0	-
Neutral Detergent Fibre %	80.6 a	80.8 ab	84.4 b	83.0 ab	82.2	1.0
Acid Detergent Fibre %	61.0 a	65.8 c	64.5 bc	62.2 ab	60.9	1.0
Acid Detergent Lignin %	7.1 a	7.0 a	10.0 b	9.6 b	8.9	0.4

Means with the same subscript letter do not differ significantly at P=0.05 (Duncan, 1955).

Table 4.33. Experiment 2.

Composition of dietary intake from oesophageal fistula samples, October 1974.

Component (Ash Free Basis)	Stocking Rate ha/hd					S.E.
	2	3	4	5	Mean	
Crude Protein % Fistula	4.5 a	5.3 b	6.2 a	4.7 a	5.2	0.1
% Sward	3.5 a	3.5 a	3.8 a	3.4 a	3.6	0.2
% Increase	28.6	54.4	63.2	38.2	44.4	-
Neutral Detergent Fibre %	88.5 a	88.1 a	87.4 a	87.4 a	87.9	1.0
Acid Detergent Fibre %	64.1 b	61.3 a	62.3 ab	62.0 ab	62.4	1.1
Acid Detergent Lignin %	9.1 a	7.8 b	9.0 a	9.0 a	8.7	0.2

Means with the same subscript letter do not differ significantly at P= 0.05 (Duncan, 1955).

Table 4.34. Experiment 2.

Composition of dietary intake from oesophageal fistula samples, May 1975.

Component (Ash Free Basis)	Stocking Rate ha/hd					S.E.
	2	3	4	5	Mean	
Crude Protein % Fistula	12.1 a	12.4 a	11.1 b	12.6 a	12.1	0.3
% Sward	9.4 a	9.5 a	9.5 a	9.6 a	9.5	0.3
% Increase	28.7	30.5	16.8	31.3	27.4	–
Neutral Detergent Fibre %	83.3 a	80.0 b	84.2 a	83.7 a	82.8	1.1
Acid Detergent Fibre %	57.2 a	56.1 a	60.9 b	56.7 a	57.7	0.9
Acid Detergent Lignin %	8.0 a	7.6 a	9.4 b	7.8 a	8.2	0.3

Means with the same subscript letter do not differ significantly at P=0.05 (Duncan, 1955).

Table 4.35. Experiment 2.

Composition of dietary intake from oesophageal fistula samples, August 1975.

Component (Ash Free Basis	Stocking Rate ha/hd					S.E.
	2	3	4	5	Mean	
Crude Protein % Fistula	6.2 ab	6.5 b	6.6 b	5.5 a	6.2	0.3
% Sward	4.1 a	4.2 a	4.4 a	4.1 a	4.2	0.3
% Increase	51.2	54.8	50.0	34.1	47.6	-
Neutral Detergent Fibre %	87.4 a	86.5 a	87.3 a	87.3 a	87.1	0.9
Acid Detergent Fibre %	65.9 a	59.5 b	61.4 c	65.1 a	63.0	0.3
Acid Detergent Lignin %	9.4 a	8.0 b	8.6 b	9.7 a	8.9	0.3

Means with the same subscript letter do not differ significantly at P=0.05 (Duncan, 1955).

Table 4.36. Experiment 2.

Composition of dietary intake from oesophageal fistula samples, September 1976.

Component (Ash Free Basis)	Stocking Rate ha/hd					S.E.
	2	3	4	5	Mean	
Crude Protein % Fistula	7.3 a	8.0 b	8.1 b	6.8 a	7.6	0.3
" % Sward	5.1 a	6.2 b	5.4 a	5.1 a	5.5	0.3
" % Increase	43.1	29.0	50.0	33.3	38.2	-
Neutral Detergent Fibre %	91.9 a	87.6 b	87.4 b	86.6 b	88.4	1.1
Acid Detergent Fibre %	65.2 ab	66.4 a	63.5 b	64.4 ab	64.9	0.8
Acid Detergent Lignin %	9.3 a	9.6 a	8.8 a	9.0 a	9.2	0.5

Means with the same subscript letter do not differ significantly at P=0.05 (Duncan, 1955).

Table 4.37. Experiment 2.

Composition of dietary intake from oesophageal fistula samples, June 1977.

Component (Ash Free Basis)	Stocking Rate ha/hd					S.E.
	2	3	4	5	Mean	
Crude Protein % Fistula	10.9 a	10.8 a	10.5 a	10.5 a	10.7	0.3
" % Sward	8.4 a	8.5 a	8.6 a	8.5 a	8.5	0.4
" % Increase	29.8	27.1	22.1	23.5	25.9	-
Neutral Detergent Fibre %	87.1 ab	86.6 a	88.9 b	87.0 ab	87.4	0.9
Acid Detergent Fibre %	59.6 a	55.4 b	61.4 a	60.5 a	59.2	0.7
Acid Detergent Lignin %	9.3 a	6.5 b	9.1 a	8.8 a	8.4	0.4

Means with the same subscript letter do not differ significantly at P=0.05 (Duncan, 1955).

crude protein level of the feed consumed by 25-50% depending on the season. Secondly, whether indicated in a positive way by crude protein, or in a negative way by fibre or lignin the composition of the diet eaten was broadly similar for the four stocking rates used, within each of the six sampling periods.

4.2.3. Faecal Output

The chemical composition and daily output of faeces for the 3 and 4 hectare/head stocking rates for the six sampling periods are presented in Tables 4.38., 4.39., 4.40., 4.41., 4.42. and 4.43. The pattern of crude protein, or faecal nitrogen broadly follows that of the oesophageal fistula samples, with, for example, the very high values of faecal Nitrogen for May 1975 and May 1977 being relatable to the high crude protein content of the feed selected at those dates. Although there were differences between the faecal crude protein contents of the 3 and 4 ha/hd samples, these differences though statistically significant at the P= 0.05 level, were not consistant and were in practice only about 5-8% so that the overall faecal Nitrogen values were effectively similar for the two stocking rates. Differences between the 3 and 4 hectare/head samples for lignin or fibre content were even smaller than for protein and in no case were the differences statistically

Table 4.38 Experiment 2

Faecal Samples June 1974

Component (Ash Free Basis)	Stocking Rate ha/hd			
	3	S.E.	4	S.E.
Crude Protein %	11.40	0.10	12.45	0.12
Neutral Detergent Fibre %	74.19	0.54	70.92	0.51
Acid Detergent Fibre %	63.88	0.48	62.40	0.44
Acid Detergent Lignin %	13.45	0.20	13.47	0.21
Faecal Output D.M. % Liveweight	0.922	0.025	0.820	0.023
Faecal Output D.M. g/kg Lwt.$^{0.75}$	38.0	1.0	34.5	1.0

Table 4.39 Experiment 2

Faecal Samples October 1974

Component (Ash Free Basis)	Stocking Rate ha/hd			
	3	S.E.	4	S.E.
Crude Protein %	8.64	0.06	9.01	0.07
Neutral Detergent Fibre %	76.13	0.41	76.41	0.42
Acid Detergent Fibre %	60.83	0.47	60.14	0.53
Acid Detergent Lignin %	13.11	0.14	13.35	0.16
Faecal Output D.M. % Liveweight	0.815	0.025	0.730	0.020
Faecal Output D.M. g/kg $Lwt.^{0.75}$	34.2	1.1	31.6	0.9

Table 4.40 Experiment 2

Faecal Samples May 1975

Component (Ash Free Basis)	Stocking Rate ha/hd			
	3	S.E.	4	S.E.
Crude Protein %	13.81	0.16	13.31	0.19
Neutral Detergent Fibre %	75.88	0.49	80.26	0.56
Acid Detergent Fibre %	58.17	0.67	61.60	0.70
Acid Detergent Lignin %	12.07	0.15	12.34	0.17
Faecal Output D.M. % Liveweight	0.983	0.031	0.876	0.029
Faecal Output D.M. g/kg Lwt.$^{0.75}$	39.1	1.7	34.4	1.1

Table 4.41 Experiment 2

Faecal Samples August 1975

Component (Ash Free Basis)	Stocking Rate ha/hd			
	3	S.E.	4	S.E.
Crude Protein %	9.36	0.10	8.98	0.07
Neutral Detergent Fibre	83.56	0.42	86.67	0.47
Acid Detergent Fibre %	64.77	0.63	67.54	0.70
Acid Detergent Lignin %	14.30	0.19	14.41	0.17
Faecal Output D.M. % Liveweight	0.939	0.038	0.837	0.031
Faecal Output D.M. g/kg $Lwt.^{0.75}$	39.1	0.8	34.9	1.3

Table 4.42. Experiment 2

Faecal Samples September 1976

Component (Ash Free Basis)	Stocking Rate ha/hd			
	3	S.E.	4	S.E.
Crude Protein %	9.95	0.11	9.67	0.11
Neutral Detergent Fibre %	81.56	0.81	81.73	0.65
Acid Detergent Fibre %	71.13	0.49	72.97	0.33
Acid Detergent Lignin %	15.41	0.17	15.20	0.11
Faecal Output D.M. % Liveweight	0.925	0.033	0.954	0.041
Faecal Output D.M. g/kg Lwt.$^{0.75}$	42.2	1.5	42.9	1.9

Table 4.43. Experiment 2

Faecal Samples May/June 1977

Component (Ash Free Basis)	Stocking Rate ha/hd			
	3	S.E.	4	S.E.
Crude Protein %	15.96	0.14	15.16	0.10
Neutral detergent Fibre %	81.50	0.26	84.18	0.61
Acid Detergent Fibre %	61.53	0.67	63.21	0.57
Acid Detergent Fibre %	12.31	0.19	12.21	0.15
Faecal Output D.M. % Liveweight	0.571	0.013	0.608	0.015
Faecal Output D.M. g/kg Lwt.$^{0.75}$	25.0	0.5	26.4	0.7

significant at the P= 0.05 level. The faecal output values indicated, whether on a liveweight or on a metabolic bodyweight basis that on each sampling occasions there was little difference between the two stocking rates.

The potential use of the lignin content of fistula and faecal samples as an indigestible marker for derivation of digestibility and feed intake values is discussed in Section 5.2.

4.2.4. Available Forage

Table 4.44. indicates the quantities of forage available to the grazing animals for the four stocking rates on 10 occasions through the grazing experiment. Of particular note is the very limited amount of forage available to the animals during the very dry year of 1976, particularly in the 2ha/hd stocking rate paddock. This would be expected to reduce the possibilities for diet selection, and hence animal performance. The results displayed in this Table will be discussed in detail, in relation to seasonal vegetation growth and animal intake, in Section 5.3.

Table 4.44. Experiment 2

Standing Crop Estimates from 10 x 2.5m^2 Cut Samples

Units - kg/ha Dry Matter

Sampling Date	Stocking Rate ha/hd				Mean
	2	3	4	5	
June/July 1974	2050(880)	2520(270)	1820(530)	2880(400)	2320
October 1974	1490(300)	1980(400)	1380(380)	1340(200)	1540
May 1975	610(40)	600(80)	680(60)	1290(180)	800
August 1975	2000(370)	2080(200)	2690(340)	2830(400)	2400
April 1976	290(50)	490(70)	500(80)	590(80)	470
June 1976	230(50)	1010(380)	780(120)	850(180)	720
July 1976	400(100)	900(160)	390(50)	560(70)	860
September 1976	150(30)	500(120)	390(50)	560(70)	400
January 1977	120(20)	450(60)	710(130)	1050(100)	580
June 1977	1510(200)	1140(70)	1610(300)	2120(260)	1600

N.B. Figures in brackets are S.E. of the mean for the stocking rate and date concerned.

4.2.5. Carcass Composition

Table 4.45 presents the fat percentage values from analysis of the animals used in Experiment 2. The overall fat contents were low compared to the requirements for top grade carcasses of ca 25%. This suggests that from range grassland it may be rather difficult to finish animals in order to achieve high value carcasses. (Creek, 1976).

The results indicated in Table 4.45 give no clear indication of the effect of stocking rate on carcass composition. This may be considered as further indirect evidence of a lack of difference in feed intake cuality across the four stocking rates.

Table 4.45. Experiment 2

Carcass Fat Content

Animal Series	Stocking Rate ha/hd 2	3	4	5	Mean	S.E.
1	14.3	15.6	14.0	14.6	14.6	1.1
2	16.3	20.6	19.5	19.3	18.9	1.7
3	16.4	17.5	18.6	15.9	17.1	1.4
4	17.1	17.2	15.8	18.7	17.2	1.6
5	17.5	19.1	17.2	17.2	17.9	1.3
6	14.2	19.8	13.3	16.2	15.9	1.3
Mean	16.0	18.4	16.5	17.0	17.0	-

N.B. No differences between stocking rate means for any one animal series were significant at P=0.05.

CHAPTER 5
DISCUSSION

5.1. Climate and Vegetation Production

5.1.1. Effect of Defoliation System on Forage Availability.

The results of Experiment I produced 15 different estimates of the standing forage available in any particular three-week period during the study. The review of relevant literature outlined in Section 2.2. indicated that there is no general agreement as to a standardised method for assessment of standing forage yield. There is therefore little value in making direct comparisons with actual yield values obtained in this trial with other estimates of rangeland productivity in East Africa, such as those of Knops, (1971), Mackay (1971), Van Voorthuizen (1972), Braun (1973), Cassady (1973), Clarke (1973) and Karue (1975). Apart from the differences of sites of study each of these workers used quite different harvesting techniques to assess the standing forage yield.

For the present study it appears more useful to compare yields obtained with the 15 different defoliation systems with each other, in relation to implications for possible range management recommendations. Results from many previous studies, both in the field and in glasshouses have suggested that the yield of any particular sward is normally found to be inversely proportional to the severity of the defoliation system (Aldous, 1930; Griffiths Davies and Sim, 1931; Richardson et al., 1932; Taylor, 1933; Louw, 1938; Bukey and Weaver, 1939; Harrison and Hodgson, 1939; Cassaday, 1953; Thaine, 1954; Branson, 1956; Nieland and Curties, 1956; Prine and Burton, 1956; Riveros and Wilson, 1970; Bekele et al., 1974; Eck et al., 1975; Karue, 1975; Beatty and Powell, 1976; Perry and Chapman, 1976; Singh and Mall, 1976; Stout et al., 1980 and Moser and Perry, 1983).

There has been a considerable measure of agreement as to the possible causes of the observed decline in yield with increasing severity of defoliation. Depletion of reserves, particularly of the carbohydrates, required to support the early regrowth stages, before leaf area builds up to the level at which photosynthesis can replenish the reserves is usually cited. (Biswell and Weaver, 1933; Crider, 1955; Kinsinger, 1961; White, 1973; Perry and Chapman, 1974). In extreme cases this could be expected to lead to a rapid decline in plant vigour or even death of the plant. However the results from the present study suggest that under range conditions the situation may be rather complex and that comparisons with other work may require considerable caution.

For the present study the defoliation regimes were maintained continuously for a period of about five years so that long term trends would be expected to have emerged. With the most severe system of defoliation used, that of 5cm cutting height and 3-week cutting interval, there was no indication of survival of the sward being threaten ed, even though the overall yield from this treatment was lower than for the other longer cutting intervals at the same height of cut (Table 4.2.). The recovery of yield in 1977, following the drought year of 1976, indicated clearly the tolerance of the present sward to severe defoliation. Although, as indicated in Section 2.2., care must be exercised in interpreting yield values due to the possible interaction of harvest methodology and defoliation treatment, in the present study the highest overall yield was obtained with the relatively severe defoliation system of 5cm cutting height with a 6 week cutting interval. This result appears to contradict the general pattern of yield response to severity of defoliation noted in the studies cited. However, this is not an isolated exception as indicated in the review by Tainton et al., (1970).

Most of the studies cited were carried out for only one or two growing seasons compared to the ten seasons used in the present study, so that the long term effects of the defoliation systems were not fully demonstrated. The problems of comparisons of results from different harvesting techniques have already been mentioned. In addition the possible losses due to decay or insect removal noted in some range studies in East Africa (Cassaday, 1973; Karue, 1975) and elsewhere (Ratliff et al., 1962; Bodine and Veckert, 1975; Hewitt et al., 1976; Hewitt and Onsager, 1983) may be expected to have more effect the greater the harvest interval, as there would be a longer period for such yield reduction processes to occur. Differences among the sward species in patterns of tiller elongation may also affect the response of the herbage components to defoliation (Branson, 1953, 1956; Booysen et al., 1963; Pearson, 1964; Vogel and Bjugstad, 1968; Gilbert et al., 1979). The particular sward/soil complex under examination in the present study has been recognised as rather robust and also capable of very rapid recovery from mis-management (Pratt and Gwynne, 1977). The tolerance of the relatively severe defoliation observed over five years in the present study is therefore not surprising. It should be noted, however, that this result cannot be directly extrapolated to tolerance by the sward of heavy grazing pressure as the effect of trampling on plant vigour and persistence when animals are present may be considerable (Quinn and Harvey, 1970; Brown and Evans, 1973; Dunne, 1977).

5.1.2. Climate & Herbage Yield Production Models

Early classifications of climate/vegetation zones (Koppen, 1936; Moreau, 1938; Holdridge, 1947; Edwards, 1956) may be considered to be crude attempts at development of environment/production models. The effects of climatic changes in such studies can be represented by adjustments to the zone boundaries on the maps of the area being studied. However, such early models allowed for only very broad vegetation classes to be considered, with changes occuring over time-scales measured in decades. Soil type, fire and the effects of human management involvement were among the factors normally excluded from such models.

As discussed in Section 2.3.3. there have been numerous attempts to derive relationships with predictive value in which environmental factors provide the inputs and herbage production is the output. The models suggested have been of two main types, simulation and empirical-statistical (Duncan et al., 1967; Waggoner, 1969; Loomis et al., 1971; Biswas, 1980; Baier, 1981; Sakomoto, 1981; Baier, 1982;

Robertson, 1983 and Konijn, 1984).

In the simulation models attempts are made to develop mathematical expressions relating the interactions among the plant, soil, climate and, in some cases, management practices. Where possible the expressions are based on known physiological processes, so that causality can be incorporated directly into the various stages of the model. Such models are usually highly complex, involving iterative calculation processes requiring high speed computing facilities. In rangeland areas the large number of required input variables are usually not available for other than very short historical periods. The physiological and production data for validation of both the internal interactions and for the final output are usually very limited. Development of simulation modelling has therefore been concentrated towards annual arable cropping as the physiological processes involved in a mono-culture are easier to elucidate and in addition the production data are to agreed standards of measurement, for example grain yield in quintals per hectare at a standard moisture content. The complex nature of the sward and the difficulties of agreement on standardised yield assessment techniques have not encouraged the development of simulation models for rangeland vegetation production (Baier, 1982).

Where simulations of the rangeland situation have been attempted they have generally included the animal as a component, as under the grazing conditions that will occur in the "real" rather than "model" world the animal is involved not only as a parameter in the output but also as an input factor through its part in defoliation, trampling and nutrient recycling. Vegetation characteristics are included in such models but only as components within the overall system rather than as outputs (Jones, 1969; Jeffers, 1972; Simpson, 1972; Sanders and Cartwright, 1979; Whelan et al., 1984). The use of simulation models in relation to animal output will be discussed further in Section 5.4.

In the empirical-statistical models, normally, a sample of yield data and of environmental measurements are taken for the same area and time period. This compilation of environment as input and yield as output is then subjected to some form of multiple regression analysis. There is much less emphasis on causality in this type of model, but the input parameters are normally chosen only after a careful consideration of the available knowledge of plant environment interactions (Carter et al., 1984). The models so derived are generally much simpler than simulation models. With fewer input variables being required than for a simulation model for any particular site there are likely to be more data available for a longer time series for the statistical model. Restriction of the number of inputs also has an advantage in that it may reduce statistical aberrations due to auto-correlation of variables (Sakomoto, 1981). Thus mean temperature and rainfall may be linked, even if in an inverse manner, through the effect of cloud cover on insolation. Where there is known to be some autocorrelation between the possible input variables it may be possible to combine them into some form of synthetic agro-climatic index values which then become the inputs for the model. A possible alternative procedure is to examine the applicability of a model which uses only one input factor which is thought to control plant growth in the particular situation. The models discussed in Section 2.3.3. are all empirical statistical models where the input factors are confined to measures of water availability as the main feature limiting plant growth. However, in other situations temperature may be considered more appropriate, for example with grass production for hay in Iceland (Fridriksson, 1973; Bjornsson and Helgadottir, 1984) or rice production in Japan (Uchijima, 1984). In the present study an empiri cal statistical model is examined, in which water availability is considered as the factor most affecting plant growth.

The discussion in Section 3.3.2.2. of the model used for the present study was confined to the consideration of the input variables related to water availability. Derivation of the regression coefficients for the multiple regression requires that a sample of water availability input values are related to a contemporaneous set of yield values. As has been discussed in the previous Section, 15 different yield values are available for the sward, depending on the defoliation system. Tables 4.7., 4.10., 4.11. and 4.12. present the regression coefficients for yield against rainfall and the various estimated values for actual evapotranspiration (AE). Table 4.13. compares the various coefficients of determination, as a measure of the potential usefulness of the regressions for predictive purposes. Except in the rather rare circumstances in rangeland that the vegetation is to be made into hay, the actual amount of vegetation is not of direct interest to the land user. It is the animal output that is of greater interest. The environmental/vegetation relationship is therefore only a component of the overall production system. In section 2.4. it was noted that animal performance may be related to the quantity of vegetation through the vegetation bulk

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density factor rather than simply to the total amount of available vegetation over the whole of the grazing area, regardless of how the material is concentrated in the sward. Animals at the same stocking rate would therefore be expected to have intakes in proportion to the forage availability per hectare. The estimation of maximum potential vegetation growth may therefore be of value in indicating the potential animal intake and hence performance, if the animal intake requirements are understood (Currie and Peterson, 1966; Stobbs, 1975; Hodgson, 1977).

In the present study the highest overall yields were obtained with the 5cm cutting height and 6-week cutting interval treatment combination, so that these yields may be considered as indicative of the potential maximum availability of forage at the site under a simulated continuous grazing system. This contrasts with the methods of yield assessment used in most of the other studies examined, where the yield assessment is made following a season-long growth period (Trumble and Cornish, 1934; Rogler and Haas, 1947; Smoliak, 1956). How such yield data are to be related to potential animal performance when the studied sward is grazed is not clear.

Examination of Table 4.13. indicates that the regressions of yield against rainfall for the 5cm cutting height and 6-week cutting interval treatment combination produced a coefficient of determination of 0.62, the highest value of any of the regressions in the Table. For the present study site it would seem that the empirical-statistical model developed for rainfall and yield may be used for predictive purposes with some measure of confidence as 62% of yield variation is accounted for by the model. The 82 three-weekly growth periods used as the sample for generation of the regression included periods of rainfall in very dry (1976) and very wet (1978) years. Estimates of yield for the site for periods outside the 1974-1978 time-series will therefore normally involve interpolation calculations within the already observed, and therefore validated, range. A shorter run of data for generation of the model, particularly where the time-series did not include extremes would be less useful, as the inputs of rainfall from other periods would be outside the observed range, and the validity of the regression in extrapolation is uncertain. (Hanson et al., 1982; Carter et al., 1984.).

For the present site the derived regression relationship for the 5cm cutting height and the 6-

week cutting interval treatment combination was used to generate values of estimated yield for the period 1974 to 1982, using the actual rainfall values for the three-week growth periods as inputs. The three-week yield estimates were combined into annual totals. The calculated annual yields are indicated in Table 5.1. together with the observed totals for the years 1975, 1976, 1977 and 1978. Even though the model does account for 62% of the variation of yield during the period 1974-1978 there are large discrepancies between predicted and actual yield for the four test years. In 1975, 1976 and 1977 the estimated yield is much higher than the observed, while for 1978 the reverse is true. These results suggest that the predictive value in practice may be rather limited on an annual basis. Tests on shorter periods, down to the individual three-week periods also show these very large discrepancies between estimates and observed yields. Tests on several of the other models described give similar discrepancies between yield actually observed and estimated (Rosenzweig, 1968; Murphy, 1970; Khan, 1971; LeHouerou and Hoste, 1977). These comments are made in reference to actual yields in kg/ha and not to any form of transformed variable. The importance of this point concerning transformation may be emphasised by an example. In the regression model derived by Rosen-

Table 5.1. Estimated potential herbage yields 1974-82 compared with maximum yield recorded in Experiment I.

Units Yield kg/ha/yr Rainfall mm/yr

Year	Yield		Annual
	Estimated	Observed	Rainfall
1974	1910	-	560
1975	2070	970	560
1976	660	170	360
1977	3720	3020	760
1978	4120	6140	840
1979	2840	-	610
1980	2630	-	610
1981	2110	-	560
1982	1780	-	580

Yield estimated by the regression equation for the 5cm x 6week cutting treatment.

zweig (1968) $\log_{10}$ yield was related to $\log_{10}$ AE on an annual basis. For an annual AE of 500mm the predicted vegetation yield is 6760kg/ha. The upper and lower 95% confidence limits are, when converted back to arithmetical values, 33110 and 1330kg/ha. The predictive value in practice of such a model is therefore somewhat questionable, whatever the statistical significance of the regression may appear to be.

When the predictive models such as those of Rosenzweig (1968) and LeHouerou and Hoste (1977) are used in the generation of estimates of carrying capacities without very careful consideration of the diet selection, feed conversion and animal growth rate parameters of the particular stock being used the validity of the predicted carrying capacities becomes rather open to question (Phillipson, 1975; Mentis, 1977). Such reservations become even more serious where the predictive model is not considered validated for the environment under study. Thus, for example. Coe et al., (1976) use the vegetation productivity model developed by Rosenzweig (1968), based on a world-wide collection of data, for generation of their carrying capacities and animal output potentials even though Rosenzweig explicitly questions the validity of his model in semi-arid areas. This point is discussed further in Section 5.4.

5.2. Climate and animal production

5.2.1. Liveweight gain

Measurements of liveweight changes in the grazing animal have been widely accepted as good indicators of the feeding value of the grazed sward ('t Mannetje et al., 1976). In the present study the results of the analysis of variance for the six series of animals shown in Tables 4.15., 4.21, 4.24., 4.27. and 4.30. indicate a general lack of apparent effect of stocking rate on liveweight gain. The period of 8½ years during which the grazing animals were monitored would be expected to show up any long term trends but there was no obvious pattern in liveweight gain per animal over the range of stocking rates used. The relationship between performance per animal and stocking rate has been examined for cattle by several reviews (McMeeKan, 1956; Mott, 1960; Riewe, 1961; Cowlishaw, 1969; Jones and Sandland, 1974; Carew, 1976). Although Mott (1960) proposed a curvilinear relationship between liveweight gain per head and stocking rate which was accepted by Van Soest (1982) in his discussion of animal productivity, the considerable body of evidence collected by Jones and Sandland (1974) suggested that a linear relationship fitted the data better. It was, however, agreed that the intercept and gradient of the relationship would be dependant on the sward composition, climate and the management conditions of the site in question ('t Mannetje, 1976). Any relationship between the stocking rate and liveweight gain would therefore be expected to be highly site specific, not suitable for general application. The decline in liveweight gain suggested by the proposed relationships implies that at high stocking rates there is a reduction in diet quantity and/or quality which would support animal growth. While such a prediction may be reasonable at very high stocking rates where the effects of defoliation, trampling and soiling of the sward by dung and urine might be expected to be intense it is not so clear how such factors would affect the diet availability as the stocking rate is lowered. In the present study there was no clear indication of any systematic decline in the liveweight gain per animal as the stocking rate was increased, within the range of 2-5 ha/animal. This finding implies that over the period of 8½ years for which the liveweight data were recorded there was little difference, between the dietary intakes of the animals on the four different stocking rates.

For the six series of animals there was a generally close relationship between the pattern of the liveweight gain and the rainfall distribution, which would be expected to affect the forage supply (Tables 4.14., 4.17., 4.20., 4.23., 4.26. and 4.29.).

That the relationship is somewhat different from that between rainfall and vegetation growth is apparent from examination of the regression equations derived from the liveweight gains and rainfall (Tables 4.16., 4.19., 4.22., 4.25., 4.28 and 4.31.). The constants in the regressions vary considerably from one series of animals to another and this point is discussed in relation to levels of intake and animal performance in Section 5.4. However, it is appropriate at this stage to emphasise that the presence of rainfall in the current three-week period (that is from 0-3 weeks before measurement of harvest or weighing) appears to have had a uniformly negative effect on liveweight, whereas the effect on vegetation growth was positive. The negative effect of current rainfall probably is due to the effects of a combination of factors associated with the onset of rain after a dry spell. The combination of the presence of much liquid water on the suface of the coarse herbage, the deleterious effects on rumen activity of the very low dry-matter content of the new growth and the increase in maintainence energy needs due to the damp, cool weather have all been associated with reduction of dry matter intake and animal performance at that time (French, 1956). The positive values of the regression coefficients for the effect of rainfall in the previous period on liveweight indicate that by three to six weeks after the onset of the rains the animal has become able to respond to the improved forage quality and quantity by increasing intake and hence liveweight.

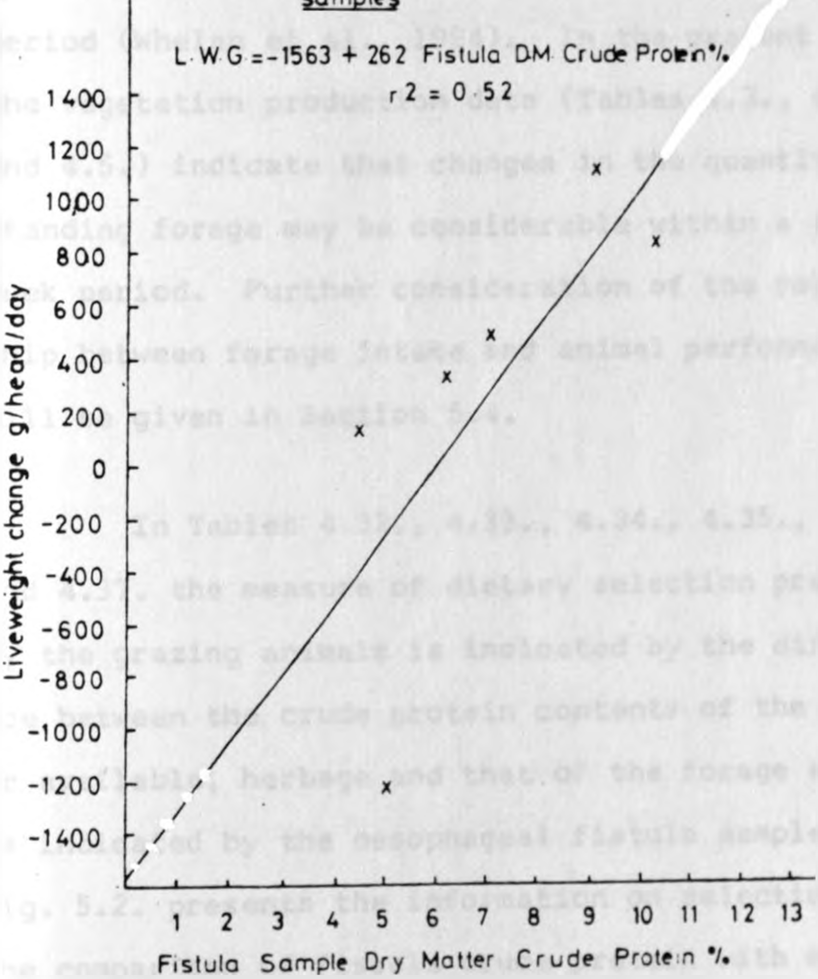
5.2.2. Forage quality

5.2.2.1. Crude protein content

Examination of the crude protein levels of the fistula samples in Tables 4.32., 4.33., 4.34., 4.35., 4.36. and 4.37 indicates that there were no systematic differences among the stocking rates at any one sampling period. Overall diet quality as indicated by protein content was therefore similar for the four stocking rates. The levels of crude protein in the diet showed considerable variation from one sampling period to another. That this variation was associated with the distribution of rainfall can be seen by comparison of the crude protein levels in the Tables mentioned with the pattern of rainfall as indicated in Table 4.6. High crude protein levels are associated with periods of rainfall and from the discussion already made, with sward growth. During periods of growth the proportion of green material in the sward is high.

Yates et al., (1964) and 't Mannetje (1974) reported that the proportion of green material in the sward could be highly correlated with liveweight gains of the grazing animal. In the present study there was a correlation between the level of crude protein in the diet, as estimated from the oesophageal fistula samples, and the liveweight change over the three week period containing the fistula sampling period. Fig. 5.1. shows the relationship between the mean liveweight gain for all animals from all four stocking rates and the crude protein of the fistula sample dry matter for each of the six sampling periods. That the coefficient of determination is not higher than 0.52 is not altogether surprising as the liveweight gain of the animal in any period will not be solely dependant on the diet quality characteristics. A variety of other factors such as age of the animal, past nutritional status of the animal, bulk density of the herbage in the sward and water availability have all been reported to affect feed intake of any particular sward and hence liveweight gain under field conditions (Blaxter et al., 1961; Connor et al., 1963; Thornton and Yates, 1968; Ledger et al., 1970; Allden, 1979). In the relationship expressed in Fig. 5.1. none of these other factors was considered. A further point to consider is that the liveweight changes were measured over a

Fig 5 1 Relationship between liveweight gain and crude protein content of fistula samples



period of three weeks whereas the fistula sample collection was carried out for only a few days, so that changes in herbage quality during the live-weight measuring period would not be apparent. Variations from 500-2500kg/ha of available forage and changes from 75-60% in the digestibility of available forage have been recorded in a one month period (Whelan et al., 1984). In the present study the vegetation production data (Tables 4.3., 4.4. and 4.5.) indicate that changes in the quantity of standing forage may be considerable within a three-week period. Further consideration of the relationship between forage intake and animal performance will be given in Section 5.4.

In Tables 4.32., 4.33., 4.34., 4.35., 4.36. and 4.37. the measure of dietary selection practised by the grazing animals is indicated by the difference between the crude protein contents of the cut, or available, herbage and that of the forage eaten, as indicated by the oesophageal fistula samples. Fig. 5.2. presents the information on selection by the comparison of fistula crude protein with sward crude protein using the mean values for all four stocking rates for the six sampling periods. Within the range examined the relationship is adequately described by a simple linear regression:-

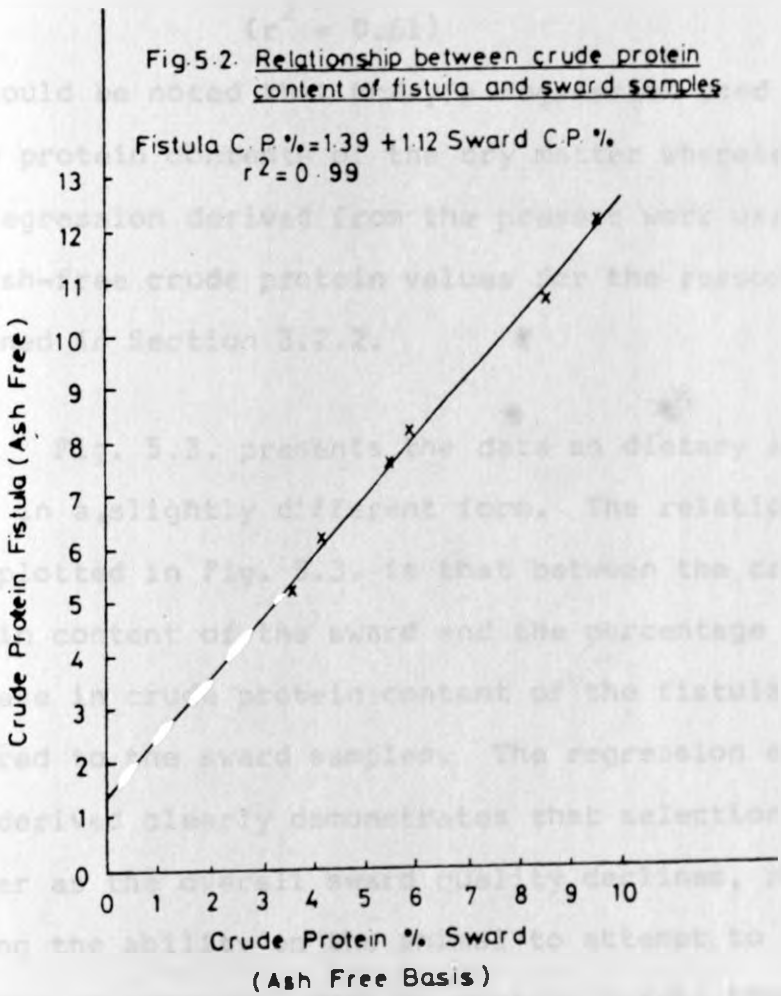


Fig. 5.2. Relationship between crude protein content of fistula and sward samples

Crude Protein(Fistula)=1.38+1.12 Crude Protein(Sward)

$$(r^2 = 0.99)$$

This regression compares with that of MacKay (1971) for a similar rangeland sward in the Rift Valley of Kenya:-

Crude Protein(Fistula)=1.27+1.23 Crude Protein(Sward)

$$(r^2 = 0.61)$$

It should be noted that McKay's regression used the crude protein contents of the dry matter whereas the regression derived from the present work used the ash-free crude protein values for the reasons outlined in Section 3.2.2.

Fig. 5.3. presents the data on dietary selection in a slightly different form. The relationship plotted in Fig. 5.3. is that between the crude protein content of the sward and the percentage increase in crude protein content of the fistula compared to the sward samples. The regression equation derived clearly demonstrates that selection is greater as the overall sward quality declines, reflecting the ability on the animal to attempt to maintain an adequate level of protein intake (Topps, 1960). The implications of this finding in relation to grazing management will be discussed further in Section 5.4.

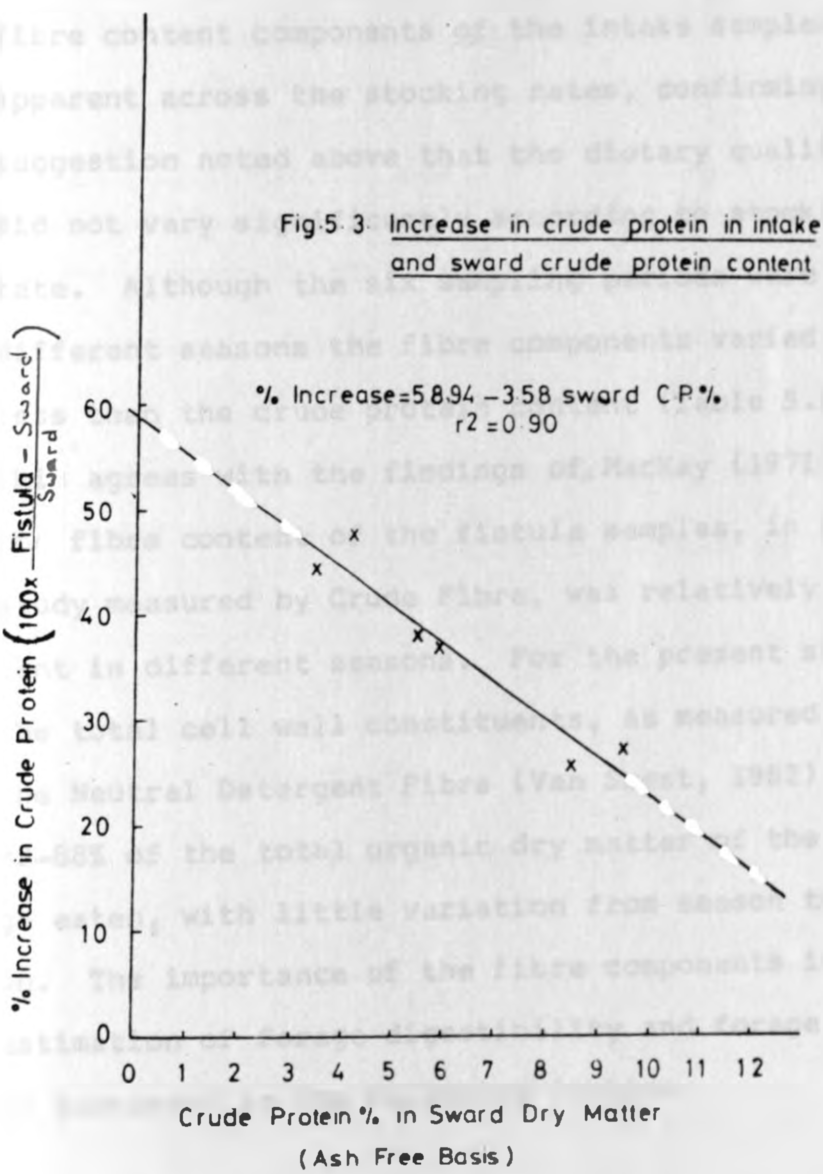


Fig.5.3 Increase in crude protein in intake and sward crude protein content

5.2.2.2. Fibre content

In Tables 4.32., 4.33., 4.34., 4.35., 4.36. and 4.37. the results of the detergent fibre analysis (Van Soest, 1963) for the fistula sample are presented. No clear indication of any trend in the fibre content components of the intake samples is apparent across the stocking rates, confirming the suggestion noted above that the dietary quality did not vary significantly according to stocking rate. Although the six sampling periods were in different seasons the fibre components varied much less than the crude protein content (Table 5.2.). This agrees with the findings of MacKay (1971) that the fibre content of the fistula samples, in his study measured by Crude Fibre, was relatively constant in different seasons. For the present study the total cell wall constituents, as measured by the Neutral Detergent Fibre (Van Soest, 1982) were 82-88% of the total organic dry matter of the forage eaten, with little variation from season to season. The importance of the fibre components in the estimation of forage digestibility and forage intake is discussed in the following Section.

5.3. Digestibility and feed intake

5.3.1. Faecal output

The reviews by Minson et al., (1976) and

Table 5.2. Fibre components of intake as estimated by the oesophageal samples for the six sampling periods.

Date of Sample	Season	Component %				
		NDF	ADF	ADL	ADL/ADF	CP.
June 1974	Wet/Dry	82.2	60.2	8.9	0.148	8.2
Oct. 1974	V. Dry	87.9	62.4	8.7	0.139	5.2
May 1975	Wet	82.8	57.7	8.2	0.142	12.1
Aug. 1975	Dry	87.1	63.0	8.9	0.141	6.2
Sept. 1976	Dry	88.4	64.9	9.2	0.142	7.6
June 1977	Wet	87.4	59.2	8.4	0.142	10.7

N.D.F. = Neutral Detergent Fibre

A.D.F. = Acid Detergent Fibre

A.D.L. = Acid Detergent Lignin

C.P. = Crude Protein.

All components were measured on ash free basis.

Cordova et al., (1978) indicate the value of faecal output estimation as a component of the determination of feed digestibility and intake. For the present study the faecal output of the animals was estimated using the Chromic oxide tracer technique (Section 3.2.2.). The values obtained were presented in Tables 4.38., 4.39., 4.40., 4.41., 4.42. and 4.43. The values in the tables are the means of the estimates derived from the morning and the afternoon faecal samples (Ruggiero and Whelan, 1977). The estimates of daily faecal output using the afternoon samples was on average about 38% higher than that from the morning samples, confirming the observation of a diurnal variation in output of the Chromic oxide tracer noted by other workers (Kane et al., 1952; Putman et al., 1957; Ruggiero and Whelan, 1977).

Kahn and Spedding (1984) suggested that the daily faecal dry matter output approaches a maximum value of 1.07kg/100kg liveweight due to the physical capacity of the digestive system of the animal. Such a limit, even if valid, would be expected to be achieved only for animals supplied with adequate feed, in terms both of quality and of quantity, otherwise the feed intake would be limiting to faecal output long before gut capacity. Under free-rangeing conditions, as in the present study the availability and composition of the forage varies in a highly seasonal manner, as indicated in Table 4.44. for quantity and in Tables 4.32., 4.33., 4.34., 4.35., 4.36. and 4.37 for quality. In this situation of highly variable forage supply it would therefore not be surprising to find considerable variation in faecal output from one collection date to another. It should be noted that the hypothesis of gut capacity limiting faecal output is rather controversial and Van Soest (1982) presents evidence that daily faecal output is directly related to the level of feed intake and that the limit to faecal output, if any, is, for sheep at least, well above the value given by Kahn and Spedding (1984) for cattle. For comparison with the Kahn and Spedding figures the outputs in Tables 4.38., 4.39., 4.40., 4.41., 4.43. and 4.43. require conversion from ash-free to total dry matter values. The faecal dry matter output values for the present study are presented in Table 5.3. on both a liveweight and a metabolic bodyweight basis. Some of the output values obtained are considerably above the limit value suggested by Kahn and Spedding (1984).

The faecal output values are not of great value in themselves but may be used with feed digestibility values to estimate daily dry matter

Table 5.3. Faecal dry matter output summary

Basis	kg/100kg Liveweight				g/kg 0.75 liveweight			
Stocking Rate	3 ha/hd		4 ha/hd		3 ha/hd		4 ha/hd	
Date of Sample	Output	S.E.	Output	S.E.	Output	S.E.	Output	S.E.
June 1974	1.24	0.04	1.11	0.04	51.1	1.3	46.7	1.4
October 1974	1.06	0.04	0.95	0.04	44.2	1.4	41.1	1.2
May 1975	1.38	0.05	1.22	0.05	55.1	2.4	47.9	1.5
August 1975	1.25	0.05	1.13	0.05	52.1	1.1	47.1	1.8
September 1976	1.29	0.05	1.35	0.06	88.9	2.1	60.7	2.7
June 1977	0.83	0.02	0.88	0.02	36.3	0.7	38.1	1.0

intake (Section 5.3.3.).

5.3.2. Feed Digestibility

Direct in vivo estimation in the field of the digestibility of herbage for grazing livestock has not proved to be practical (Cordova et al., 1978). Attempts to examine the feed intake by some form of pre-and post-grazing cutting of the grazed sward do not take full account of factors such as diet selection by the grazing animal, the growth characteristics of the sward components during the grazing period and the removal of some of the forage by non-grazing processes such as by insects or decay (Minson et al., 1976; Cordova et al., 1978). Where oesophageal fistula samples of the diet selection, and therefore assumed eaten, are available it may be possible to predict in vivo digestibility from an in vitro analysis of the fistula sample (Tilley and Terry, 1963; Minson and McLeod, 1972), with a potential accuracy of about ± 5 digestibility units (McLeod and Minson, 1969).

For the present study in vitro digestibility determination facilities were not available so that the use of indirect methods of digestibility had to be investigated. Such methods rely on the use of an internal marker in the feed, with the marker having known digestibility characteristics

(Kotb and Luckey, 1972). For the present study the internal markers available for use were faecal nitrogen and lignin content.

Chromogen, an accetone soluble pigment derived from chlorophyll, which has been proposed as an alternative internal marker (Reid, 1962) is degraded in the mature, dry herbage which the present sward consists of for most of the year (Van Soest, 1982). For the present study the use of chromogen is therefore inappropriate.

In their review Blaxter and Mitchell (1948) presented evidence that faecal nitrogen excretion was related to the level of dry matter intake. Following this various workers investigated the relationships between faecal nitrogen level and feed digestibility. Cordova et al., (1978) presented a review of a number of proposed regression models which had been derived from various grazing situations. The regressions were normally derived from the use of pen-feeding studies in which animals were fed with cut samples of the herbage under investigation (Van Soest, 1982). However as Owen (1961) had pointed out, there are considerable dangers in extrapolation of the use of these regressions from the pen-feeding situation to the free-grazing field situation. The accuracy of the estimate of digestibility may be affected by the selection of diet by the animals in the field and by the level of dry matter intake (Heaney et al., 1963; Laredo and Minson, 1975; Minson et., 1976). Even with botanically very simple swards, where the faecal nitrogen regression has been derived from pen feeding studies the accuracy of the estimate of digestibility has been shown to be no better than ±3 digestibility units compared with in vivo estimation (Minson and Kemp. 1961). For a more complex sward, such as that in the present study, the collection of a sample of herbage for use in the pen feeding studies as an accurate representative of the diet that will be selected by the grazing animal is very difficult. The diet actually selected has been shown to be affected by the seasonal changes in the sward characteristics (Greenhalgh et al., 1960; Lambourne and Reardon, 1963; Langlands and Sanson. 1976; Raymond, 1969; Wallace and van Dyne, 1970). High residual errors of the regression estimates are thus not surprising. Values of ±9 (Lancaster, 1949), ±13 (Jeffery, 1971) and even ±17 (Lambourne and Reardon, 1963) in terms of digestibility units being reported. Table 5.4. indicates the range of digestibilities estimated by a selection of the regressions proposed using faecal nitrogen. Where necessary the original equations have been

Table 5.4. Organic matter digestibility % estimated using various predictive regressions from faecal nitrogen level.

3 ha/head								Stocking Rate	4 ha/head							
1	2	3	4	5	6	7	Mean	Sampling Date	Mean	1	2	3	4	5	5	7
63 (3)	63(3)	64(3)	58(3)	57(5)	52(3)	64(3)	60(3)	June 1974	62(3)	65(3)	65(3)	66(3)	50(3)	57(5)	53(3)	65(3)
52 (6)	56(5)	58(6)	49(6)	59(1)	49(6)	57(6)	54(6)	Oct. 1974	55(5)	54(5)	57(5)	59(5)	49(5)	58(2)	49(5)	58(5)
70 (3)	68(2)	68(3)	64(2)	57(5)	56(9)	67(2)	64(2)	May 1975	63(2)	69(2)	67(2)	68(2)	63(2)	57(5)	55(2)	66(2)
55 (5)	58(5)	60(5)	51(5)	58(3)	50(4)	59(5)	56(5)	Aug. 1975	55(5)	53(6)	57(5)	59(5)	49(5)	58(2)	49(5)	58(5)
58 (4)	60(4)	61(4)	53(4)	58(3)	50(4)	60(4)	57(4)	Sept. 1976	57(4)	57(4)	59(4)	60(4)	52(4)	58(2)	50(4)	60(4)
74(1)	71(1)	71(1)	68(1)	59(1)	53(1)	69(1)	67(1)	June 1977	66(1)	72(1)	70(1)	70(1)	67(1)	59(1)	58(1)	69(1)

Figures in brackets refer to ranking in column.

1. Lancaster (1949) – Digestibility O.M. % = 1-0.[illegible] N%
2. Lancaster (1954) – " = 1-(1/(0.9 + N%))
3. Lancaster (1954) – " = 1-(1/(1.02 + 0.97 N%))
4. Elliot and Fokkema (1962) – " = 1-(1/(0.48 + 1.04 N%))
5. Lambourne and Reardon (1963) – " = 1-(1/(3.66 – 1.39 N% + 0.36 $(N\%)^2$))
6. Moran (1976) – " = 36.71 + 8.63 N%
7. Vera (1973) – " = 23.25 + 31.88 N% – 5.424 (N%)

recalculated from a feed to faeces ratio to a digestibility percentage figure. All of the regressions used estimate an organic matter digestibility value, rather than a total dry matter value. There is a general agreement among the equations as to the ranking of the digestibilities of the diets for the six sampling periods, but there is considerable variation in the actual percentage digestibility values estimated by the equations for any one sampling period. The difficulties associated with the validation of the regression equations has already been mentioned, but without a validation for the actual sward in question it is questionable as to how far the faecal nitrogen index can be used to estimate diet digestibility in such a botanically complex sward.

The ratio of lignin in feed and faeces has been used to estimate digestibility, especially in studies in U.S.A. (Wallace and Van Dyne, 1970). In this technique it is assumed that all of the lignin in the faeces is derived from the feed and that none of the feed lignin is digested during its passage through the animal. The digestibility of the feed is then calculated using the formula:-

$$\text{Digestibility \%} = \left(1 - \frac{\text{Feed lignin \%}}{\text{Faeces lignin \%}}\right) \times 100$$

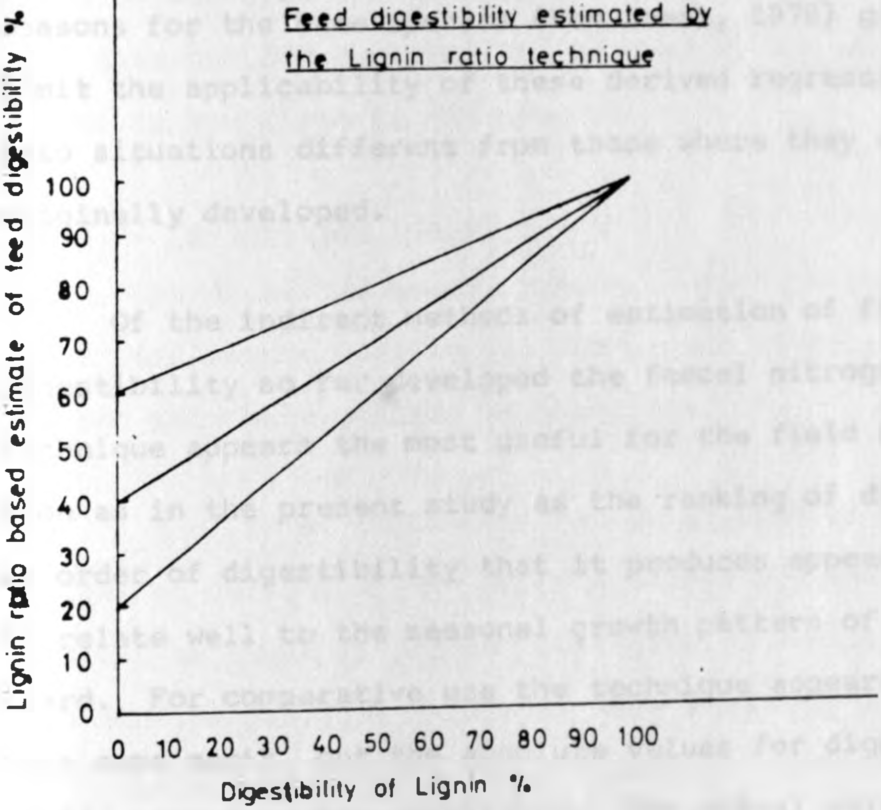
Feed lignin may be estimated from oesophageal fistula samples. However, the lignin component is not a single entity (Van Soest, 1982) and certain chemical constituents which comprise the lignin fraction as estimated, for example by the acid detergent method (Van Soest, 1963) may be to some extent digestible in the animal. Wallace and Van Dyne (1970) demonstrated that, far from being fully indigestible the lignin fraction could be up to 46% digestible in immature herbage, with even 4% being digestible in mature material. Such a digestible lignin result causes a downward bias in the estimation of digestibility based on the lignin ratio (Rittenhouse et al., 1972; Scales et al., 1974). For the present study the lignin ratio derived estimate for digestibility is indicated in Table 5.5. That the estimates of digestibility derived from lignin ratio may be unreliable is indicated by a knowledge of the seasonal characteristic of the sward at the time of sampling. Thus in May 1975 and June 1977 sampling was carried out during the latter part of the growing season when the sward was still of good nutritive value as indicate by the relatively high crude protein contents recorded for the oesophageal fistula samples at these times (Tables 4.34. and 4.37.). The digestibilities estimated from the lignin ratio were rather low for

Table 5.5. Organic matter digestibility estimated from lignin ratio.

Date		Stocking Rate		
		3 ha/hd	4 ha/hd	Mean
June	1974	48	26	37
October	1974	40	33	37
May	1975	37	24	31
August	1975	44	41	43
September	1976	38	42	40
June	1977	47	30	30

these two sampling dates, a result which would be unexpected, considering the relatively immature state of the herbage. Fig. 5.4. indicates the effect of the digestibility of the lignin on the overall estimated feed digestibility using the lignin ratio. The digestibility actually recorded by the lignin ratio technique, assuming that the lignin was indigestible, is shown as the intercept on the vertical axis for three sample values of 20, 40 and 60%. The effect of increase in lignin digestibility on the value for feed digestibility is shown for the three starting values. The lower the original value of the feed digestibility the greater the rise in estimated value for overall feed digestibility as lignin digestibility increases. If, as described by Wallace and Van Dyne (1970) some of the lignin in immature herbage may be digestible, the feed digestibility values for May 1975 and June 1977 would be raised from 30.5% and 36% to 57% and 61% respectively if the lignin digestibility was 40%. The actual digestibility of the lignin fraction in the present study was not known but the conclusion may be drawn that the value of feed digestibility estimated using the lignin ratio technique at these two sampling dates was lower than the true value. In the absence of knowledge of the actual level of lignin digestibility of the diet the lignin ratio based estimation of diet digestibility is of some what dubious validity.

Fig 5.4 Effect of Lignin digestibility on Feed digestibility estimated by the Lignin ratio technique



The use of other fibre fractions, such as acid detergent fibre (ADF), neutral detergent fibre (NDF) or ratios of, for example, ADL/ADF for estimation of digestibility has been discussed by Van Soest (1982). Variation in the proportions of the various component fractions between species (Sullivan, 1966) or between seasons for the same species (Van Soest, 1978) greatly limit the applicability of these derived regressions into situations different from those where they were originally developed.

Of the indirect methods of estimation of feed digestibility so far developed the faecal nitrogen technique appears the most useful for the field situation as in the present study as the ranking of diets in order of digestibility that it produces appears to relate well to the seasonal growth pattern of the sward. For comparative use the technique appears to have some merit, but the absolute values for digestibility remain rather unreliable. The actual values for organic matter digestibility which are predicted from the equations used in Table 5.4. and indeed from several other regressions examined appear to indicate rather small differences in the values between wet and dry season forage samples. The values of digestibility estimated for the dry season samples, in October 1974 and September 1976 appear to be higher than those recorded by other workers using hay made from species present in the sward (French, 1956; Marshall, 1967). How much of the difference between the results of such pen-feeding studies and these of faecal nitrogen studies such as in the present work might be due to the inaccuracies of the methodologies and how much to the maintenance of high diet quality by selection of diet by the grazing animal in the field is not clear.

5.3.3. Feed intake quantity

As discussed above, direct in-field measurement of feed intake quality has not proved to be practical and this also applies to quantity.

The use of exclosures for estimation of the removal of herbage by the grazing animal has the same problems as those of pre-and post-grazing sampling (See Section 5.3.2.). Attempts have been made to estimate intake by measuring the number of bites made by the animal (Stobbs, 1974). The estimates based on this techniques rest on two assumptions. In the first place the number of bites must be accurately recorded and with the use of suitable micro-electronics this has proved possible (Stobbs and Cowper, 1972). The second assumption is that the amount consumed per bite is accurately determinable. In a botanically complex sward where dietary selection is being practised it may not be possible to accurately assess the intake per bite or whether this amount is constant (Stobbs, 1973) so that the accuracy of the method remains questionable in practice.

If the digestibility of the diet and the total faecal output by the animal are known the diet intake quantity can be calculated by the formula here:-

$$\text{Feed intake} = \frac{\text{Faecal Output}}{1 - (\text{Digestibility }\%/100}$$

Faecal output has been measured either by total faecal collection using animals with attached bags (Schneider et al., 1955), or by means of some faecal marker technique as with Chromic oxide in the present study. Although there has been much discussion regarding possible deleterious effects of the presence of the collection bags on the animals' behaviour (Brisson, 1960)many studies have claimed that with a suitably designed collection bag the effects on the animal are minimal (for example, Raymond et al., 1953; Greenhalgh, et al., 1960; Ingleton, 1971). The accuracy of the estimation by the marker techniques has been discussed with reference to the example of Chromic oxide in the present study (See Section 5.3.1.). By either the total collection, or marker techniques, provided that the inter-animal (sufficient) variability effects are reduced by using ~~different~~ numbers of animals the faecal output has been shown to be measurable to a reasonable level of accuracy (Van Dyne, 1969; Scales, 1972).

The estimation of the digestibility of the diet is much more difficult than the determination of the faecal output. Estimates of absolute levels of intake by the use of the above equation may therefore be subject to considerable uncertainty. However, if the view is accepted that intakes estimated by this method are useful for comparative rather than absolute intake determination (Welch and Smith, 1969; Moore and Mott, 1973) the values derived in the present trial may be examined. Table 5.6. indicates for the present study the estimated intakes using the average of the seven values for digestibility from Table 5.4. and the faecal outputs from Tables 4.38., 4.39., 4.40., 4.41., 4.42., and 4.43. The values obtained for intake were considerably higher than those that were reported from pen-feeding studies in Uganda with the grass Themeda triandra, used at the flowering stage (Marshall, 1967). This grass was by far the most abundant in the sward at the present study site and observation of grazing behaviour indicated that it must have comprised a considerable part of the intake of the cattle in the grazing paddocks. The diet quality as measured by the crude protein content of the oesophageal fistula samples of the grazing paddocks for the dry season herbage

Table. 5.6. Daily organic matter intake based on faecal nitrogen derived digestibility and Chromic oxide tracer derived faecal output.

3 ha/hd		Stocking Rate	4 ha/hd	
kg/100kg Lwt.	$g/kg^{0.75}$ Lwt.	Date	kg/100kg Lwt.	$g/kg^{0.75}$ Lwt.
2.31	95	June 1974	2.16	91
1.77	74	Oct. 1974	1.62	70
2.73	109	May 1975	2.37	93
2.13	89	Aug. 1975	1.86	78
2.15	98	Sept. 1976	2.22	100
1.73	76	June 1977	1.79	78

sampling of October 1974 was much higher than that of the hay used in Marshall's study (Table 5.7.). This may be due to the ability of the animal to select from within the sward under grazing conditions, whereas the opportunity for selection in the pen-feeding situation is much more limited, as indicated by the comparisons of feed and intake composition presented by Marshall (1967). That the intake estimated for the grazing animals appeared to be higher than in the pens is in agreement with the general observation that intake and diet quality are directly related as reviewed by Minson (1982). The estimated intakes are in general higher than those recorded in the compilation by Cordova et al. (1978) although the tropical results derived using similar indirect methods gave dry matter intake values of 82-95g/kg $^{0.75}$ liveweight which is quite close to the present values in Table 5.6. (Oyen uga and Olubajo, 1975). Until the methodology of indirect estimation of digestibility is further refined there appears to be little value in comparison of the results of the present study with those from different situations.

5.4. Environment and animal performance

Some of the complexities hidden in the apparently simple environment/vegetation/animal system depicted in Fig. 1.2. have now been raised. The difficulties associated with modelling the stages of the

Table 5.7. Comparison of Crude Protein, estimated organic matter digestibility and daily organic matter intake of *Themeda triandra* hay with dry season grazing.

(Organic Matter basis)	*Themeda triandra* hay	Grazing Trial Results
Crude Protein	3.6	5.2
Digestibility	58	55
Intake kg/100kg Lwt.	1.4	1.7
Intake g/kg 0.75	56	73

system up to intake and digestion of the diet indicate the problems of determining under field conditions the exact diet in terms of quantity and quality that has been consumed. The hypothesis presented earlier, that the maximum vegetation production estimation may be useful in setting the limit to animal performance potential, relies on a knowledge of the intake characteristics of the grazing animal. Even for such a comparatively simple system of the beef steer it is clear that the intake characteristics will be dependant on the particular combination of climate, soil, vegetation and grazing animal factors at the particular time under investigation, with changes in any one affecting intake.

In spite of the difficulties just mentioned, there have been attempts to model the whole production system, using the large capacity of modern computing systems (Sanders and Cartwright, 1979; Konandreas and Anderson, 1982; Kahn and Spedding, 1984). Such models requires large amounts of input data and in some cases that availability of the data may limit the validity of the conclusions drawn. The Texas A and M University model (Sanders and Cartwright, 1979) has been criticised for example as the forage input parameters are input on a monthly basis, while it is known that within one month very great changes in forage quality and quantity may occur (Whelan et al., 1984). Intake characteristics for certain ages or classes of stock may not be available. Assumption have to be made for certain of the parameters or relationships, which will require further work to elucidate. For example, a production model used in Botswana includes assumptions regarding the voluntary intake parameters for young calves (Konandreas et al., 1983). The development of the models may, however, be extremely helpful in highlighting areas of lack of knowledge so that the need for research on the required parameter can be justified.

CHAPTER 6

SUGGESTIONS FOR FURTHER WORK

Of many possible avenues for further work suggested by the present study, two areas in particular are suggested as priorities.

The cutting trial has indicated the ability of this particular sward to withstand severe defoliation over ten seasons without evidence of serious loss of vigour. Other swards have not proved so robust. Clarification of the factors of soil, climate and the vegetation which provide this tolerance to defoliation would assist greatly in the criteria for selection of management practices to ensure good range condition in areas other than that studied.

With regard to the grazing study, during the course of the trial the selection of diet by the grazing animal appeared to be efficient even at a stocking rate of two hectares per head. The diet selected at that stocking rate appeared to be as good as that of the animals at more lenient stocking rates. An examination of the consequences of increasing the stocking rate even further to the point where selection becomes restricted and the reduction in sward bulk density affects quantity of intake would be of considerable value in the development of range management strategies. Within the range of stocking rates used in the present study the production per animal was relatively constant, so that production per hectare was increased with increased stocking rate. As intake quantity and quality are reduced with an increase in stocking rate to even higher levels the performance per animal will be expected to fall, but the consequences for production per unit area, so important under a settled pastoralist system, require careful elucidation.

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