APPLICATION OF NITROGEN AND IRRIGATION TO PASTURE TO ENHANCE DRY SEASON CATTLE PRODUCTION IN UGANDA

by

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A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Agriculture in the University of East Africa

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DECLARATION

I, Enos Robin Tiharuhondi, do hereby declare that the work presented in this thesis is my own and has never been submitted for a degree in any other University.

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(ENOS ROBIN TIHARUHONDI)

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I wish to acknowledge with gratitude the tremendous amount of help I have received from my supervisors, Dr. F.J. Olsen and Dr. R.S. Musangi, in the initiation and conduct of the study, and in the preparation of this thesis. Before the experiment was completed Dr. Musangi left Makerere University for the University of Nairobi but kindly accepted to remain my supervisor throughout; Dr. Olsen continued to call on me or visit the experimental site very often to advise and discuss with me any issues arising from the study.

Mr. S.V. Soneji occasionally advised me on analytical and sampling techniques applicable to our contemporary and related fields of research. Mr. Francis Bale and Miss Tarla Ghodgoankar carried out laboratory analyses for C.F. and C.P. in herbage, while the Chemistry Section, Kawanda Research Station, did the soil chemical analysis. The two groups of cattle used for the study were kindly borrowed from Nakyesasa Livestock Experiment Unit. Mr. Aloysius Kabanda and his casual staff assisted me in collecting most of the field data. Mr. Paul Kazibwe painstakingly typed this thesis. The helpful contribution

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CONTENTS

SUMMARY

In Section I a review was made of the problem of providing sufficient and nutritious pasturage in the tropics during the dry seasons when productivity is low owing mainly to the lack of soil moisture and partly due to the generally observed low nutrient content of most tropical soils. It was stressed that due to this handicap the indigenous cattle take longer to reach maturity and are made more susceptible to various local diseases which lower their lifetime productive performance.

Most of the means hitherto devised to circumvent this problem have, at least in the Uganda environment, offered no overall remedy, or are just expensive. In order, therefore, to maintain high and uniform productivity from pasture throughout the year, this study was initiated to ascertain the role of fertilizer nitrogen and/or supplemental irrigation in bridging the dry season shortage gap.

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In Section II 2.1 a brief review was made of the past research on Uganda pastures. It was noted that this has mainly been on species introductions from outside the

country and selection from local and introduced species and varieties for adaptation to different ecological zones under various management practices. The reduction in dry matter and quality yields in herbage during the dry seasons was acknowledged.

In subsection 2.2 the role of fertilizer N in pasture production was reviewed. Several workers seemed to agree on its incremental effects on the following: herbage dry matter yields; % C.P. and protein yield per unit area of sward; water use efficiency by individual plants; plant uptake of soil N; and herbage palatability, intake and digestibility. Note was also made of the forms, mobility and plant uptake of soil N; the type of N fertilizer to apply, the natural flush of N on moistening the soil following a period of dryness (the Birch effect); the frequency and time of applying N; hazards that may accompany the misuse of N fertilizers, being mainly over-succulence and lodging in plants, diminishing returns and the accumulation of nitrate-N to toxic levels in herbage. In addition, factors that may limit response to N were also listed as deficiency of other nutrients and lack of soil moisture.

In subsection 2.3, the place of irrigation in pastur production was reviewed. Note was made of the role of water in the life of the plant, where and when to irrigate and the comparative advantages and disadvantages of sprinkler and channel irrigation. Two factors that affect pasture response to irrigation were excessive irrig tion - which may lead to overflooding, soil erosion and leaching of nutrients in the soil - and the type of pastur and its grazing management.

Lastly, a brief review (subsection 2.4) was made of the methods of measuring pasture out-put. The merits and demerits of grazing vs. clipping were considered. Yields which are estimated by clipped samples would obviously be inflated since, in practice, the grazing animal would tread on, defoul, and selectively graze, herbage. For better utilization of grazed pasture attention was drawn t the use of animals of high production potential as well as the attainment of optimum grazing management.

Section III describes the experimental site, design, materials and methods, the results of which are presented in Section IV. These are, weather, soil moisture and chemical composition, herbage dry matter yields and chemica composition, cattle-days, stocking rates and liveweight gains. The section ends with a note on basic input/output considerations.

In Section V the results of the experiment are discussed and conclusions drawn from them. Pasture management is a bipartite enterprise which entails first the techniques for the production of herbage and then its utilization by livestock. It was found that only the application of N with irrigation maintained steady herbage production which, in the two highest N treatments, were able to keep cattle at pasture throughout the year. With nitrogen alone grass production was curtailed during the dry seasons, which necessitated reduction on stocking rate or deferment of grazing. For N to be of some benefit, it had to be applied when there was moisture to dissolve it into the soil for mobility and ease of uptake by plants. Irrigation of grassland alone progressively reduced herbage yields and consequently this treatment produced the least animal liveweight gain.

The crude protein composition of herbage was significantly increased by each increment of N. Within treatments % C.P. fluctuated seasonally in the non-irrigated swards but was more or less uniform in the irrigated swards. There was a moderate decrease in the C.F. content at each increment of N. None of the levels of N accumulated NO_3-N in herbage to reportedly toxic concentrations, nor did any of the treatments have detrimental effects on the constitution of other soil nutrients. This was most probably due to the application of N in splits in combination with rapid frequencies of rotational grazing which offered satisfactory grazing management.

The highest net gain was obtained by using 400 lbs N per acre in irrigated and non-irrigated pasture. Thus, one may choose either the timely application of N alone up to about that level but with a probability of pasture shortage during the dry seasons, or irrigation with N for uniform and higher productivity throughout the year.

A schedule was drawn up for the timely application of N for three types of environments: (i) areas receiving rainfall evenly throughout the year or where irrigation is practised, (ii) areas with a bimodal pattern of rainfall, and (iii) areas with a unimodal type of rainfall. Profitable pasture overhead irrigation was recommended for intensive dairy production and for the breeding stock on extensive beef production ranches; small-scale producers were excluded owing to economies of scale. Positive response to grassland irrigation with N which was obtained in the moist tropical climate of Kabanyolo gave promise for higher response in drier areas of East Africa, while the prospect of an irrigation system in the tropics would ensure plentiful supplies of water for other crops, other farm and domestic activities, as well as for cattle at pasture.

In drawing conclusions, necessity was felt for more information on some of the aspects not adequately covered by this study, namely, (i) a similar study carried over a longer period than just two years, (ii) the use of more yielding breeds of beef cattle, (iii) evaluation of similar pastures in terms of milk yield, and (iv) a study of internal parasite infestation that may result from the use of heavy rates of N with irrigation.

I. INTRODUCTION

Tropical grassland forages are characterised by rapid growth rates during those periods when there is adequate moisture in the soil, followed by reduced yields and a deterioration in quality in the dry season (French 1957). Later workers, Oyenuga (1957), Bredon and Horrell (1961), Bredon and Horrell (1962), Johnson, Hardison and Castillo (1967) also presented similar evidence. In the Philippines for instance Johnson *et al.* (1967) reported that herbage yield increased at an increasing rate with maturity but was depressed by about 40% in the dry season, accompanied by a corresponding decrease and increase, respectively, in crude protein (C.P.) and crude fibre (C.F.).

This phenomenon is best explained by two groups of early workers. Firstly, Woodman and Evans (1930), observed that dessicating environmental conditions do stimulate an early onset of lignification, thus forages of tropical regions where rainfall is erratic often develop higher proportions of carbohydrates and high lignin content at an earlier vegetational stage than in temperate regions. Secondly Richardson, Trumble and Shapter (1931), observed that N and P_2O_5 absorption is greater in the early vegetative phases but decreases as the early leaves reach maturity. It will be noted that N and sometimes P are the constituents of protein.

The foregoing observations also comform with the results obtained much later from pastures at Kabanyolo by Musangi (1965) who found that there was a decline in herbage digestibility due to increased C.F. content, and decreased C.P. content as the dry season progressed. The fall in C.P. and the rise in C.F. in the herbage was much faster than in the temperate latitudes where the period of good quality herbage production is long.

As pointed out by Milford and Minson (1965), the depression in herbage quantity and nutritive value in turn leads to reduced performance of livestock that mainly depend on grassland. In Uganda, Harker, Taylor and Rollinson (1954) had observed a tendency for animals to have extended grazing hours in dry seasons when inferior pastures prevailed. This adaptation of grazing hours to grass availability offers suggestion as to why under tropical conditions generally rearing for slaughtering is longer, and therefore lifetime efficiency of food conversion lower, than in the temperate regions. Animals are kept at maintenance or sub-maintenance conditions because no amount of extension of grazing hours in a poor pasture can make good those nutritional deficiencies.

Several ways have been devised to circumvent the effects of drought. Supplementary or "emergency" feeds can be purchased or improvised on the farm. Unfortunately most supplementary feeds are more expensive than grazed grass which was shown by Hamilton (1955) to be the cheapest source of food for ruminant livestock. However, in dairy cattle the level of concentrate supplementation will depend on the relative prices of concentrates and milk.

Conservation of wet season surplus herbage as hay is not a countrywide remedy. In Buganda, for example, the time when nutritive value of grass is optimum for cattle feeding and when hay should be made coincides with heavy rains and cloudy weather. Ensiling requires special skills seldom to be found in a majority of farmers. Moreover, there are losses in nutritive value and palatability when herbage is converted into silage or hay, as was shown by French (1939); these can be magnified if the process of conservation is carried out badly.

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The centuries - old nomadic system of migrating from place to place in search of fresh pasturage and water, and the firing of grasslands during the dry season to induce a flush of young grass in the following rains are good practices as long as there is still plenty of unclaimed or unsettled land.

Stobbs (1967) had suggested that part of the livestock could be sold before the dry season and additional animals bought during the seasons of flush growth in order to adjust animal numbers to forage resources. However, this would result in seasonal peaks in the number of livestock offered for sale, thus causing inefficiencies in the marketing system and a depression in prices. Alternatively, one could do very little or just nothing about fodder conservation or supplementary feeding and hope that one's stock would recuperate after the period of undernutrition through compensatory growth (Wilson and Osbourn, 1959). This is largely what is being done under the traditional systems of animal husbandry in the country where such intermittent growth patterns are rather more debilitating than beneficial to the animal's productive vigour.

The most important part of the diversification programme for agriculture in Uganda's Five-Year Plan (1966-71) is the development of the livestock industry. This is aimed at checking the present big deficiency in protein diet of the population, and to meet the rising demand for meat, milk and other dairy products which are presently being imported in large quantities. Most of this extra milk output will have to come from exotic breeds of dairy cattle managed on intensive grasslands in the wetter and cooler areas of the country, while beef will have to come mostly from several of the large-scale ranches planned in the drier areas of the country.

Liebig's-Law-of-the-Minimum indicates that "the yield of a crop is determined by the amount of the growth factor (water, light, heat and essential nutrients) present in the least abundance". As for light and heat, Huxley (1962) found that even in a cloudy area like Buganda, these would not limit plant growth throughout the year. It has already been shown that water is a limiting factor during the dry periods so far as pasture production is concerned. With regard to nutrients, grass production is limited mainly by lack of nitrogen. This is supported by substantial increased herbage D.M. obtained in E. Africa by Birch (1959), Dougall (1954), Horrell and Court (1965), and Poultney (1959) when nitrogen was provided on short grasses. However, none of these workers used higher rates of nitrogen than 200 pounds per acre. In Puerto Rico, however, Vicente-Chandler et al. (1959) obtained strong response to 800 pounds of actual nitrogen per acre from three tropical grasses.

The problem, therefore, is one of finding cheap and applicable ways and means with which to bridge the dry season gap so as to obtain uniform production from pasture and livestock all the year round. This study was therefore initiated to investigate the dry season productivity of a planted pasture when sufficient amounts of the two limiting growth factors, nitrogen and water, were supplied appropriately at various levels throughout the year.

Responses to four rates of fertiliser nitrogen, each with and without irrigation were studied under the following objectives:

(i) to obtain seasonal and annual liveweight gains and grazing days from cattle grazing the experimental pastures,

(ii) to determine the progressive effect of these treatments on the chemical composition of the soil and sward growing on it, and

(iii) to evaluate the place of pasture irrigation in this environment and the level of fertilizer nitrogen that could profitably be combined with it.

II. REVIEW OF LITERATURE

2.1. Previous Research on Uganda Pastures

2.1.1. Introduction

The better utilisation of permanent or natural pastures has hitherto been studied by the Department of Veterinary Services and Animal Industry while the Department of Agriculture has mainly worked on temporary or planted pastures, plus a bit of work on re-seeding or oversowing permanent pasture with more desirable grasses and legumes for grazing.

2.1.2. The birth of ley farming concept in Uganda

In the 1920's continuous cultivation was tried but failed to maintain productivity. Consequently in 1933 the Department of Agriculture instituted a policy of cropping for 2 years and resting under natural regeneration for 4 years, for the "short grass" (or annual cropping) areas (Martin, 1944). In addition long term experiments were set up to ascertain the optimum crop/rest ratio for maximum arable crop production in the absence of fertilizer use.

It was first recognised by Martin and Biggs (1937) that regeneration of vegetation on resting lands was often slow and ineffective at first in controlling soil erosion, especially when it was grazed. Thus Martin and Badcock (1937), Hosking and Stephens (1941) and Horrell (1963) initiated work on finding suitable grasses to plant on these lands.

Martin (1944) showed the inability of pure stands of legumes to achieve the same result. He, however, observed that the ideal would be a combination of grass rotation with manuring, either organic or artificial in order to preserve crumb structure.

Mills (1953), in a trial running since 1933 with no inorganic fertilisers, showed that continuous cultivation was possible as long as adequate erosion control measures were practised and heavy dressings of manure applied. These results were confirmed by another long term rotation trial by Jameson and Kerkham (1960) who showed the necessity for a rest period and the use of farm yard manure especially in densely populated areas practising mixed farming.

(a) Grazing the resting land

Although Martin (1944) had suggested controlled grazing of the resting land, little attention was paid to grazing in the early years. It was thought that resting land should beleft ungrazed so as to provide a cover that would reduce soil temperatures and oxidation of organic matter to prevent the carry off of nutrients by stock. But Kerkham (1947) showed that utilising the resting land with stock caused no drop in subsequent crop yields and would increase the gross cash return from the land. This was confirmed by Stobbs (1969), and from the studies of Joblin (1960) on the effects of day grazing and night paddocking on subsequent crop yields. Thus the original idea of grass "rest" was replaced with the new concept of profitable ley-farming.

(b) Fertilization of pasture

Martin (1944) had indicated the desire for the application of manures to leys so that the regeneration of soil structure could be coupled with the benefit of manuring. In spite of this and the fact that Mills (1954) had laid fertilizer trials on Chloris gayana as early as 1950, until 1958 most trials were carried out in the absence of inorganic fertilizers. Thus, when it became apparent that pasture species could not realise their full potential if unfertilised, in the years 1958-60 soil fertility investigations were centred on defining the major soil nutrient deficiencies. For the Serere soil types these were N, P and S.

Horrell and Court (1965) showed that grasses responded heavily to N but not to P and S in the absence of N, and that, on the other hand, pasture legumes responded very markedly to P and S. These findings led to evolution of the idea that the most profitable ley farming system would be based on the use of mixed grass/legume pastures with the dressings of locally produced (and cheap) single superphosphate, containing both phosphate and sulphur. Confirmation of this hypothesis came from a large-scale grazing trial by Horrell and Newhouse (1965), in which substantial benefits were obtained from a pasture at relatively small costs.

(c) Inclusion of legumes in pasture

Following the success of clover in pastures in temperate countries and the highlands of Kenya, various indigenous and introduced legumes were tried as pasture species both at Kawanda (Simpson, J.R. Unpublished) and Serere (Horrell, 1958a) first in observation plots where persistence, production, nodulation, nitrogen fixation, need for inoculation and seeding properties were noted. Then the most productive and persistent in small plots were sown in trial mixtures with various grasses and their performance measured under both cutting and grazing. Subsequently, Horrell (1964) and Tiley (1965) reported the beneficial contribution to yields of grass components in a mixed sward of grass and legumes, while Joblin (1960) and Stobbs (1967) obtained improved liveweight gains from grass/legume pasture mixtures.

Williams (1967) recently concluded from reviews of results from West Indies and South America that legumes fix N in inverse relation to the amount of nitrogen available in the soil. Thus, in situations where relatively higher levels of N are applied to grassland the legume will almost be useless as a source of nitrogen.

2.1.3. Elephant grass as a fodder in Uganda

Following early observations as partly reported by Martin (1931) of the decline in soil fertility under continuous cropping and of the value of the grass ley in accelerating the processof soil improvement, the Department of Agriculture in the 1930's initiated studies on planted elephant grass as a resting crop at Bukalasa and Kawanda. Both places are situated within a belt of country where the grass is a natural dominant species (Langdale-Brown, et al., 1964). Later, the original idea of grass "rest" was replaced with the new concept of profitable ley-farming, first advocated by Kerkham (1947). Greater emphasis was then put on managing elephant grass as fodder for cattle particularly during the dry season.

Much of the information relating to the problems encountered by early workers on the establishment and management of elephant grass under grazing and cutting will be found in a review by Tiley (1958) for the years 1936-59. The most outstanding problem, even today, is the tendency for elephant grass to die out under regular or intensive grazing as was reported by Thomas (1937, 1938 and 1941), Kerkham (1947) and Horrell (1958). On the other hand Edwards (1952) and Kerkham (1949) reported the grass to have considerable powers of persistence under cutting treatments.

The desire to graze rather than to cut and carry the grass to stock is based on the following points of advantage:

(i) The increased cost of labour in having to cut and transport a bulky material of about 80% water to stalls and the disposal of the rejected material. It is cheaper to take an animal to its food than the reverse.

(ii) As herbage is cut and carted away fertility is removed from the land faster.

(iii) Because of the plant's tall and thick but flexible stem growth, very little loss is incurred from trampling and soiling - an attribute not found in other tropical grasses where lush growth (through fertilization) becomes soiled readily on trampling and is not eaten by the animal.

(iv) Selective or preferential grazing is non-existent in row planted elephant grass mainly because the animal droppings fall to the ground and do not soil the forage growth. This leads to uniform recovery after grazings.

Past work on fodder elephant grass has hitherto been confined to introduction and selection from the introduced and indigenous material for adaptation to local conditions and productivity under various management practices.

There are to-date some 150 strains at Kawanda collected from several localities all over the world. It is now felt that a stage is set for a start on improving some of the present species' characteristics through breeding. Some of this work has been initiated by Fernandes (1969) with the aim of breeding strains of elephant grass x bulrush millet that are capable of maintaining high dry matter yields and digestibility particularly during the dry seasons. Musangi (1969) gave the following example in which the nutritive value of elephant grass deteriorated with advancing maturity:

Weeks after establishment	% digestible C.P. in elephant grass
3	14
6	12
9	6

It is hoped that intermediate hybrids will be obtained which will possess the sturdiness and perennial habit of elephant grass and the tenderness, annual habit, shortness and early maturity of bulrush millet.

2.1.5. Conclusion

Studies on grass and legume species for planting in the temporary leys have been carried out in Uganda for many years. As a result of systematic examination of numerous grasses and legumes at Serere Research Station since 1954 and at Kawanda Research Station since 1956, basic recommendations for ley plantings are now available to farmers in the various ecological zones of Uganda (Agricultural Production Programme, 1966). However, most farmers in these areas continue to operate under natural conditions in which grassland production is curtailed in drought periods in particular, and by low soil fertility in general.

2.2. The role of fertiliser nitrogen in pasture production

2.2.1. Introduction

In most plants all the vital processes are associated with the presence of a functionally reactive plasma in the proteins of which N is always present. N is also present in chlorophyll, the nucleotides, phosphatides, alkaloids, many enzymes, hormones and vitamins - all of which are of great physiological importance in metabolism. If a plant is deficient in N it therefore remains small and rapidly turns yellow for lack of protein and chlorophyll. The assimilatory power of the plant is restricted and carbohydrate production is diminished. This, in grasses for instance, leads to premature and defective inflorescence and seed development whereby the growing period is shortened.

2.2.2. Records of the previous experiments with fertiliser N.

The use of fertilizer N in tropical and sub-tropical pastures was reviewed by Henzell (1962) and De Geus (1967). There is sufficient evidence from workers in the above reviews and elsewhere in the temperate latitudes to show that, when other factors are not limiting, N benefits a pasture in two main ways:-

(i) increasing herbage dry matter yields, and

(ii) increasing the % C.P. and protein yield per unit area of sward.

(a) Nitrogen and water use efficiency.

Coupled with dry matter yield increases as a result of N fertilization is the enhanced water use efficiency by individual plants. Smika *et al.* (1961), Smika *et al.* (1965), Haas (1958) and Black (1968) reported that the water use efficiency of their pasture grasses increased with the increasing levels of N and was related curvilinearly to available moisture supply. This they attributed to a larger and deeper root system that is developed in fertilised plants.

(b) The effect of N fertilization on the release of soil N.

Bokde (1967) reported that applied N was more effective in increasing the total protein yield than in increasing the green fodder or dry matter. The increase in N in plants has been shown to be proportional to the rate of application. Aleksic *et al.* (1967) and workers who were reviewed by Allison (1966) concluded that the application of N greatly increased the amount of N taken up by plants from the soil. This suggests that applied N has a priming effect on the mineralisation of soil N, which in turn enhances the development of more roots and shoots that take up more N from the soil.

(c) The effect of N fertilization on herbage palatability, intake and digestibility.

There is evidence by Miller and Terwillinger (1961) and Andrews and Hoveland (1965) that N fertilisation increased the apparent palatability of their grass species to cattle. Burton, Southwell and Johnson (1956) found no evidence that rates of N up to 1500 lb. per acre decreased the palatability of coastal Bermuda grass; in fact N tended to increase its palatability. Reid, Odhuba and Jung (1967) observed that herbage fertilised with higher levels of N or N and P was consumed in greater amounts than the non-fertilised grass. Hardison *et al.* (1954) showed that grazing cattle ate 23% more C.P. and 29% less C.F. than was indicated in the clipped herbage samples. Subsequently Heady and Torrell (1959) observed that sheep, not only selected different plants but also different parts of those plants. This largely explains the fact that in the studies by Weir and Torrell (1959) sheep ate 4.1% more C.P. and 3.5% less C.F. than was indicated in clipped samples.

On digestibility, Reid, Jung and Kinsay (1967) found that digestibility of dry matter increased slightly as N level increased, while in the studies by Leslie, Hemken and Clark (1966), Reid, Jung and Murray (1966), and Reid and Jung (1965b) digestibility of D.M. usually increased as N levels increased. Reynolds, Barth and Fryer (1969) using 100 and 200 lbs N/acre found that doubling the rate of N nearly doubled the estimated TDN within each harvest frequency. On the other hand Moon (1954), Bratzler *et al.* (1959) and Markley *et al.* (1959) obtained an increase in the apparent digestibility of C.P. due to N fertilization, the latter two obtaining an increase in digestibility of energy. These results agree with those of Sullivan (1964) who found that % C.P. was highly correlated with % digestible protein (r = 0.99) for all the data he studied, and that C.P. content was highly correlated with digestion coefficients of D.M. and C.P.

Milford and Minson (1965) stated that the rate of intake of a feed depends on the rate at which digesta disappears from the rumen, i.e., on the rate at which it is broken down by a process of bacterial and protozoal fermentation. Thus, an animal which (selectively) grazes nitrogen-rich plants will provide more energy to the rumen flora, and consequently have higher dry matter intake and increased digestibility of nutrients. It follows from this that the low feeding values of many mature tropical grasses are due to low energy intake caused by lack of C.P. as a source of energy for the rumen flora.

2.2.3. Soil Nitrogen

The natural reserve of N in the soil depends on the presence of organic matter (convertible into mineral N by soil microorganisms) as can be found in those of organic origin such as the moor soils (peats). As there are no soil forming minerals which contain N, most mineral soils are consequently poor in N. Thus, most fertiliser N represents a net gain to agriculture since N fertilizers are now obtained chiefly from the industrial fixation, and from such natural sources as Chilean nitrate of soda and coal that lie outside the soil/plant system.

(a) Mobility and Uptake of Soil N by plants

Plants can take up their N either as NH_4^+ or NO_3^- ions but largely as the latter although most plants probably can use either equally easily (Russell, 1950). However, by nature of their charges, all the nitrate ions in the soil are dissolved in the soil solution whilst, if the soil contains much clay or humus, much of ammonium will be present as an exchangeable cation and hence not in solution, and thereby not readily available.

Thus, in comparison with the NH_4^+ ion which is absorbed by soil colloids, the NO_3^- ion is extremely mobile in the soil and can easily be lost by leaching (Parish *et al.*, 1962). For this reason a nitrate fertilizer is sometimes regarded as more available and rapid acting than an ammonium fertilizer. But in most arable soils, especially the moist soils of the tropics, added ammonium ions are rapidly oxidised to nitrate so that nitrate is the form present in appreciable concentration in the soil solution for the plants to take up.

(b) <u>The type of N fertilizer to apply.</u>

In the tropics ammonium sulphate has been the most commonly used N fertilizer in spite of its harmful effects of lowering soil pH and the leaching of soil bases especially Ca and K, as was recorded by Haylett and Theron (1955) in South Africa; Weinmann (1950) and Saunder (1959) in Rhodesia; and Abruna, Pearson and Elkins (1958) in Puerto Rico. Volatilization has been noted in water-logged or ponded soils. The absence of O_2 in such soils causes N_2 loss to the air from NO_3^- through denitrification. Thus, nitrate fertilizers are a poor choice for paddy soils. Urea and ammonium nitrate would seem to offer the best alternatives, urea because it offers the cheapest form of N, and ammonium nitrate for having both NH_4^+ and NO_3^- in equal proportions. To avoid a build up of acidity, calcium ammonium nitrate can be applied.

(e) Nitrification in soils after dry periods

In his exhaustive studies of East African soils, Birch (1960) showed that drying soil samples prior to moistening them remarkedly increased the mineralization of natural N during subsequent incubation. He found that for a particular soil, the amounts of N mineralized were proportional to the C content of the soil, and a direct function of the logarithm of the length of time that the soil was dry before wetting and incubation, and of the temperature of the soil during the dry period. The magnitude of these effects for a given soil dried for a given period gradually diminished with each successive drying and re-wetting as the supply of material involved was depleted. Similar findings were obtained more recently by Semb and Robinson (1969). Although several possible causes for this phenomenon (now commonly referred to as "the Birch effect") have been put forward by several workers elsewhere, under the East African conditions, the large accumulation of nitrates in the surface soil can be ascribed mainly to microbiological processes during the dry season associated with a freshly developing population and a result of the decomposition of micro-organisms killed during the preceding drying.

These findings are of very great importance especially in countries with pronounced dry and wet seasons. For instance, after 9 weeks of drying, Birch (1960) obtained an equivalent of one ton, and 341 lb. of sulphate of ammonia per acre per annum from the soils with the highest and least amount of carbon, respectively. Therefore, among several other things, in N fertilizer trials, account would have to be taken of the time, frequency as well as place of application. Where irrigation is practised it is highly likely that continuous irrigation would have different results from irrigation with periods of drought in between.

(d) Frequency and time of applying N.

Nowadays it is conventional to apply N fertilizer to pasture in split applications rather than in a single huge application. This practice has the following advantages:

(i) similar or uniform yields are obtained at each cutting or grazing;

(ii) the possibilities of scorching the herbage or reaching the toxic level of nitrites and nitrates in herbage as would result from large single applications are minimised; and

(iii) losses of N through volatization, leaching or erosion are also minimised.

Weir and Davidson (1968), Henzell (1963) and Crowder, Michelin and Bastidas (1964), noted that the yields and nutritive value of tropical forages were increased for only the first few months after application, but thereafter they were not significantly greater than the unfertilized controls. This is the basis for timely split applications as a means of altering the seasonal pattern of pasture production with important consequences for animal production.

The number of splits per annum will largely be governed by the seasons of a particular area, and the method of utilizing the resultant herbage. Apart from increasing labour costs and farm expenses, Anon (1956) found that splitting the fertilizer into too many dressings reduced yields.

Burton and de Vane (1952) found that 2 or 4 equal applications compared with annual single applications increased yields in wet seasons but had no effect in a year of average rainfall with no unusually heavy rains. In Puerto Rico Vicente-Chandler et al. (1959) found no advantage in applying N in more than six applications per year. Applications can therefore conveniently be made possible after each, or every other, cutting or grazing.

The National Research Council (1963) recommended 9 to 10% C.P. as minimum requirement for 600-lb. yearling cattle. This means that increased protein contents due to fertilization would not affect gains per head if all the contents are above its minimum needs. In areas where hay can successfully be made, light N applications could be given to a pasture just to raise the % C.P. to the required minimum for the grazing animal, and heavier dressings given just a few weeks before harvesting the herbage for hay. This would allow the crop to absorb much of the added N but little time for the synthesized protein to increase the growth of the crop appreciably (Ferguson, 1948 and Lewis, 1941). The hay containing higher nutritive value would then be fed during periods when protein contents in the feed are near or below the minimum requirements. Employing this practice, Moon (1954) found that the increased protein was associated with a higher digestibility of the protein, and that fertilizer N which was absorbed by plants appeared to be converted into completely digestible protein.

Horrell and Bredon (1963) suggested that pastures could profit from application of N fertiliser towards the onset of the rains and dry season. The need for application at the onset of the dry season is clear as this could produce abundant forage to be carried over into the unfavourable part of the dry season. However, where a substantial amount of N is expected from the natural flush due to the Birch effect, and if the overproduction of succulent herbage is to be avoided, N fertiliser should be applied about the middle, not at the start, of the rains when the effects of the first rains and the Birch effect are beginning to tail off.

2.2.4. Hazards that may accompany the misuse of N fertilizers.

(a) Succulence

Plants with a very low N supply usually have leaves with small cells and thick walls, and they are consequently harsh and fibrous. On the other hand, excessive dressing of N induces a luxuriant development of aerial vegetative organs. Such plants will be strongly stimulated to use the bulk of their assimilates (carbohydrates) to synthesize protein for the fresh vegetative tissues. Insufficient amounts of the higher carbohydrates will be used in the structural and strengthening tissues. Such tissues will then be spongy, weak, and plants will become more susceptible to lodging and certain diseases.

It has frequently been expressed that little of the succulent grass resulting from heavy N dressing would be taken by animals. However, Holmes and Lang (1963) showed that the D.M. intake of cattle feeding on such fresh herbage was unlikely to be restricted either by a high internal water content in the herbage or by rain on the leaf surface. Moreover, from the studies by Wilson et al. (1962) and Wilson (1961b) it was observed that grazing cattle took less free water plus more feed water in the wet season, and more free water plus less feed water in the dry season. Reasonably succulent herbage could therefore be considered as a means of offering part of the water to animals at pasture without affecting their intake.

(b) Diminishing returns

In most of the experiments reported in the review by Henzell (1962), yields of tropical grasses, as determined by cutting techniques, increased in proportion to the quantity of N fertilizer at low and intermediate rates of application. Within limits there is a "straight line" response but with heavier rates of N the law of diminishing returns operates and ultimately yields are depressed by excessive quantities of fertilizer.

Russell (1950) showed that the N/yield relationship followed a sigmoid curve although the lower part of the S may often be obscured if there is a large gap between the nil treatment and the lowest fertilizer rate. McGinnies (1968) noted that the increase in yield per unit weight of N applied declined as the rate of N increased. Thus, with the massive doses of up to 2000 lbs N per acre, Little *et al.* (1959) and Rodriguez (1949) both from Puerto Rico obtained the most efficient addition to dry matter production with 200 or 400 lbs N per acre, irrespective of the kind of grass or the frequency of cutting, although % C.P. rose up to the highest rate. In Uganda, Olsen (1969) reported the

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In the celebrated Puerto Rican experiment by Little *et al.* (1959) it was reported that the nutritive value of their forages decreased very rapidly with age irrespective of the level of fertilization. Similar inference was obtained in temperate latitudes by Rogler and Lorenz (1969) who reported that forage continuously grazed was higher in protein than forage protected by cages. Therefore the use of N calls for better utilization of pastures so treated, that is, at the stage when the nutritive value is optimum.

(c) Nitrate poisoning

The use of large amounts of N fertilizer on forages causes an accumulation of excessive amounts of nitrate-N and nitrite-N in forage plants that can pose serious problems to animals (Case (1957), and Wright and Davison (1964)). Deaths of ruminant animals, loss in milk production, abortion and loss in weight have been noted and attributed to the non-protein portion of the nitrogenous constituents of forage plants, mainly the nitrate-N.

Crawford, Kennedy and Johnson (1961) listed factors that greatly affect the concentration of nitrates in forages as the level of N fertilization, the species of forage, the part of the plant, the stage of maturity and the light intensity. They found that the time of N application, the kind of N carrier, the placement of N fertilizer and the addition of other plant nutrients had only small effects on the concentration of nitrate in forages. Hanway and Englehorn (1968) noted that frequently the nitrate content of plants increased as the level of N fertilization was increased. Similarly, Murphy and Smith (1967) reported a direct effect on nitrate-N accumulation by increased N fertilization, and a decline of it with advancing plant maturity. Working in Canada, Cairns (1968) tested three fertilizer sources of N at 100 lbs N/acre per annum and noted that nitrate levels did not vary with sources of N and were highest in crops in the years of adequate rainfall. In contrast, Kretschmer (1958) had noted that drought conditions enhanced nitrate accumulation in forages, although he was not sure whether this was due to the decreased growth rate or merely due to plants accumulating nitrate. The same worker also observed that annual crops tended to be nitrate accumulators while perennial crops tended to be non-accumulators.

Bradley et al. (1940) considered a minum toxic level to be about 0.20% of the dry matter as nitrate-N. Morris, Cancel and Gonzalez-Mas (1958), using up to 2400 lb. of a 10-10-10 mixture detected no poisoning within five weeks of application. Engibous et al. (1958) noted that the toxic level tended to be very high so much that some grasses could tolerate as much as 480 lbs N per acre at a time. Similarly, Little et al. (1959) detected only traces of nitrates that could be toxic to cattle even at the highest level of 1600 lbs N/acre. However, from his preliminary work on tropical grasses in Uganda, Olsen (1969) obtained an average of 0.2 + % nitrate-N at 800 lbs, reaching an average of 0.45% at 2000 lbs N/acre given in five splits per year. Therefore it would appear that the extremely high levels of N fertilization might be toxic to livestock, here.

It is interesting to note that in future it may be possible to pre-treat fertilizers with chemicals that have been shown, for instance by Nowakowski and Gasser (1967), to prevent the accumulation of nitrate-N to toxic levels in forages.

2.2.5. Factors that may limit response to N fertilization

(a) Deficiency of other nutrients

Only potassium and phosphorus will be discussed here since these two are the major nutrients that are found to limit grassland response to N, especially where large amounts of N are applied.

In plant metabolism K is important in the synthesis of amino acids and proteins from ammonium ions (Wall, 1940), and also important in the photosynthetic process or carbondioxide assimilation (Gregory and Richards, 1925; Gregory and Baptiste, 1936; Eckstein, 1939).

Phosphorus plays a fundamental role in the very large number of enzymic reactions that depend on phosphorylation. It is a constituent of the cell nucleus and is essential for cell division and for the development of meristem tissue (Russell and Martin, 1949).

Since N fertilization is usually accompanied by increased plant growth, K and P become necessary so as to play their part in the processes that mainly accompany growth. In the field K supply in the soil may be adequate for crop growth where N and P are in a low supply but it becomes inadequate when these are increased. So would P if N and K were increased. In their studies on long term effects of fertilizers on herbage production Heddle and Crooks (1967) found that without applied K and P herbage K and P concentration fell with time especially under heavy N application. Heddle (1967) reported that whenever the K supply was reduced below a certain minimum the response to N fell. A similar result was recorded by Castle and Holmes (1960) over a period of 12 years.

Under the intensive management of forage in Puerto Rico, Little *et al.* (1959) noted that factors that affect yields largely determine the fertilizer requirements. Thus P and K requirements of grasses were increased severalfold when yields were increased by N fertilization. Similarly, N requirements were increased when yields were increased by irrigation. K is relatively more mobile in the soil than P which is strongly fixed against leaching. For this reason the above workers recommended that K should be applied in several applications yearly to avoid luxury consumption by the first growth after fertilization to the detriment of latter crops. Phosphorus should be applied only once in a year as there is little luxury consumption of this nutrient by forages.

(b) Lack of moisture (See sub-section 2.3.4 (c))

2.2.6. Summary and conclusion

The foregoing evidence shows that when the right type and quantity of fertilizer N is applied to pasture at the right time and in the absence of other limiting factors, it would have the following incremental effects on: herbage dry matter yields, % C.P. and protein yield per unit area of sward, water use efficiency by individual plants, plant uptake of soil N, herbage palatability, intake and digestibility.

2.3. The place of irrigation in pasture production

2.3.1. The role of water in the life of a plant

This can be summarised from the records and reviews on the subject by Russell (1959), Gates (1964) and Slayter (1967) as follows:

(i) Water is required to transport raw materials and finished products within the plant;

(ii) it maintains the proper consistency of the living protoplasm in which the growth processes take place;

(iii) it provides the necessary working pressure in the growing cells;

(iv) it provides the sole means whereby plants obtain nutrients from the soil; and

(v) it is required for photosynthesis.

Eighty per cent or more of the plant's substance is composed of water. Thus, if water is lost by plants faster than it can be taken up from the soil, or if there is insufficient soil moisture available, the result is loss of turgor, and the plant will droop and wilt. This forces the stomata to close so as to reduce transpiration. The closure of stomatal openings is accompanied by reduced intake of carbondioxide and reduced carbohydrate production and, finally, cessation of growth, for only turgid cells can grow. Secondly, Rickard (1956) has observed that high temperatures in the surface soil are destructive to the delicate and shallow roots of pasture plants. This was shown to delay recovery when water again became available.

2.3.2. <u>Where and when to irrigate</u>

Under practically all climatic conditions there are certain periods during the year when soil moisture becomes a limiting factor for plant growth even in areas of high rainfall. Trumble and Walker (1952) quoted figures from Nicaragua which indicate that in spite of a rainfall of 152 inches per year supplemental irrigation is beneficial in the period February to April, although an average of 20 inches of rain is received during those three months. Similarly, Kleinschmidt (1967) had to include an irrigation treatment as "periods of moisture stress are common at Lawes (Qd., Australia), even during the wet season". In the tropics wet and dry seasons are in most places definite so that irrigation can be planned beforehand.

The question of when to irrigate (and when not to irrigate or to stop irrigating) is best answered when the total requirement of a crop is known. This in turn requires a knowledge of how much of the incoming water (rain and irrigation) is lost in a specific time. The total requirement is governed by the length of the growing season, ambient temperature, method and frequency of irrigation, and depth of wetting. On the other hand, losses will be incurred through surface evaporation, surface run-off, transpiration from the foliage, deep percolation below the root zone, and use within the plant.

Schofield (1952) and Penman (1963) have drawn attention to the fact that for a full cover of a green crop which is kept plentifully supplied with water, the rate of transpiration from the field is dictated primarily by the weather (radiation, mean air temperature, mean air humidity and mean wind speed), and scarcely at all on the nature of the vegetation. But as soon as plants experience water stress or under drought conditions, the plants themselves become much more important in regulating the rate of water loss.

The total requirements of irrigation water will differ very considerably for crops with different seasons and periods of growth. Thus in an arid climate perennial pastures will require irrigation throughout the year while, say, fodder catch crops will require water for only a few months.

Penman (1963) developed equations whereby total evaporation (including transpiration) can be computed from the local weather data, which together with measurement of rainfall can provide the basis for the control of irrigation. However, where the desire is to maintain the growth of a crop by maintaining soil moisture at field capacity, as in the case of perennial pastures, guidance can be obtained by a quicker and simpler method. Soil moisture can be measured as a resistance using nylon/stainless steel electrical resistance units which were fully described by Farbrother and Harrison (1957). When calibrations for field capacity and wilting point are ascertained for the soil in question, meter readings taken at appropriate times will indicate whether to irrigate (high readings) or not to irrigate (low readings). For instance, field capacity and wilting point calibrations were given by Farbrother (1964) as 2.95 and 4.5 log ohms for Namulonge, while Banage and Visser (1967) quoted 2.1 and 4.2 log ohms for Kabanyolo, respectively - the former place being about 4 miles north of the latter.

The units can be burried at six inches below the soil surface to cover the average rooting zone for most grasses. A period must then be allowed for the units to establish equilibrium with the surrounding soil before reading can be started. In addition, local experience can provide a guide in deciding when to irrigate. During the rainy season, for instance, irrigation requirements will be reduced partly because rain water will enter the root zone and partly because of the overcast sky there will be a reduction on evaporation and transpiration.

2.3.3. <u>How to irrigate</u>

The method of irrigation is dictated by soil type, topography, available water supply and capital. There are two main types, sprinkler (overhead) and channel (surface). Details concerning irrigation methods were reviewed by Keller and Peterson (1950), while Peterson and Hogan (1952) outlined irrigation principles and practices for pasture. Below is a summary of the disadvantages of channel and sprinkler irrigation. (The disadvantage of one system becomes an advantage of the other).

(a) <u>Channel Irrigation</u>

(i) Land has to be levelled.

(ii) Application is always heavy, leading to percolation losses and surface run-off.

(iii) Excess water will cause drainage and other problems.

(iv) Many ditches will waste land and harbour weeds, etc.

(v) Ditches may take time to be stabilized to allow maximum passage of water.

(vi) Some skill and continuous attention will be needed.

(vii) Pastures and fodder so irrigated are well suited to zero grazing as animals would destroy ditches, furrows, etc., while grazing.

(b) Sprinkler Irrigation

(i) Initial heavy capital outlay for pumps, pipes, etc.

(ii) Always requires power to maintain pressure in the sprinkler lines, which increases operational costs.

(iii) If laterals have to be moved frequently this incurs heavy recurrent costs, although modern systems with light-weight pipe and quick-coupling joints have greatly reduced the cost of labour for moving the pipes.

(iv) Winds will affect the distribution of water.

(v) The system is not flexible, that is, the pump is designed and installed for a particular capacity and can thus not be adjusted on emergency.

(vi) Where very tall fodder crops are to be irrigated, it will be difficult to extend the risers above the crop.

In either case, Whyte, Moir, & Cooper (1959) give three formulae by which the amount of water applied to a field at any given time can be determined, as:

(i) $$\frac{\text{Flow in ft}^3\text{/sec. x hours run}}{\text{Number of acres irrigated}} = \text{inches depth applied}$$

(ii) $$\frac{\text{Flow in gall./min. x hours run}}{\text{450 x number of acres irrigated}} = \text{inches depth applied}$$

(iii) $$\frac{\text{Flow in m}^3\text{/hour x hours run}}{\text{100 x number of hectares irrigated}} = \text{cms. depth applied}$$

2.3.4. Some factors that affect pasture response to irrigation

(a) Excessive irrigation

Too frequent irrigation can waste labour and limit the utilization of the pasture. It can lead to losses of water and nutritients in solution through surface run off and leaching. Thus Hallgren (1947) observed that his yields increased with increasing precipitation up to an optimum point; beyond that point yields decreased as precipitation increased still further.

(b) The grazing stock

Tanner and Mamaril (1959) noted that the compaction of surface soil by livestock trampling is a major factor contributing to reduced water infiltration rates and plant growth. They therefore recommended that where irrigated pastures are directly grazed in the field a system of rotation grazing should be established that would keep livestock off the pasture until the surface is sufficiently dry after irrigation.

(c) Interdependence between moisture and fertility

There is considerable experimental evidence to show that tremendous wastage does occur when irrigation water is applied to pastures which are severely limited in their response by inadequate soil fertility, particularly nitrogen. The reverse is equally true. Baker and Jung (1968) observed that maximum response to fertilizer was not obtained if water supply was inadequate, they reported that when moisture was low and temperatures high addition of fertilizer decreased yields and that addition of either fertilizer or water alone often did not significantly increase yields but the combination of these two factors. Similarly, Robinson et al. (1952) and Robinson and Sprague (1952) found that in dry years irrigation markedly increased the return from N fertilization.

An interdependence between water and higher nitrogen supply was established by Greenhill (1935) in their effects on the productivity of pastures; with lower rates of application the effects of N and irrigation water appeared to be independent. Kleinschmidt (1967) also obtained response to irrigation at 200, but lacked response between 0 to 50 lbs N per acre, which suggested that N was the first limitation to production but that water was limiting at higher N levels. The same explanation can be inferred from Rogler and Lorenz (1969) who reported that in dry years soil moisture was depleted more rapidly in the fertilized pastures. It can thus be concluded, as did McGinnies (1968), that the magnitude of the response to N and the relative efficiency per unit weight applied depend upon moisture availability.

(d) <u>The type of pasture</u>

Swaminathan (1968) stated that the yield of a plant depends both on its innate genetic potential and the availability of sunlight, moisture and nutrients. He observed that sunlight is abundant in the tropics, moisture is low in many areas but could be conserved, but that lack of nutrients was the most important limiting factor for getting yields from the varieties with a good genetic potential for yield. This is exaggerated by the inability to make nutrients available through the soil due to the lack of adequate moisture in the soil.

Two types of pasture are known, the natural pastures (consisting of all kinds of plants growing on hard virgin land), and planted pasture (made up mostly of selected species with desirable genetic potential and growing on tilled soft and deep soil). Johnson *et al.* (1968) and Breese (1968) obtained better response to fertilizers with irrigation from planted pasture than from natural pasture.

This was expected since water and nutrients were not only shared by weeds but also more liable to surface run-off for lack of infiltration into the hard and undisturbed soils of the natural pasture.

2.3.5. <u>Conclusion</u>

There is evidence that irrigation can play a very big role in increasing the productivity of tropical pastures, particularly during the dry seasons. Best results can, however, be achieved by applying the correct amount of water at the right time, coupled with high soil fertility and optimum grazing management. The aspect of high soil fertility thus precludes the irrigation of extensive natural grasslands.

2.4. Measurement of pasture output

2.4.1. Grazing versus clipping

Pasture production can be evaluated in terms of herbage dry matter yields per unit area of land using herbage samples clipped at appropriate stages of growth. The results may then be used in estimating the potential grazing yields and, therefore, animal production. However, a number of workers have reported errors that usually accompany the use of such cutting techniques to estimate pasture utilization.

Although Robinson et al. (1937) and Brandt et al. (1939) obtained comparable forage yields from clipping and grazing, Wagner et al. (1950), Cowlishaw (1951) and Bryant and Blaser (1961 and 1968) obtained higher herbage yields under clipping than under grazing. Thus, Jones et al. (1937), Brown and Munsell (1945) and Castle (1953) have questioned the validity of utilising data obtained by clipping for predicting grazing yields, which invariably give inflated yields. Likewise, Hull et al. (1965) pointed out that yield and chemical analysis of pregrazed forage would not be indicative of the amount and quality of forage consumed by the animals. It would only represent a preliminary evaluation of what is offered to the animals and somewhat an indication of the expected animal production.

Since the sole purpose of pasture trials is to judge its ability to support animal production, this creates the need for pasture evaluation in terms of animal products (meat or milk) obtained directly from the grazing animals themselves. Noting that treading , selective grazing and animal droppings, all affected the sward differently, Sears (1956) advised that the only way pastures could be evaluated in their true ecosytem of soil, plant and animal is by self-contained blocks of each treatment.

2.4.2 Carrying capacity

Definitions

Mott (1961) defined the phrase 'stocking rate' as the number of acres (hectares) per animal, or the number of animals per acre (hectare). As this term does not take into account the amount of forage available, another phrase, 'grazing pressure' (or 'grazing intensity') is used, which connotes the number of animals per unit of available land. 'Carrying capacity' which is sometimes used as synonymous to 'stocking rate' only means the stocking rate at optimum grazing pressure. When a fixed number of animals is kept on a unit area of grazing land throughout a season this would be referred to as 'set stocking' (or 'fixed stocking'), while if some animals are added to or removed from pasture to adjust to herbage availability, this is called 'variable stocking'.

Measurement of pasture productivity in terms of carrying capacity therefore entails a system of varying stocking so as to achieve optimum grazing pressure. This is usually expressed as the number of animals times the number of days spent on a unit area of land.

The main drawback to carrying capacity alone as pointed out by Brown and White (1933) and Williams (1946b) is that the measure does not allow for heavy as well as low yielding animals, or changes in live-weight, that is, there is no indication of pasture quality. Baker et al. (1964) indicated that for farm survey work cow-days gave an equally good measure of utilised grassland output as did utilised S.E. However, he conceded that carrying capacity was best used with other measures of productivity. Furthermore, Rogler and Lorenz (1969) noted that values on carying capacity were only a partial evaluation of pasture performance without supporting data. Beef production values alone without data on carrying capacity did not take into account the length of the grazing period and the ability of the pasture to maintain the weight of the animal as well as to produce net weight gain. It would therefore seem necessary in grazing experiments to take herbage cuts for D.M. yields and chemical analysis just as a preliminary measure of production as well as for checking with the final economic output of meat or milk.

2.4.3. The type of animals for grazing trials

The type of experimental animals will largely be determined by the objectives of the experiment and by the system within which the experiment is conceived. In Uganda, for instance, milking cows would be used in dairying or intensive areas while beef animals would be used in evaluating extensive areas. Indeed, Morley and Spedding (1968) aptly stated that grazing experiments should be relevant to some agricultural or ecological system, actual or conceptual.

However, in several instances liveweight gain trials have been found to be easier than milk production evaluation trials, for the following major considerations:

(1) It would be difficult to obtain milking cows of the same breed and age, which will have given the same number of calves and are at the same stage of lactation - all of which factors influence the amount of milk produced.

(2) As the milking animals will have attained higher body sizes and weights they would therefore require larger experimental grazing land.

(3) The animals would have to walk to the milking yard twice a day thereby wasting their productive energy and grazing hours.

(4) If the milking animal is still growing, or if it becomes pregnant in the course of the experiment, part of the nutrients off pasture would be partitioned respectively to its body tissue formation or the growing foetus.

(5) High yielding breeds normally do not obtain their maximum milk production from pasture alone. If they have to be supplemented with concentrates, for instance, this would introduce the 'associative effect' of feeds as was elucidated by Musangi et al. (1965), and therefore confound the results of the pasture trial.

The use of liveweight gain as a measure of pasture production implies that intake is directly related to production. Therefore animals of adequate production potential should be used in such trials (Ivins, 1959). This is especially so where the quality of pasture has been improved, otherwise there would be considerable waste of nutrients due to maintaining genetically inferior stock.

French and Ledger (1957) summarised the factors that govern responses to pasturage as: Quantity and quality of herbage, type of animal, breed, age, weight stage of maturity, metabolic efficiency, adaptability to environmental conditions, the nature and level of productivity, and the animals' antecedent nutrition (which should be similar) prior to the experimental period. Furthermore, since young animals grow at a faster rate than later in life (Hammond, 1955), young animals should be used in liveweight gain trials.

In Uganda, the choice is between the indigenous cattle (*Bos indicus*) or the exotic breeds (*B. taurus*) or their crossbreds. Working at Serere, Kyeyune-Sendagi (1970) has obtained faster post-weaning growth rates of the *B. taurus* x *B. indicus* crossbreds than the indigenous Zebu. Also working at the same station Stobbs (1967) used the Zebu stock to evaluate planted and improved pastures in terms of liveweight-gain. He noted that over the period of the trial the proportion of nutrients that went into animal production was just less than 25%. Yet from the temperate regions, Linehan et al. (1946) showed that during the growing season 50-70% of the nutrients went into production, while Watson (1951) and McMeekan (1952) put this figure at about 50%. It would seem that for pasture evaluation in terms of liveweight gains in Uganda, pure exotic breeds or their crosses would have to be used in preference to the indigenous stock.

2.4.4. Grazing management

Holmes (1962) defined the object of grazing management as 'to ensure a large supply of nutritious grazing over the grazing season at a low cost and to utilise it in such a manner that physical waste of herbage and inefficient utilisation by the animal are minimised and the productive capacity of the sward is maintained'. The above can only be attained if due attention is paid to several governing factors. These are mainly, the level of stocking, the frequency of herbage defoliation, and whether it is the quantity (output per unit area of land) or quality (output per animal) of the product that is sought.

Stocking rate has been shown to be one of the strongest factors influensing animal production. Okorie *et al.* (1965) showed that at low stocking rates it was not possible to identify differenses between pasture species. Earlier on Ivins *et al.* (1958) had stated that the animals rather than the pastures were being evaluated at the lower levels of stocking. Furthermore, Ivins (1959) illustrated that where the value of grassland is measured in terms of animal production, the yields obtained are only a true measure of pasture differences when grassland potential is the limiting factor - a situation created by intensive stocking and high yielding animals.

In economic terms, higher total output per unit area of land is generally the aim of grazing management. Several workers, McMeekan (1956), Mott (1961), Broadbent (1964), Bryant *et al.* (1965), Peterson *et al.* (1965), Smith (1966) and Stobbs (1967) obtained higher output per acre (and lower individual animal production) from heavy stocking than from the low stocking rates. The foregoing emphasize the need for high stocking rates in order to evaluate pastures satisfactorily.

Improvement on output per acre was shown by Mott (1961) to be possible by equalising grazing pressure between treatments, or, according to Jordan *et al.* (1961), by adjusting stock numbers according to herbage availability - rather than using a fixed stocking rate. This may introduce subjective errors into the experiment but it is likely to become less difficult where large differences are to be measured, such as those in fertiliser and irrigation trials.

An ideal grazing management should be such that no system should be exploited at the expense of the other. Martin Jones (1958) is of the opinion that the state of the plants should determine whether to graze or not to graze, and definitely not the needs of the animals. This fact is of importance in the tropics where there are marked seasonality of pasture growth as compared with the more or less constant nutritional requirements of the animal. Holmes (1962) warns that any grazing management that ignores these fluctuations is bound to result in under-utilization of herbage during the period of maximum growth. This would lead to undernourishing of stock and possible deterioration of pasture, botanically.

Continuous heavy grazing was observed by Stobbs (1967) to force out the more palatable species and to cause considerable weed invasion. Rotational grazing is therefore preferred for the following advantages:

(1) With adequate rest periods the animal gets herbage at the most nutritious stage of growth.

(2) The system discourages the build up of internal parasites on pasture.

(3) Previously grazed paddocks can then be fertilized, etc., or their rank growth topped.

Outside experimental considerations, rotational grazing allows conservation of herbage at periods when it is plentiful. It also gives room for old pastures to be ploughed up for either annual cropping or grass re-establishment. The resting intervals will depend on the number of paddocks and/or the size of the stock; but it should not be too long to allow herbage to grow rank and too fibrous, nor should it be too short to lead to over-grazing and exhaustion of pasture plants.

2.4.5. The Design of Grazing experiments

Mott and Lucas (1952) pointed out that experimental errors in grazing trials arise from two primary sources, namely, (a) variation among pastures upon which the same experimental treatments are imposed, and (b) variation among animals subjected to the same environment. Most aspects of experimentation and design of trials that would take care of such variations have been covered by Fisher (1942), Cochran and Cox (1957), Staff of the Grassland Research Institute (1961), and LeClerg, Leonard and Clark (1966).

The size and shape of individual paddocks will be determined by the size of herd per plot or treatment, the type of stock, and topography of the land. To prevent soil erosion in the tropics, Stobbs and Joblin (1966a and 1966b) advised that plots should be laid out along the contour. Split plot designs would be necessary where larger treatments, e.g., burning or irrigation are studied in combination with other treatments. The application of fire or water to scattered small plots would otherwise be difficult.

III. EXPERIMENTAL

3.1. Experimental site

3.1.1. Location. The experiment was conducted at Makerere University Farm, Kabanyolo (0° 28'N, 32° 37'E, at an altitude just below 4000feet). Kabanyolo is some 9 miles NNE of Kampala and the nearest part of the northern shore of Lake Victoria lies only about 11 miles to the South.

The countryside in which the farm is situated is typical of a large part of Buganda. It is characterised by small flat-topped ridges slopping to swamps which eventually drain to the North into the Nile system. The vegetation is typically long grass (*Pennisetum purpureum*) and small trees, but the area is intensively cultivated.

3.1.2. Climate. The climate at Kabanyolo is classified as moist tropical. The locality near the Equator subjects the site to the normal pattern of equatorial climatic changes resulting from the passage of the sun across the tropics and the associated subsequent low pressure area which is formed (the Equatorial Trough, or Intertropical Convergence Zone). The most variable seasonal factor is rainfall, which is localised mainly in the form of showers brought about by convection storms of short duration. The frequency of these storms is associated with the presence of the Equatorial Trough. Thus the two most rainy periods of the year occur in April/May and October/November when there is often convergent air movement from high pressure zones to the North and South. As the Equatorial Trough moves South from the equator in October to January the prevailing wind is from the North East; often from dry regions. As the Trough moves north from the equator in April to July the prevailing wind is generally from the South East. Occasions can occur throughout the year, however, when upper winds become westerly and from zones of convergence with the NE or SE winds. This gives extensive medium cloud and fairly prolonged rainfall. In addition, because of the proximity of Lake Victoria, there is usually superimposed on these wind systems an onshore (southerly) breeze during the day, and an off-shore (northerly) breeze at night.

Annual rainfall is about 51.2 in. with two peaks in April and November and two lows in January and July. Potential evapotranspiration is about 59.1 in. per year with monthly totals varying from about 5.5 in December-March period to 4.5 in. in May-July. Brief periods of soil water deficit occur annually at the end of dry spells, most often in January-February and July-August.

Although there can be large diurnal changes in various weather factors, seasonal variations of solar radiation, temperature, humidity, and wind speed are not large in magnitude. Mean maximum temperatures vary from 28.5°C in January to 26.0°C in July, minimum temperatures from 17.4°C in April to 15.9°C in July and August. Solar radiation averages 400 cal. cm^{-2} day^{-1} with little monthly variation except for a relative drop to about 350 cal. from June to August. Long term mean for sunshine duration is 6 hours daily out of a possible 12 hours.

3.1.3. Soils

The upland cultivated soils of Kabanyolo have been described by Harrop (1967) as latosols or ferrallitic soils and classified by Radwanski (1960) as belonging mainly to the Buganda Catena, giving red clay-loams or loams underlain with soft laterite. These are deep, high weathered and leached, fine textured and well drained. pH values are about 5.0 and the humus content which is appreciable (2-3%) only in the surface soil is the main source of cation exchange capacity (8-12 m.e. in surface).

3.2. Experimental design

The lower strip of block B3 which a year before had been sown to *Panicum maximum*, *Setaria sphacelata* and *Chloris gayana* in about equal proportions was taken up for this experiment. A split plot design was employed, the main plots being for irrigation and no irrigation, and the split plots (each 0.1 acre) for the four levels of nitrogen. There were five replicates on the ground, and eight in time (8 seasons: 4 wet and 4 dry).

3.3. Experimental materials and methods

3.3.1. Fertilizers

Nitrogen was applied at 0, 200, 400 and 600 lbs of actual nitrogen per acre in six equal splits at appropriate intervals throughout the year. Calcium ammonium nitrate was used to avoid a build up of acidity on the laterite soil. Potash and phosphate were applied uniformly to all plots at 200 lbs of actual K_2O (from sulphate of potash) per acre in two equal splits per year and 100 lbs of actual P_2O_5 (from single superphosphate) per acre in one dose per year, respectively.

3.3.2. Irrigation

The farm lies on a ridge with its broad crest running in a north-south direction. The experimental site lies on a gentle slope of between 5% and 7% gradient, on the eastern side of the ridge, about 1000 feet from the valley floor where a 15 horse-power water pump for the irrigation water was installed. A sprinkler system was used. Water was conveyed to the unit in 3" main pipes and into the main plots by 2" laterals. Sprinkler heads were attached onto laterals at ground level, and not on risers so as to minimise the deflection of water jets by wind.

Gypsum/Nylon resistance units were buried to 6" of soil in the first irrigated main plot. Meter readings off these - using calibrations for field capacity and wilting point as 2.1 and 4.2 log ohms, respectively, for the Kabanyolo soil (Banage and Visser, 1967) - were used as a guide on when to irrigate. In addition, the amount of water delivered into "rain-gauges" when the system ran for 1, 2, 3 and 4 hours was determined. Weekly soil samples were also taken for % moisture determinations. Consequently an irrigation schedule was fixed at once per week (except during heavy rains) for 3 hours when some 2" of water would be delivered. This was enough to keep the soil near field capacity for most of the week.

3.3.3. The grazing stock

Yearling ½-Jersey - ½-Nganda crossbred heifers were used in the first year, and yearling ½-Jersey - ½-Nganda crossbred steers in the second year of the experiment. (See Appendix 7 for initial and final liveweight of both groups).

3.3.4. Grazing procedure

The first grazing cycle of each year was used for conditioning the animals. The five ground replicates were rotationally grazed, each replicate at a time. A form of variable stocking which was suggested by Blaser *et al.* (1956) was used. "Tester" animals remained in their respective plots throughout a grazing cycle or season, while "grazer" animals were added to or taken away from treatments depending on the amount of herbage in the treatment, or on the season. Grazing cycles varied from 2 to 3 weeks (i.e. time taken to graze the five replicates.). Sufficient water and mineral licks were made available for experimental animals in their paddocks all the time.

3.3.5. Weighing of animals

Animals were weighed before entering the first replicate and when they completed the fifth replicate. The total liveweight gain per treatment each cycle was computed as the weight gain of the "tester" animal plus the product of the "grazer" animal-days and the average daily gain per "tester" animal. Before weighing, animals were starved overnight in a yard previously cleared of grass.

3.3.6. Herbage samples for yield estimation and chemical analyses

Fertilizer N was applied to swards about every two months. Pre-grazing herbage samples were obtained every grazing cycle for % C.F. and % C.P. analyses. For NO_3-N analysis samples were obtained before and after grazing in July, 1969 (middle of the dry season) and April, 1970 (middle of the west season). In each case this was done two weeks following the application of N. Herbage samples were obtained twice in the first (long dry) season and twice in the last (long wet) season for D.M. yield estimation.

Plots were topped to remove rank and ungrazed spots whenever these became outstanding. Trash and dung were spread evenly in each plot. Notorious weeds were kept to the minimum in all plots. No attempt was made to assess the botanical composition of the different swards.

3.3.7. Soil samples for moisture and chemical analyses

In the second year of the experiment soil samples (top 6") were obtained weekly from the 4 irrigated and 4 non-irrigated sub-plots in the first replicate. Irrigation was usually done on Wednesdays and sampling on Fridays. Samples were weighed fresh and after drying in the oven for 2 days at about 90°C. Differences in weight represented the amount of water present in the fresh soil samples.

Similar types of readings were obtained from calcium/nylon resistance units buried at 6", one in an irrigated plot (I) and the other in a non-irrigated plot (NI). Meter readings started from January, 1969 in I and from July, 1969 in NI.

For chemical analysis the first samples were taken six weeks following the application of the first year's sixth instalment of N. The second and third samples were obtained six weeks following the application of the third and sixth instalments of N, respectively.

<u>N.B.</u> In the sections which follow where the results of the experiment are reported and discussed, the eight treatments will simply be written as 0 or 200 or 400 or 600, and 0I or 200I or 400I or 600I, to read as follows:

Treatment		
0	=	0 lbs N per acre WITHOUT irrigation
200	=	200 " " " " " "
400	=	400 " " " " " "
600	=	600 " " " " " "
0I	=	0 lbs N per acre WITH irrigation
200I	=	200 " " " " " "
400I	=	400 " " " " " "
600I	=	600 " " " " " "

IV. RESULTS

4.1. Weather

This experiment was conducted through eight seasons as indicated in Table 4.1. Normally, Kabanyolo Farm has four seasons each year, one long (L) and one short (S) dry seasons alternating with one short and one long wet seasons, respectively (Table 4.1). Meteorological data, particularly the daily rainfall of the station, were used to determine the beginning and end of seasons. Some intermediate periods between dry and wet seasons which were ill-defined were used for conditioning the animals to their respective treatments and their data excluded from the rest. Thus, the eight seasons had unequal lengths of grazing days and grazing cycles.

A summary of some of the important weather factors is shown in Table 4.2. This well covers the two-year period of the experiment.

Table 4.1. The duration of seasons and number of their grazing cycles

Season	Duration From	To	Length of grazing	No. of grazing cycles
1 Dry (L)	20. 6.68 -	1.11.68	119 days	8
2 Wet (S)	2.11.68 -	20.12.68	49 "	3
3 Dry (S)	31.12.68 -	19. 2.69	41 "	3
4 Wet (L)	20. 2.69 -	27. 5.69	78 "	6
5 Dry (L)	4. 6.69 -	25. 9.69	111 "	6
6 Wet (S)	26. 9.69 -	22.11.69	57 "	4
7 Dry (S)	28.11.69 -	4. 3.70	87 "	6
8 Wet (L)	5. 3.70 -	14. 6.70	97 "	6

Table 4.2. Rainfall and other weather records for Kabanyolo

Monthly rainfall (in.)	1968	1969	1970	10-Year mean
January	0.9	3.0	2.2	2.2
February	7.7	5.1	0.7	3.9
March	4.9	7.1	5.0	5.9
April	8.6	8.8	5.5	7.9
May	5.3	6.6	4.5	4.9
June	3.6	3.2	1.8	3.1
July	2.5	2.4	2.9	2.1
August	1.9	2.2	4.6	3.0
September	2.0	5.6	3.6	4.1
October	3.8	4.4	4.4	6.5
November	7.1	10.9	3.2	7.9
December	5.7	2.0	1.5	4.0
Total	54.0	61.3	39.9	55.5
Pot. evaporation (in.) Penman	59.8	61.8	60.8	
Mean max. temp. °C	27.0	27.6	27.2	
Mean min. temp. °C	16.7	16.7	16.7	

4.2. Soil Moisture

The results for 52 weeks (June, 1969 to May, 1970) are shown in Appendix 2.1. These are expressed as percentages of the weights of fresh soil samples. The overall average moisture contents for irrigated and non-irrigated treatments were 21.0% and 17.1%, respectively. Statistical analysis using the t test for the average moisture percentages of the irrigated and non-irrigated treatments for one year of recording showed that irrigated plots had higher soil moisture content (P-0.001) than the non-irrigated plots (Appendix 4.5).

Similar types of readings from calcium/nylon resistance units are shown in Appendix 2.2. Field capacity and wilting point for the Kabanyolo soil were quoted by Banage and Visser (1967) as 2.1. and 4.2 log ohms, respectively. Thus the irrigated plot remained near field capacity for most of the time, averaging 2.3 log ohms for 17 months. The non-irrigated plot was more or less intermediate between field capacity and wilting point, and occasionally reached and exceeded wilting point. The average for the latter for 11 months was 3.1 log ohms.

4.3. Soil chemical composition

Appendices 3 (a) to (g) show the results for pH, O.M., N, P, K, Ca and Mg, respectively. Appendix 3 (h) is a guide to the rating of soil analysis results. This was prepared at Kawanda Research Station, Soil Chemistry Division, where these samples were analysed. Generally the experimental treatments had no significant effects, diminutive or incremental, on the constitution of these nutrients.

4.4. Herbage yields

Although pasture production was mainly assessed in terms of liveweight gain, some estimation of herbage quantities produced by various treatments was undertaken. D.M. yields are shown in Table 4.3. In both seasons yields increased as the level of N fertilisation increased, and with irrigation where N was applied. Yields in the last season were slightly lower than those in the first season in the non-irrigated pasture. With irrigated swards the drop was highest in treatment 0I and least in treatment 600I.

Table 4.3 Herbage Dry Matter Yields (lbs/acre) for the first (dry) and last (wet) seasons.

Lbs N/ac.	Dry season 1968			Wet season 1969			% Drop of mean (b) vs. (a)
	July	Sept	Mean (a)	Mar	May	Mean (b)	
0	3956	3644	3800	3525	3367	3446	9.3
200	4080	3682	3881	3863	3281	3572	8.0
400	4350	3700	4035	3930	3510	3720	7.8
600	4812	3802	4307	4208	4368	4288	6.7
0I	4210	4008	4109	2776	2484	2634	35.9
200I	4962	4760	4861	4014	3800	3907	19.6
400I	5217	4819	5018	4602	4066	4334	11.9
600I	5644	5804	5724	5165	5505	5355	6.4

4.5. Chemical composition of herbage

4.5.1. Crude protein

The percentage of crude protein in herbage was determined by the Micro-Kjeldahl method outlined in Appendix 1.1. The crude protein content was shown to vary with the type of season (dry or wet). It used to be highest a couple of weeks after each N application, and then tail off towards the end of the two-month period. In Table 4.4 the results are given as means of samples taken per season. This minimises the variation in composition due to the length of time between N application and sampling.

Crude protein composition ranged from 3.1% to 15.2%. In all seasons, the amount of crude protein significantly increased (P = 0.001) with increasing levels of N. There was a definite sequence in which lower C.P. content in the dry seasons alternated with higher C.P. content in the wet seasons in the non-irrigated treatments. There were very slight fluctuations in the C.P. content of irrigated pasture. Irrigation had no significant effect on C.P. composition during the dry seasons but had a significant (P = 0.01) lowering effect during the wet seasons (Fig. 2 and Appendix 4.5).

Table 4.4. Mean seasonal % C.P. from irrigated and non-irrigated grazed pasture at 4 levels of nitrogen fertilization

	Seasons. (d = dry, w = wet).									
Lbs N/ac.	1,d.	2,w.	3,d.	4,w.	5,d.	6,w.	7,d.	8,w.	Dry season Mean	Wet season Mean
0	4.8	6.1	3.4	5.4	4.7	3.1	4.1	4.2	4.2 ± .3 e	4.7 ± .7 v
200	5.9	8.9	7.1	9.1	6.3	5.7	5.9	10.1	6.3 ± .3 d	8.4 ± 1.0 t
400	7.0	9.2	9.8	13.0	10.2	9.4	8.8	13.2	9.0 ± .7 b	11.2 ± 1.1 r
600	7.5	12.3	12.9	13.2	13.2	12.4	12.1	14.0	11.4 ± 1.3 a	13.0 ± .3 p
0I	5.2	4.6	4.0	4.4	4.1	3.6	4.2	3.8	4.4 ± .3 e	4.1 ± .2 w
200I	5.8	6.6	6.1	6.0	6.9	5.8	5.4	6.2	6.1 ± .3 d	6.2 ± .2 u
400I	6.5	8.2	9.0	10.7	9.3	9.6	9.0	8.4	8.4 ± .7 c	9.2 ± .5 s
600I	8.9	8.7	11.4	12.5	13.8	15.2	12.2	12.9	11.6 ± 1.0 a	12.3 ± 1.3 q

N.B. Means underscored by the same letter are not significantly different at the 5% level.

4.5.2. Crude fibre

Herbage samples were analysed for crude fibre content by the Whitehouse *et al.* (1945) method (Appendix 1.2.). Cyclical values for each treatment were composited for each season, as shown in Table 4.5. Values ranged from 27.6% to 34.8%. The C.F. composition in herbage was not influenced by irrigation but was significantly reduced ($P = 0.001$) by fertilizer nitrogen in all seasons (Figs. 1 and 2 and Appendix 4.6).

4.5.3. Nitrate-Nitrogen

Oven-dried and ground herbage samples were analysed for NO_3-N content using the Harber Method outlined in Appendix 1.3. The results are shown in Table 4.6.

Neither season nor level of N nor irrigation enhanced the accumulation of NO_3-N in herbage to a minimum level of 0.20% which Bradley *et al.* (1940) reported as toxic to livestock. During the dry season 600 and 600I showed more concentration of NO_3-N in post-grazed than pre-grazed samples but for other levels of N this was the reverse. During the wet seasons all post-grazed samples contained lower concentrations of NO_3-N.

Table 4.5. Mean seasonal % C.F. from irrigated and non-irrigated grazed pasture at 4 levels of N fertilization.

Lbs N/ac.	Seasons. (d = dry, w = wet). 1,d.	2,w.	3,d.	4,w.	5,d.	6,w.	7,d.	8,w.	Dry season mean	Wet season mean
0	31.8	32.8	30.9	32.1	33.2	33.6	34.8	30.7	32.7 ± .8 a	32.3 ± .6 p
200	29.6	32.3	32.2	32.5	33.2	33.2	29.4	28.9	31.1 ± .9 abc	31.7 ± .9 pq
400	29.3	31.4	29.3	31.0	31.2	31.5	30.6	28.4	30.1 ± .5 bc	30.6 ± .8 pqr
600	28.0	30.6	29.4	28.6	29.2	27.6	29.6	28.6	29.0 ± .4 d	28.9 ± .6 r
0I	30.3	31.0	31.9	31.9	31.9	32.2	31.8	33.8	31.5 ± .3 ab	32.2 ± .5 p
200I	31.0	30.5	31.3	29.9	32.0	30.3	31.1	30.2	31.4 ± .2 abc	30.2 ± .1 pq
400I	30.6	30.0	31.8	29.4	31.6	30.4	30.4	30.4	31.1 ± .3 abc	30.0 ± .2 r
600I	28.6	29.3	28.8	30.2	32.2	28.2	30.0	30.4	29.9 ± .8 c	29.5 ± .5 r

N.B. Means underscored by the same letter are not significantly different at the 5% level.

FIGURE 1.

DRY SEASON MEAN % CRUDE PROTEIN AND MEAN % CRUDE FIBRE

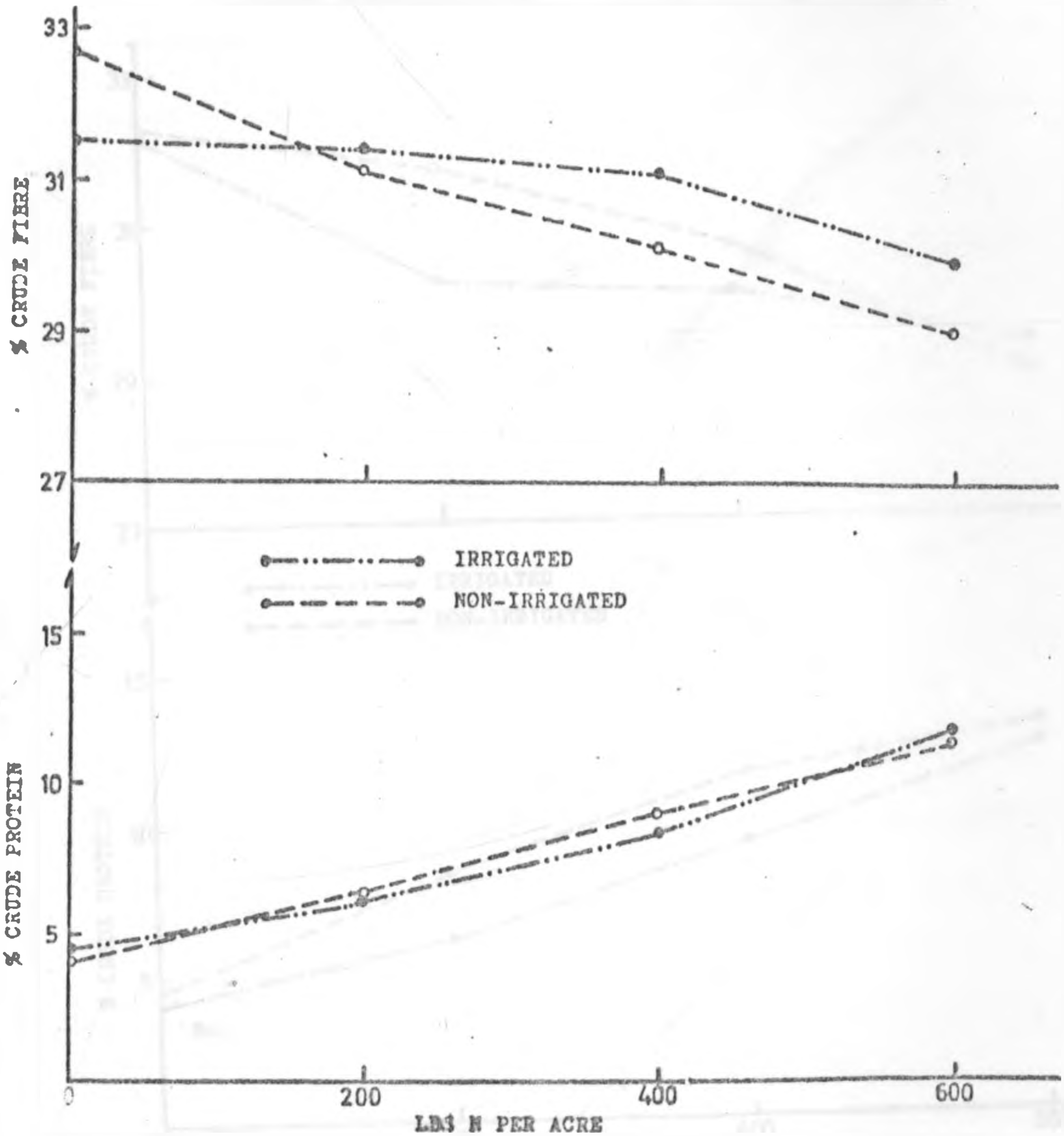


FIGURE 2.

WET SEASON MEAN % CRUDE PROTEIN AND MEAN % CRUDE FIBRE

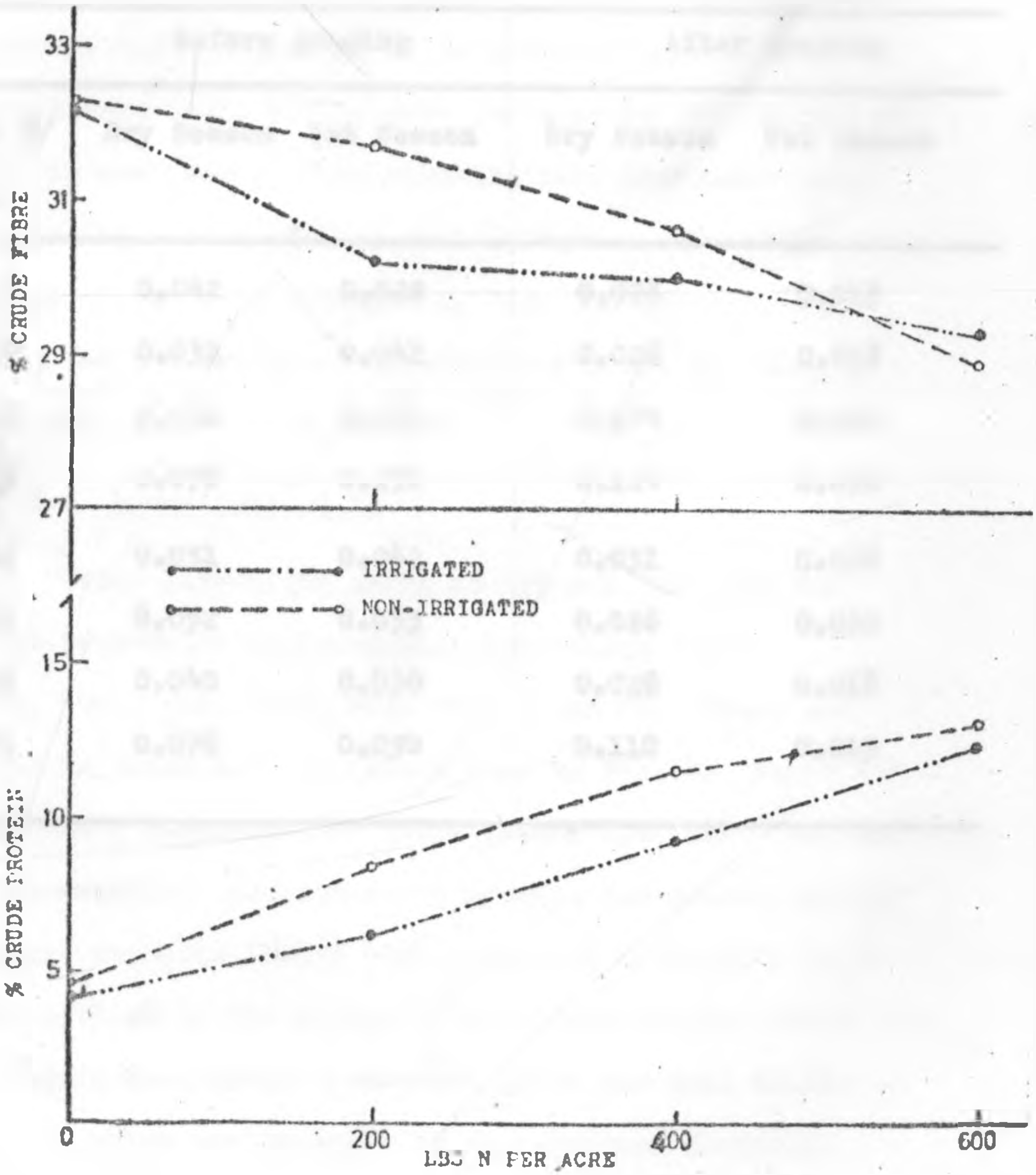


FIGURE 2.

WET SEASON MEAN % CRUDE PROTEIN AND MEAN % CRUDE FIBRE

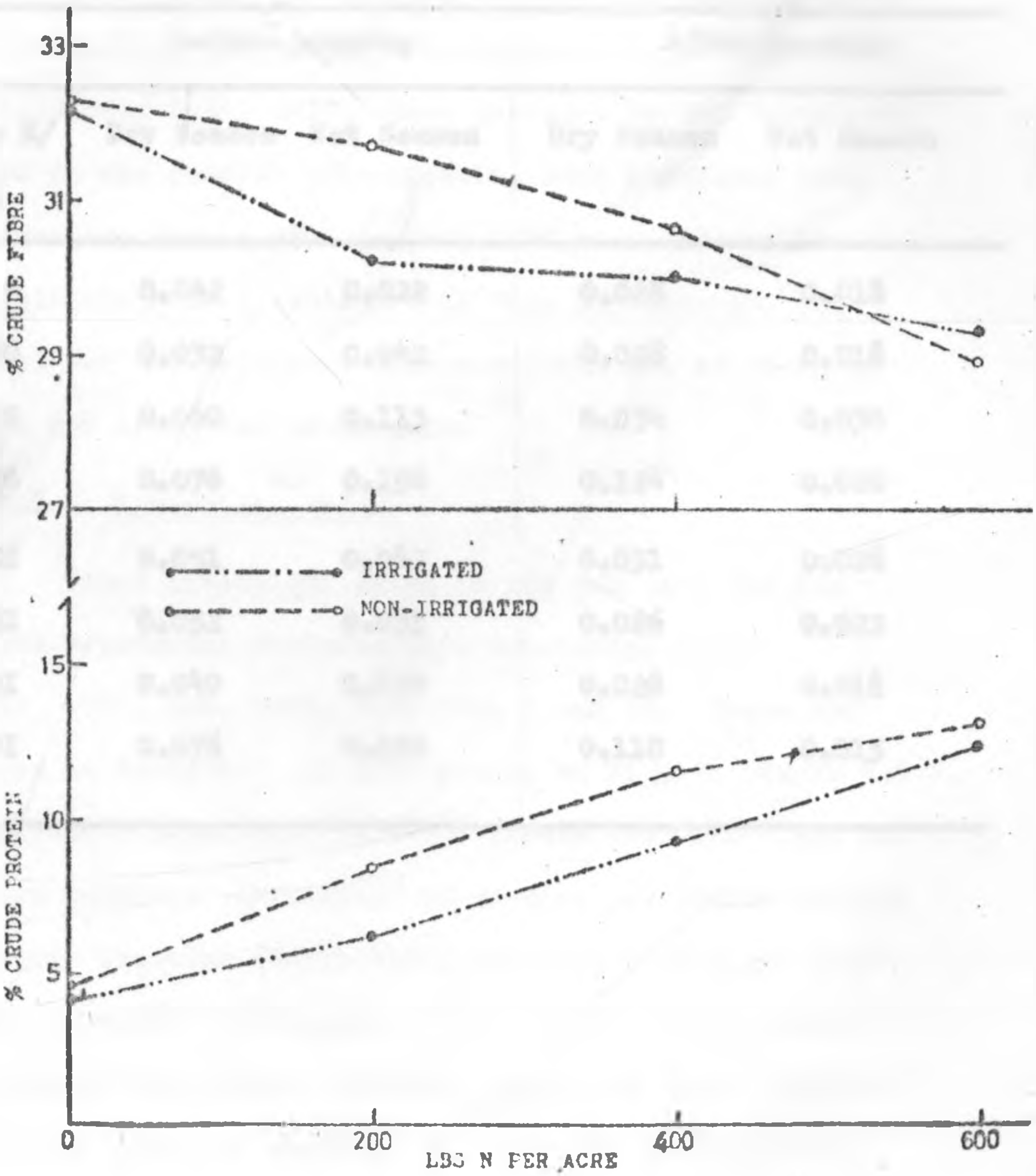


Table 4.6 Nitrate-nitrogen (ppm.)

	Before grazing		After grazing	
Lbs N/ ac.	Dry Season	Wet Season	Dry Season	Wet Season
0	0.042	0.022	0.028	0.018
200	0.032	0.042	0.028	0.018
400	0.060	0.113	0.034	0.030
600	0.076	0.196	0.124	0.020
0I	0.051	0.042	0.031	0.026
200I	0.052	0.033	0.026	0.022
400I	0.040	0.030	0.028	0.018
600I	0.076	0.050	0.110	0.015

4.6. Livestock production

4.6.1. Cattle-days and stocking rates

The total number of cattle-days per acre is given in Table 4.7. Stocking rates per acre were calculated by dividing total cattle-days per acre by 365 (number of days in one year). The stocking rate increased with increasing levels of N in both irrigated and non-irrigated treatments - as illustrated by Fig. 3. However, the graph for non-irrigated treatments was not as steep as that for irrigated treatments.

4.6.2. Liveweight gains

Total liveweight gains in lbs per acre for the eight treatments followed this descending order: 600I, 400I, 600, 200I, 400, 200, 0 and OI. These are shown in Table 4.7 and illustrated by Fig. 4. Table 4.8 presents a break-down of these totals into the 4 dry and 4 wet seasons. As periods of grazing per season were of unequal duration (Table 4.1), seasonal liveweight gains were divided by the number of days each season lasted to obtain mean daily liveweight gains per acre (Table 4.9) on which the analysis of variance was conducted (Appendix 4.)

(a) Irrigation (i) During the dry seasons treatments 200I, 400I, and 600I produced significantly more liveweight gains (P = 0.001) than treatments 200, 400 and 600, respectively. In the combined dry and wet seasons only 200I and 400I produced significantly more live-weight gains (P = 0.001) than 200 and 400, respectively.

(ii) During the wet seasons treatments 200I, 400I and 600I did not produce significantly more liveweight gains than 200, 400 or 600, respectively.

(iii) Treatment 0I produced less total liveweight gains than treatment 0 but their mean daily liveweight gains were not significantly different.

(iv) There was no significant interaction between irrigation and nitrogen in all seasons.

(b) Nitrogen. For the dry and wet seasons liveweight gains increased with increasing levels of N with and without irrigation. However, treatments 400 and 600, and 400I and 600I did not produce significant differences in liveweight gains in all seasons. Treatments 400 produced significantly more liveweight gain than 200 during the wet seasons and the combined dry and wet seasons, while 400I produced significantly more liveweight gain when the dry and wet seasons liveweight gains were combined.

Fig. 4 shows a histogram for total liveweight gains per acre for irrigated and non-irrigated treatments. Irrigated treatments produced about 18% less, and 59%, 42% and 37% more liveweight gain than their respective unirrigated treatments at 0, 200, 400 and 600 lbs N per acre. Fig. 5 shows dry season and wet season total liveweight gains per acre for irrigated and non-irrigated treatments. That there was no statistically significant response to artificial irrigation during the wet season is well illustrated here. During the dry season response to irrigation started with a smaller increase at 0 lbs N per acre but shot up to a significant increase at 200, 400 and 600 lbs N per acre.

4.6.3. <u>Mean daily liveweight gains per acre (MDGA) and per beast (MDGB)</u>

Mean daily gains per acre were obtained by dividing the total liveweight gain by the total number of days each treatment was grazed. Gains per animal were obtained by dividing total gains by total cattle-days per treatment. Since for most of the time (except for treatments 0 and OI) more than one animal grazed each fertilised treatment, MDGA values were higher than MDGB values at the same level of N, and increased with increasing levels of N. There was no definite trend in the MDGB values. Except for treatments O and OI, MDGA in the irrigated treatments were higher than MDGA in the non-irrigated treatments at the same level of N. Similarly, MDGB in the irrigated treatments were higher than the corresponding MDGB in the non-irrigated treatments.

all the seasons from irrigated and non-irrigated grazed pasture at 4 levels of N fertilization.

Lbs N per acre	Total livewt. gain per acre	Total cattle days per acre	Stocking rate per acre	Mean daily gains per animal	Mean daily gains per acre
0	304	482	1.3	0.63	0.46
200	498	734	2.0	0.68	0.76
400	753	867	2.4	0.87	1.26
600	884	1114	3.0	0.79	1.53
0I	249	504	1.4	0.49	0.36
200I	794	793	2.2	1.00	1.27
400I	1067	1056	2.9	1.00	1.68
600I	1214	1296	3.6	0.94	1.89

FIGURE 3.

STOCKING RATES PER ACRE PER ANNUM

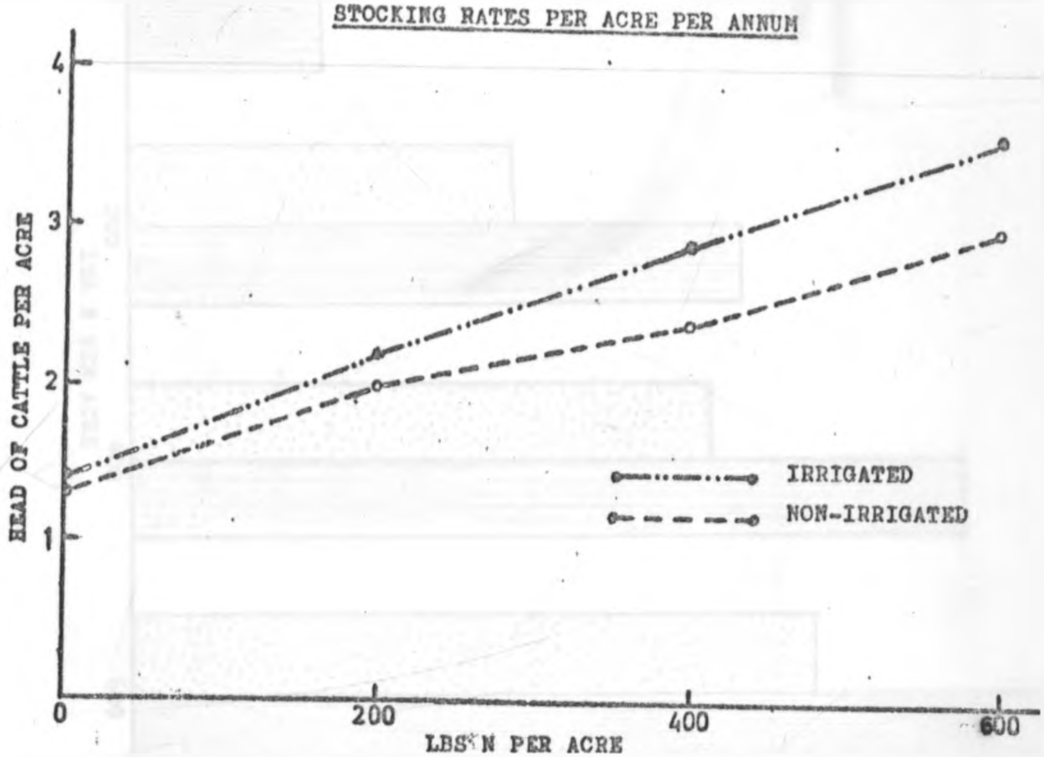
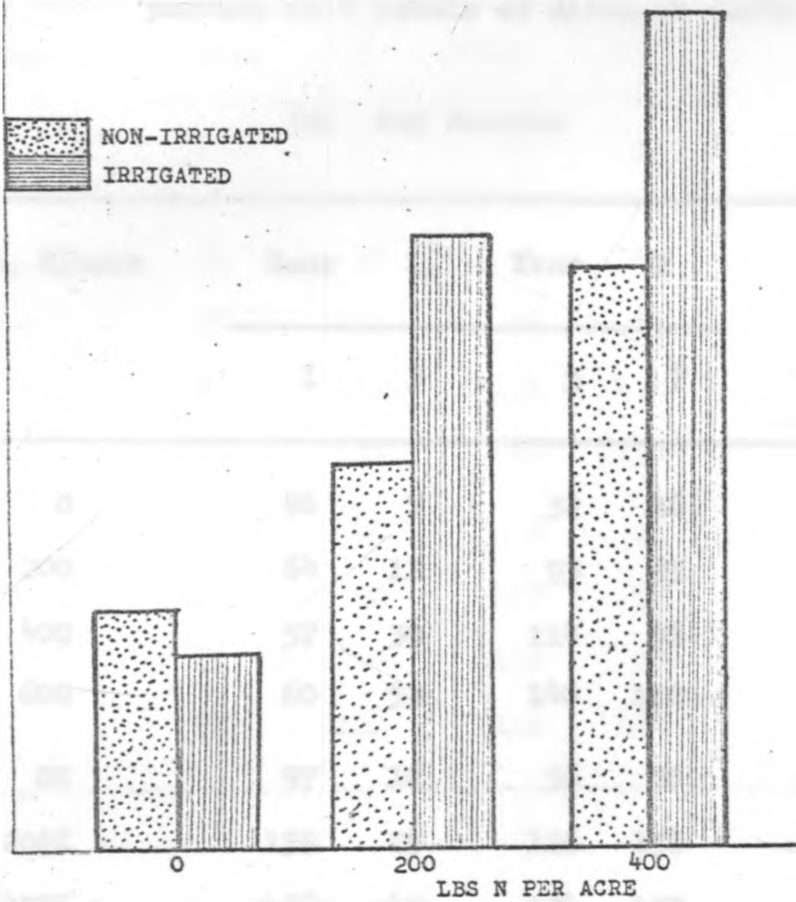


FIGURE 4. TOTAL LIVEWEIGHT-GAIN (LBS) PER ACRE PER ANNUM



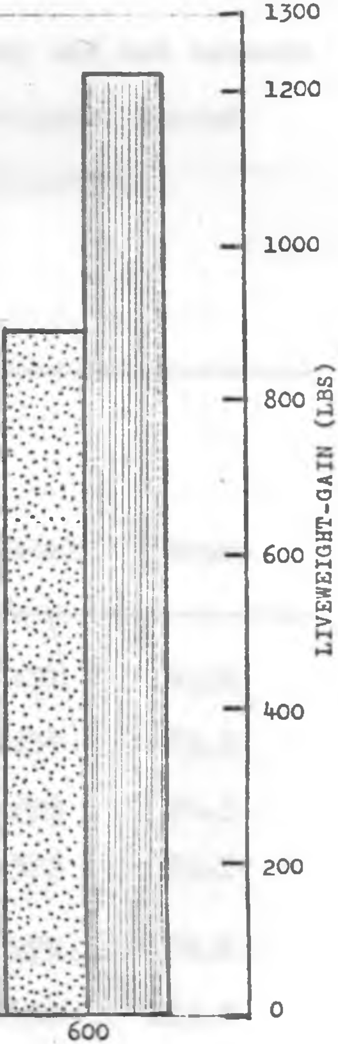

1300
1200
1000
800
600
400
200
0
LIVEWEIGHT-GAIN (LBS)
600

Table 4.8. Liveweight-gains (lb. per acre) for dry and wet seasons as obtained from irrigated and non-irrigated grazed pasture at 4 levels of nitrogen fertilization

(a) Dry Seasons

Lb. N/acre	Year 1.		Year 2		Total	Mean
	1	3	5	7		
0	86	7	32	46	171	42.8
200	64	12	93	85	254	63.5
400	57	30	114	98	299	74.3
600	60	53	140	120	373	93.3
0I	97	16	36	30	179	44.8
200I	159	29	126	138	452	113.0
400I	196	45	184	179	604	151.0
600I	204	50	238	205	697	174.3

(b) Wet Seasons

Lb. N/acre	Year 1		Year 2			
	2	4	6	8	Total	Mean
0	54	38	0	41	133	33.3
200	38	62	56	88	244	61.0
400	80	111	131	132	454	113.5
600	138	133	110	130	511	128.8
0I	22	26	0	22	70	17.5
200I	60	90	137	55	342	85.5
400I	81	146	146	90	463	115.8
600I	87	148	156	126	517	129.3

FIGURE 5.

TOTAL LIVEWEIGHT-GAIN PER ACRE FOR DRY AND WET SEASONS

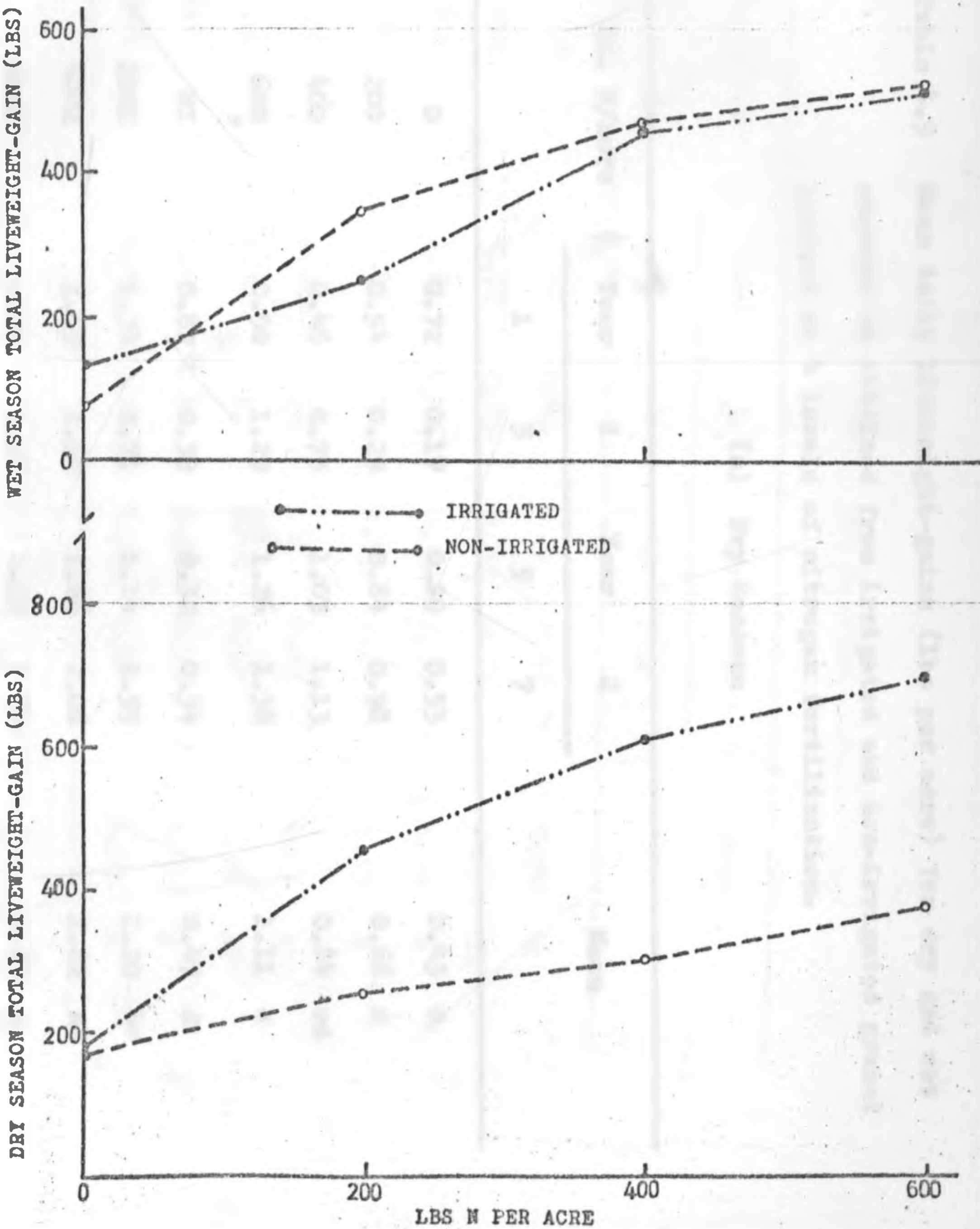


Table 4.9 *Mean daily liveweight-gains* (lbs per acre) for dry and wet seasons as obtained from irrigated and non-irrigated grazed pasture at 4 levels of nitrogen fertilization.

(a) Dry Seasons

Lb. N/acre	Year 1		Year 2		Mean	
	1	3	5	7		
0	0.72	0.17	0.29	0.53	0.43	d
200	0.54	0.29	0.84	0.98	0.66	d
400	0.48	0.73	1.03	1.13	0.84	cd
600	0.50	1.29	1.26	1.38	1.11	c
0I	0.82	0.39	0.32	0.34	0.47	d
200I	1.34	0.71	1.14	1.59	1.20	bc
400I	1.65	1.10	1.66	2.06	1.62	ab
600I	1.71	1.22	2.14	2.34	1.85	a

(b) Wet Seasons

Lb. N/acre	Year 1		Year 2		Mean	
	2	4	6	8		
0	1.10	0.49	0	0.42	0.50	g
200	0.78	0.80	0.98	0.91	0.87	fg
400	1.63	1.42	2.30	1.36	1.68	e
600	2.82	1.71	1.93	1.34	1.95	e
0I	0.45	0.33	0	0.22	0.25	g
200I	1.22	1.15	2.40	0.57	1.34	ef
400I	1.65	1.87	2.56	0.93	1.75	e
600I	1.78	1.90	2.74	1.30	1.93	e

(c) Dry + Wet Seasons

Lbs. N/ac.	8 Season-mean	
0	0.46	r
200	0.76	r
400	1.26	q
600	1.53	pq
0I	0.36	r
200I	1.27	q
400I	1.68	p
600I	1.89	p

For (a), (b) and (c) means underscored by the same letter are not significantly different at the 5% level.

Table 4.10. Total cattle-days for dry and wet seasons as obtained from irrigated and non-irrigated grazed pasture at 4 levels of nitrogen fertilization

(a) Dry Seasons

Lbs. N/acre	Year 1		Year 2		Total
	1	3	5	7	
0	139	27	56	55	277
200	159	51	92	69	351
400	139	51	151	80	421
600	238	52	162	125	577
0I	154	27	69	44	294
200I	182	41	129	84	436
400I	209	71	178	132	590
600I	258	79	206	169	712

(b) Wet Seasons

Lbs. N/acre	Year 1		Year 2		Total
	2	4	6	8	
0	49	28	65	63	205
200	78	97	102	106	383
400	98	128	86	134	446
600	98	144	126	169	537
0I	49	28	65	68	210
200I	49	97	116	95	357
400I	78	128	122	138	466
600I	94	144	146	200	584

4.7 Input and output considerations

This trial covered a total of 4 acres of pasture three of which received regular applications of N. Only two acres were irrigated weekly (when there was not sufficient rainfall) using a 15 HP water pump. Delivering 1" of water per operation, this pump had a capacity to irrigate 10 acres per week.

Inputs: As N fertilization and irrigation were being evaluated for dry season production only the costs of fertiliser N and irrigation equipment have been considered. The cost of labour was unnecessarily made high by concentration on a smaller area of land and fewer head of cattle, whereas labour in the country has been (and for a long time will remain) very cheap on large farms. Phosphate and potash requirements will vary from farm to farm. In this trial large and uniform quantities were applied in order to obtain maximum response to N without limitation from lack of these nutrients.

Output: An estimation of saleable beef was fixed at 55% of total liveweight. This was based on an average Cold Dress Weight (CDW) percentage of 55% obtained by Musangi

(1967) from groups of Friesian and Nganda steers raised on pasture at Kabanyolo. At slaughter their liveweight ranged from 520 to 800 lbs as compared with 502 to 564 lbs from heifers in the first year, and 470 to 648 lbs from steers in the second year of this experiment.

There are, in addition, some intangible returns that might accrue from grassland irrigation, particularly in the hot and dry tropics, whose prices cannot easily be fixed. On mixed farms it would be possible to irrigate other crops and to have plenty of water for various other farm activities. Secondly, cattle at pasture would be afforded plenty of drinking water, the importance of which was emphasized by Leitch and Thomson (1944) and French (1956).

The various costs, returns and net gain are shown in Tables 4.11 and 4.12. These were based on the prices of inputs and outputs shown in Appendix 6.

Table 4.11. Costs and Returns

Costs (Shs./acre)				Returns (Shs./acre)		
Lbs N/acre	N	Irrig.	Total	Lbs beef	Value (Shs.)	Net gain (Shs.)
0	-	-	0	167	380	380
200	206	-	206	274	621	415
400	412	-	412	414	940	528
600	618	-	618	486	1104	486
0I	-	160	160	137	311	151
200I	206	160	366	437	991	625
400I	412	160	572	584	1324	752
600I	618	160	778	668	1515	737

Table 4.12. Net gain and conversion ratio

Lbs N/acre	Net gain (Shs/acre) by N.	Net gain (Shs/acre) By irrig.	Lbs. beef per lb. of N No Irrig.	Lbs. beef per lb. of N Irrig.
0	380	-229	-	-
200	415	+210	0.97	2.72
400	528	+224	1.12	2.04
600	456	+251	0.97	1.61

V. DISCUSSION AND CONCLUSIONS

5.1. Herbage production

The main objectives of pasture management are:

(i) to produce large quantities of high quality forage evenly throughout the year in the case of the tropics, or during the growing season in temperate countries, and

(ii) to ensure an efficient utilization of that herbage without wastage so as to obtain maximum returns through animal production.

The purpose of this study was to ascertain whether timely applications of water and/or nitrogen to pasture would produce steady and large quantities of nutritious herbage for cattle at pasture throughout the year. This would then remove the limitation to pasture and animal production hitherto imposed by the dry season.

Pasture production was mainly estimated in terms of cattle liveweight gain. However, few herbage yield estimates were obtained (Table 4.5). Before each grazing cycle each pasture treatment was inspected and notes taken on the general state of its sward. These were used partly in deciding the initial stocking and partly as adjuncts in the interpretation of animal liveweight changes in various treatments.

It was evident that a combination of high levels of N with irrigation was able to maintain a steady production of large quantities of herbage. Where little or no N was applied herbage yields declined progressively. This is illustrated by treatment OI which produced the least amount of herbage and consequently the least total liveweight gain.

The first instalment of N was applied when the rains were tailing off in May, and the second in early August when the rains were anticipated. No sufficient rains came; in fact the dry season stretched to the end of October. Consequently, non-irrigated swards showed very little positive response to N that season. Where N was applied the grasses appeared to be wilted or scotched. This effect was in turn reflected in the amount of liveweight gains obtained from non-irrigated swards that season (Table 4.7). The non-fertilised treatment, O, produced the highest liveweight gains while the other three treatments had about the same. In subsequent seasons where N applications were timed to coincide with some rain, herbage yields and liveweight gains increased with increasing levels of N. Therefore, for N to be of some benefit it has to be applied at a time when there is moisture to dissolve it into the soil for mobility and easy uptake by grasses.

The nutritive value of herbage in the eight pasture treatments was also assessed in terms of crude protein and crude fibre composition. In Table 4.4 crude protein composition increased with increasing levels of N per acre. Non-irrigated swards generally had lower % C.P. during the dry seasons but more in the following wet seasons; there were very small fluctuations in the irrigated swards. The pooled regression of the levels of N per acre on % C.P. is shown in the following equation (Appendix 5a):

$$Y = 4.275 + 2.59 X \pm 0.84, \quad P = 0.001$$

Where Y = % C.P.

X = units of N per acre (1 unit = 200 lbs)

There was a strong positive correlation ($r = 0.96$) between the levels of N and percentage crude protein composition.

The most important deficiency of the nutritive value of tropical pasture and fodder grasses is known to be in their C.P. content. Therefore, the C.P. content is a good guide when assessing the feeding value of herbage from different sources. Several workers in Section 2.2.3 have shown that animals selectively graze protein-rich herbage, and that C.P. content is highly correlated with digestion of D.M. and D.C.P. The National Research Council (1963) recommended 9% to 10% C.P. as minimum requirement for 600-lb. yearling cattle. Milford and Minson (1966) reported results in which bacterial activity in the rumen was depressed when C.P. in the temperate grasses fell below 8.5%, and a marked decline in intake when it fell below 7% in the tropics. In this trial a level of 8% C.P. and above was maintained by swards which received 400 and 600 lbs N per acre, being less fluctuating in the irrigated swards. This is a considerable improvement over the low and fluctuating values generally reported on tropical pasture species.

The amount of C.F. in pasture herbage at Kabanyolo was reported by Musangi (1965) and Soneji (1970) to increase with advancing maturity. This was not expected in this experiment where most of the herbage was grazed about every three weeks and then allowed to grow again. Within treatments there were very slight seasonal variations in the C.F. composition. Fertilizer N was the only factor which moderately reduced its composition among treatments. There was a negative correlation (r = - 0.76) between levels of N and percentage crude fibre composition. The pooled regression of the levels of N per acre on % C.F. is shown in the following equation (Appendix 5b):

$$Y = 32.14 - 0.92\,X \pm 0.95,\ P = 0.001$$

Where Y = % C.F.

X = units of N per acre (1 unit = 200 lbs).

It is true that the nutritive value of a feedingstuff very much depends on its digestible, and not crude, composition. In ruminants, however, the crude fibre can be a source of nutrient (digestible cellulose) while its indigestible fraction (lignocellulose) can provide bulk to satisfy appetite, aid mastication and rumination, and to prevent constipation and bloat. Thus, in grassland production, the type of herbage produced should strike a balance between nutrient content and bulk in terms of dry matter. Although C.F. composition in this study fell with increasing levels of N, it is evident that bulk was not limiting even at the highest level of N with irrigation.

Indeed this treatment produced the highest herbage D.M. yields and the highest total liveweight gain.

5.2. Grazing management and animal production

The grazing intervals in this trial never exceeded three weeks. Under unfavourable conditions this would be a short period of rest in which sufficient herbage would be produced for the next grazing cycle. In comparison, Rivera-Brens *et al.* (1968) reported from Puerto Rico satisfactory results from rotational intervals ranging from 6½ to 10 days throughout the four years of their experiment. Also working in the tropics, Brougham (1959), Creek and Nestel (1965) and Stobbs (1967) obtained more liveweight gains per acre from rapid frequencies of rotational grazing than from systems of slow or infrequent rotational grazing. Even under cutting regimes, Holliday and Wilman (1965) found that grassland subjected to frequent defoliation responded better to fertilizer N, and that this accelerated the re-establishment of the leaf area after each cut.

Brougham (1956) and others have shown that over short periods pastures mown to leave a long stubble regrow more rapidly than those mown to leave a short stubble, and hence more D.M. at the same time interval after mowing. In the tropics where species have been shown to attain physiological maturity and high nutritive values very early in growth, a rapid rotation of grazing would catch the grasses at this optimum stage of growth. In this trial plots were grazed or slashed back after every other grazing to a stubble of between 6 and 12 inches. It was evident that in the presence of the two growth factors, water and nitrogen, a reasonably tall stubble left behind after grazing quickly sponsored a top nutritious regrowth. Most of this would be eaten in the following grazing cycle, plus a nip at the old stubble, apparently to provide roughage and bulk. Although it is obvious that a very closely grazed or mown sward would offer an animal a relatively highly nutritious ration, Stapledon et al. (1924) observed that the animal would have to walk far and work hard to pick up an adequate maintenance allowanse of D.M., and to work harder and walk farther to pick up a fattening allowance.

It has often been postulated that plants growing in arid and semi-arid areas of Eastern Africa, e.g., Northern Kenya, Ethiopia or Somalia, are richer in the essential nutrients owing to little rain which causes little leaching, as compared with the lush vegetation of the wet and humid shores of Lake Victoria, where soils are ever exposed to leaching in the frequent rainstorms. This may well be true since it was shown in this trial that irrigation without N reduced herbage yields and consequently diminished animal production. Moreover, the generally observed superior physical features and productivity of the Boran cattle over the Nganda cattle - the two types of Zebu cattle being indigenous to the two regions, respectively - tend to support the above conjecture. Secondly, Chalmers and Synge (1954) have shown that a ruminant animal is likely to chew coarse roughages of low C.P. much longer, thereby producing saliva which will be incorporated in the feed. Saliva contains ammonia, a precursor of urea. This return of N to the rumen, they considered, was likely to be of metabolic importance when the intake of N in the original feed is low. This case is likely to arise in the absence of artificial fertilisers when coarse herbage from arid areas or unirrigated swards are compared with the tender and lush herbage from high rainfall areas or irrigated swards. Thirdly, where dependence is made on the natural flush of essential nutrients owing to little rain which causes little leaching, as compared with the lush vegetation of the wet and humid shores of Lake Victoria, where soils are ever exposed to leaching in the frequent rainstorms. This may well be true since it was shown in this trial that irrigation without N reduced herbage yields and consequently diminished animal production. Moreover, the generally observed superior physical features and productivity of the Boran cattle over the Nganda cattle - the two types of Zebu cattle being indigenous to the two regions, respectively - tend to support the above conjecture. Secondly, Chalmers and Synge (1954) have shown that a ruminant animal is likely to chew coarse roughages of low C.P. much longer, thereby producing saliva which will be incorporated in the feed. Saliva contains ammonia, a precursor of urea. This return of N to the rumen, they considered, was likely to be of metabolic importance when the intake of N in the original feed is low. This case is likely to arise in the absence of artificial fertilisers when coarse herbage from arid areas or unirrigated swards are compared with the tender and lush herbage from high rainfall areas or irrigated swards. Thirdly, where dependence is made on the natural flush of soil N following a dry period, the findings of Birch (1960) indicate that this natural flush of N would be forgone under continuous precipitation or irrigation. Therefore, it is highly possible that the irrigation of pasture without fertilization (particularly N) may, through continuous withdrawal by the growing plants, leaching or forfeiture of the natural flush of N, progressively exhaust the unreplenished soil nutrient reserves while only lush herbage of diminishing nutritive value is produced.

Except when experimental procedure demanded that cattle be put off pasture, it was otherwise possible to graze one acre of treatments 400I and 600I in rotation all the year with a minimum of two and three animals, respectively. At a grazing interval of two to three weeks, treatment 200I used to have insufficient herbage in about the seventh or eighth week from the time the last instalment of N was applied; grazing was then deferred. None of the non-irrigated swards could be grazed continuously without deferment, particularly during the dry season.

The importance of maintaining a high and constant rate of growth in livestock cannot be overstressed. Late maturity which has been observed in most cattle of the tropics is largely attributed to the seasonally undulating liveweight curves, while the setback in their growth increases their susceptibility to diseases. The production of sufficient and high quality herbage for animals at pasture all the year round is therefore an important breakthrough and a solution to the setbacks mentioned above. This has been shown in Table 4.7 in which the fertilized and irrigated swards at each level of N had higher mean daily liveweight gain per animal, higher stocking rate, more total liveweight gain per acre and higher conversion ratios (Table 4.12) than the non-irrigated swards.

Considering the cost of N and irrigation, Tables 4.11 and 4.12 show that the highest rate of N with irrigation respectively produced about four times and five times the value of beef produced by the zero level of N without and with irrigation. However, the highest net gain in cash returns was obtained in each group from pasture where N was applied at 400 lbs per acre with and without irrigation. Thus, one may choose either the timely application of N alone up to about that level but with the probability of pasture shortage during the dry seasons, or N with irrigation for uniform and higher productivity throughout the year.

Nitrogen. Three categories for the timely application of N are envisaged as follows:

(i) In areas where rain is received evenly all the year round, such as the lake shores and around mountains, N may be applied in any number of splits. However, in order to reduce labour costs, N may be applied every other grazing. At a rotational interval of about 4 weeks, this approximates to 6 splits per year. The same goes for places where irrigation is practised.

(ii) Areas with a bimodal pattern of rainfall may apply N in four splits, a smaller proportion a couple of weeks after the start of the rains when the natural flush of N, generally known in East Africa as the Birch effect, is waning, and a larger proportion towards the end of the rainy season. The larger amount would equip the grasses with more and deeper roots and more tillers with which to carry production far into, or through the dry season.

(iii) Areas having a unimodal rainfall pattern, depending on the length of the rainy season, may apply any convenient number of smaller splits of N, and a larger amount towards the end of the rainy season.

In following this schedule a few points have to be borne in mind. Firstly, split applications, rather than a single huge application, are recommended because, besides obtaining less fluctuating herbage yields between applications, possible losses of N through volatilization, leaching or erosion are minimised. The fact that in this trial the level of nitrate-nitrogen remained negligibly low (Table 4.6) might also have been due to the application of smaller quantities of N at a time. Secondly, whenever higher herbage yields are desired than can be produced by the natural flush of N, fertilizer N may be applied at the beginning of the rains. Thirdly, in extensive dry seasons N alone without irrigation will hardly maintain a constant supply of fresh pasturage through the dry season. In this case recourse would have to be sought elsewhere, which is outside the scope of this thesis.

Irrigation. Profitable pasture overhead irrigation can only be considered for two categories of farming, namely:

(i) intensive dairy production, and

(ii) extensive beef production ranches where some paddocks near homesteads can be irrigated for utilization by the breeding stock, that is, by calves and cows which are about to calve down or have just done so.

Small scale producers who have a couple or so head of cattle on a small area of land would certainly not profit from pasture overhead irrigation; their returns would not justify the expenditure.

Positive response was shown to irrigation with applied N by grassland at Kabanyolo whose climate is moist tropical. This suggests that higher responses could be obtained from the same treatments in drier areas of East Africa. For, in these areas the sky is generally less overcast so that a combination of water with the prevailing higher light intensities would enhance the net assimilation rate in grasses, leading to higher dry matter yields. Moreover, increases in plant density and mutual shading which normally result from the use of heavy rates of fertilizer N would require an extra supply of radiant energy without which, as was studied by Muller (1951), plant growth would seriously be impaired.

5.3. <u>Scope for future research</u>

It has been shown from these studies that:

(a) In both the irrigated and non-irrigated pasture, applied N substantially increased herbage yield in terms of D.M. and C.P., and moderately decreased the C.F. composition in herbage.

(b) Grassland irrigation without applied N progressively reduced herbage D.M. yield and consequently produced the lowest animal liveweight gain.

(c) A combination of high levels of N with irrigation produced sufficient quantities of herbage for cattle at pasture throughout the year. As a result, N-fertilized and irrigated swards produced significantly more total liveweight gains than their respective non-irrigated swards.

However, for a more complete picture, there is need for more information on the following aspects which have arisen as a result of, or were not adequately covered by, those investigations:

(a) The duration of the experiment was only two years. To simulate the normal duration of planted pastures in East Africa, data would preferably have been collected over a period of, say, four or more years.

(b) Nganda x Jersey cattle crosses were used for pasture evaluation in this study. Comparable liveweight-gain data would be necessary from high yielding breeds of cattle such as the Aberdeen Angus or the Hereford when they are kept on similarly improved pasture, or even irrigated pasture receiving higher levels of N.

(c) The place in which the study was conducted is more suited to dairying than to beef production. A study of the response to pasture irrigation with similar or higher levels of N in terms of milk production is essential, particularly in Uganda where the price of milk is presently among the highest in the world.

(d) The application of heavy rates of N and irrigation to pasture in the tropics coupled with heavy stocking rates and shorter grazing intervals, is likely to encourage a build-up of internal parasites which would pose a serious problem to cattle at pasture. Although all the experimental animals generally looked healthy, cases of infestation could not have been ruled out. This could be investigated in future.

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VII. APPENDICES

Appendix 1. CHEMICAL ANALYTICAL METHODS

1.1 Nitrogen determination in herbage

The procedure used for the determination of nitrogen was a modification of the original method devised by Kjeldahl (1883).

Method.

A 0.1 g. very finely ground sample was accurately weighed and transferred quantitatively to a clean 30 ml. Kjeldahl flask. About 1 g. of catalyst mixture (160 g. Na_2SO_4, 10 g. $CuSO_4$ and 3 g. Selenium powder) was added to the flask and the whole contents moistened with distilled water. Finally 3.5 ml. of concentrated H_2SO_4 (analar) was added in the flask. The flask was then placed on the digestion heater and heated gently at first until the mixture became clear, and then strongly for 30 minutes. The flask was then cooled for a few minutes (since prolonged cooling leads to crystallisation of the digest) and the contents transferred quantitatively into a 50 ml graduated flask with fresh distilled water and made up to mark.

Ten ml. of the prepared solution were pipetted into a steamed Markhan apparatus and about 10 ml. of 46% solution of NaOH (W/V) were run in and the distillation were carried out. The evolved ammonia was absorbed into about 10-12 ml. 2% boric acid (W/V) containing 2 to 3 drops of mixed indicator (3 parts 0.1% Bromocresol green and 2 parts 0.1% Methyl Red, both dissolved in ethyl alcohol), until about 2/3 flask was filled. The absorbed ammonia in the boric acid was then titrated against standardized 0.02 N HCl. Knowing the amount of 0.02 N HCl equivalent to ammonia, the weight of nitrogen in the sample was culculated. At least duplicate titrations were done for each sample.

Calculation of % N in sample and D.M.

$$3NH_3 + H_3BO_3 \rightarrow (NH_4)_3\ BO_3 + 3HCl \rightarrow 3NH_4Cl + H_3BO_3 + NH_3$$

$$NH_3 + HCl \rightarrow NH_4Cl$$

1 litre of 1 N HCl = 14 g. Nitrogen

1 ml. of 1 N HCl = 14 mg. Nitrogen

1 ml. of 0.02 N HCl= 14 x 0.02 mg. Nitrogen

= 0.28 mg. Nitrogen

water and once with industrial spirit. Open out the paper, remove the residue with a spatula and transfer the fibre to a silica dish. Dry overnight at 105°C. Transfer to a desiccator and weigh when cool. Ash at 600°C to completion. Allow to cool and reweigh.

% Fibre = Difference in weighings x 100.

1.3. <u>Determination of NO_3-N in herbage</u>

The Harper Method outlined by Chapman, H.D. and Pratt, P.F. (1961) in: Methods of Analysis for Soils, Plants and Waters was used.

<u>Preparation of grass sample</u>

Weigh out 0.25 g. of oven-dried and ground grass sample and 100 ml. water and 5 ml. 1 N $CuSO_4$ sol. into a shaking bottle. Repeat for a complete set of bottles including one blank in each set. Blank should contain no grass material but include all reagents and operations. Shake for 10 min. and allow to settle. Filter the supernatant liquid through fluted filter paper (Whatman No. 1) into 250 ml. conical flasks.

a) $\% N \text{ in sample D.M.} = \frac{0.28 \times 100 \times \text{vol. of titre} \times 50}{\text{Wt. of sample (mg)} \times 10}$

b) % C.P. in sample D.M. = % N in sample x 6.25

1.2. Crude Fibre Determination

The Trichloroacetic Acid Method by Whitehouse, Zarrow and Shay (1945) was used. This is an alternative to the more conventional crude fibre procedure.

Reagent:- Trichloroacetic acid digestion reagent

Mix 500 ml. glacial acetic acid, 450 ml. water and 50 ml. conc. nitric acid. Dissolve 20 g. trichloroacetic acid in this mixture.

Method: Weigh out 1 g. milled material into a 500 ml. conical flask. Add 100 ml. digestion reagent, washing down the sides of the flask. Bring to the boil and reflux for exactly 40 minutes, counting from the time heating commenced. Use a 3-foot long air condenser or a water jacketed condenser to prevent loss of liquid. Remove the flask from the heater and cool under a cold tap. Filter through a 15 cm. No. 4 Whatman paper. Wash 5 times with hot

Pipette from each flask 5 ml. of grass extract into evaporating dishes. Add about 0.05 g. $CaCO_3$ to each basin and evaporate to dryness over water bath in the fume cupboard. Cool and add 2 ml. of phenol disulphonic acid into each basin from a burette. Rotate the basin and, by means of the ball-shaped end of a glass rod, allow the acid to come into contact with the entire residue. Allow the acid solution to react and mix. Run 50% NH_4OH solution slowly from a burette with gentle stirring until solution changes to permanent yellow. Add 2 ml. 50% NH_4OH solution in excess, cool and transfer solution into 100 ml. volumetric flask. Dilute to volume and mix. Read colour density over SP 600 or EEL absorptiometer at wavelength 420m.

Preparation of Standard Curve

1 ml. of standard nitrate solution (see below) contains exactly 100 g./ml. of N.

ml standard solution	ppm N in final 100 ml. of yellow solution	
	100 ppm	10 ppm
0	0	0
1	0.1	0.01

2	0.2	0.02
4	0.4	0.04
6	0.6	0.04
8	0.8	0.08
10	1.0	0.10

Calculation

If weight of plant extract = a

volume of water used = b

aliquot of extract evaporated = c

final volume of solution = d

reading of calibration curve = y

$$\therefore \text{ ppm in plant material} = \frac{b}{a} \times \frac{d}{c} \times y = \frac{bd}{ac} \times y$$

Reagents

(1) Phenol disulphonic acid

Dissolve 25g. of pure crystals of phenol in 225 ml. conc. H_2SO_4 acid (S.G. 1.84). Heat solution in loosely stoppered bottle or flask in a boilding water bath for 6 grs. Cool and store in a brown reagent bottle.

(2) Ammonium Hydroxide solution

Mix equal volumes of NH_4OH (S.G. 0.88 - 0.90) and distrilled water.

(3) Standard Nitrate solution

Dissolve exactly 0.722 g. of Potassium nitrate (Analar) in distilled water and dilute to a litre. Shake well. This solution contains 100 ppm N as nitrate.

(4) Powdered Calcium sulphate

(5) Powdered Calcium carbonate

Appendix 2

2.1 Weekly % moisture in the soil (top 6") during second year of the experiment.

WEEK	LBS N/ACRE							
	Non-irrigated plots				Irrigated plots			
	0	200	400	600	0I	200I	400I	600I
1	16.6	16.9	17.3	16.7	21.1	20.5	20.1	19.7
2	17.9	16.8	17.6	19.1	21.6	21.9	21.6	23.8
3	17.0	14.7	16.1	15.6	23.1	20.9	20.4	20.3
4	18.7	16.9	17.1	17.1	23.2	22.9	21.8	21.8
5	16.1	15.3	15.5	15.4	21.2	21.5	20.9	22.1
7	15.8	16.0	14.8	14.7	22.2	21.9	20.2	21.8
8	17.8	17.8	16.9	15.6	22.9	22.2	22.1	22.1
9	17.3	16.8	16.0	15.4	21.5	20.7	20.0	21.2
11	18.8	18.4	18.1	14.6	21.3	22.2	20.6	21.0
12	17.4	16.0	16.1	15.6	19.3	21.4	20.0	21.0
13	15.0	13.8	13.6	13.6	20.0	20.9	18.8	20.1
14	18.4	17.7	18.6	16.0	22.0	21.9	20.9	21.6
15	19.6	17.9	19.2	19.3	21.3	21.7	21.0	21.1
16	19.9	21.0	19.8	18.9	22.1	22.0	21.0	21.5
17	16.2	16.1	15.6	15.1	20.4	19.7	19.1	19.7
18	15.0	14.1	14.1	14.4	19.7	19.0	19.5	21.4
19	14.6	14.6	14.6	14.9	20.9	21.3	21.1	23.1
20	15.7	14.7	14.4	14.2	19.7	20.2	20.3	19.9
21	15.4	16.3	15.9	16.4	20.0	19.0	19.3	20.4
22	20.1	17.2	17.3	17.6	21.6	22.6	21.5	21.6
23	18.1	16.6	18.1	16.4	21.8	21.2	20.8	21.4

WEEK	0	200	400	600	0I	200I	400I	600I
24	20.2	18.8	19.1	17.1	21.7	21.6	21.0	20.7
25	21.3	21.8	20.8	20.7	22.7	22.9	22.7	21.4
26	21.3	21.8	21.8	21.0	23.1	23.2	22.5	22.0
27	18.6	16.6	16.5	14.8	18.4	17.8	17.2	18.8
28	19.0	17.1	17.9	18.1	21.5	20.5	20.7	21.5
29	16.3	15.4	16.6	17.1	22.7	22.2	20.8	20.9
30	16.7	16.5	15.7	15.9	19.6	19.4	19.7	19.2
31	14.4	14.2	14.6	14.5	17.4	17.7	17.2	18.6
33	15.9	15.6	15.4	15.6	23.6	21.8	21.8	22.0
34	18.2	16.9	16.9	16.4	23.2	23.8	22.9	22.6
35	14.3	13.6	13.8	13.5	18.7	17.3	17.8	17.8
36	15.1	15.7	14.5	14.1	19.4	18.0	19.0	18.4
37	14.5	14.6	15.3	13.7	17.7	17.6	17.0	17.1
38	13.5	13.5	13.4	13.9	20.5	20.8	19.3	19.2
39	14.5	14.0	14.0	14.7	21.4	21.5	19.8	21.0
40	19.6	17.5	17.4	16.8	21.6	21.3	21.8	21.3
41	18.2	16.9	17.4	17.1	20.8	21.0	19.0	19.1
42	17.3	15.5	15.1	15.4	21.0	20.8	19.0	19.5
43	20.0	19.0	20.0	19.3	22.7	22.0	21.4	21.0
44	20.0	19.0	18.2	18.9	22.1	21.9	20.2	21.5
45	21.3	20.0	20.9	20.5	22.9	22.9	21.8	21.7
46	22.1	20.3	21.6	20.6	22.7	23.2	22.9	22.2
47	19.3	18.6	18.1	18.1	22.8	22.2	21.4	21.5
48	18.2	17.1	18.0	18.7	21.6	21.5	19.5	20.7
49	21.5	20.8	21.0	21.2	24.3	22.4	21.7	22.6
50	21.1	21.0	22.1	20.9	23.3	24.0	23.1	21.7
52	15.8	15.5	15.3	15.8	21.5	21.1	20.6	20.7
Mean	17.7	16.9	17.0	16.7	21.4	21.2	20.5	20.9

Irrig.

2.2. Soil moisture (mega ohms) from resistance units burried at 6" in irrigated (I) and non-irrigated (J) plots

Date			I	NI
1969	Jan.	1	2.2	-
	"	18	2.3	-
	"	21	2.3	-
	"	23	2.4	-
	"	30	2.1	-
	Feb.	14	2.0	-
	"	18	2.3	-
	"	21	2.4	-
	"	24	2.2	-
	"	27	2.2	-
	Mar.	3	2.4	-
	"	6	2.5	-
	"	10	2.4	-
	"	13	2.3	-
	"	17	2.3	-
	"	20	2.2	-
	"	24	2.2	-
	"	27	2.1	-
	"	31	2.2	-
	Apr.	10	2.5	-
	"	14	2.5	-
	"	17	2.5	-
	"	21	2.5	-
	"	24	2.5	-
	May	5	2.3	-

Date			I	NI
1969	May	19	2.2	-
	"	22	2.3	-
	Jun.	9	2.4	-
	"	16	2.1	-
	Jul.	18	2.4	4.4
	"	21	2.4	4.5
	"	25	2.5	2.7
	"	28	2.6	2.8
	"	31	2.5	2.8
	Aug.	4	2.5	2.5
	"	7	2.6	2.7
	"	11	2.7	2.7
	"	14	2.4	2.4
	"	18	2.3	2.4
	"	28	2.6	2.6
	Sept.	2	2.3	2.5
	"	4	2.4	2.7
	"	11	2.1	2.1
	"	18	2.3	2.3
	"	25	2.4	3.0
	"	29	2.4	3.5
	Oct.	2	2.3	4.9
	"	14	2.6	5.5
	"	16	2.6	2.5
	"	28	5.4	5.6
	"	30	2.2	2.1

Date			I	III
1969	Nov.	3	2.1	4.3
	"	6	2.5	2.3
	"	10	3.2	2.9
	"	13	2.3	3.9
	"	17	2.3	2.5
	"	21	2.3	2.6
	"	25	2.1	2.2
	"	27	2.1	2.2
	Dec.	3	2.3	2.4
	"	5	2.4	3.0
	"	8	2.3	2.8
	"	15	2.4	3.8
	"	18	2.6	3.8
	"	22	2.2	4.1
	"	29	2.5	4.3
1970	Jan.	6	2.3	2.4
	"	8	2.2	3.2
	"	12	2.4	3.7
	"	15	2.0	2.4
	"	19	2.2	2.1
	"	22	2.3	2.4
	"	26	2.4	3.0
	Feb.	2	2.5	3.9
	"	9	2.5	4.3
	"	23	2.3	4.1

Date			I	NI
1970	Mar.	2	2.5	4.2
	"	9	2.3	2.4
	"	16	2.1	2.3
	"	23	2.4	3.4
	"	31	2.4	3.4
	Apr.	6	2.0	2.3
	"	13	2.0	2.2
	"	20	2.6	3.1
	"	27	2.4	2.5
	May	4	2.3	2.8
	"	11	2.3	3.3
	"	16	2.6	4.1
	"	18	2.4	2.7
	"	21	2.0	3.1
	"	25	2.3	2.6
Total			216.6	191.3
Mean			2.4	3.1

Appendix 3. Soil pH, O.M., N, P, K, Ca & Mg in the 2nd year of experiment.

(a) pH

N/Irrig.	Start	Middle	End	Mean
0	5.7	5.5	5.7	5.63
200	5.6	5.5	5.6	5.57
400	5.6	5.5	5.5	5.53
600	5.5	5.3	5.2	5.33
0I	5.6	5.5	5.6	5.57
200I	5.6	5.4	5.6	5.53
400I	5.6	5.5	5.6	5.57
600I	5.6	5.4	5.4	5.47

(b) % O.M.

N/Irrig.	Start	Middle	End	Mean
0	4.6	4.6	4.8	4.67
200	4.5	4.5	4.7	4.57
400	4.8	4.3	4.6	4.57
600	4.0	4.4	4.5	4.30
0I	4.3	4.5	4.6	4.47
200I	4.6	4.5	4.6	4.57
400I	4.4	4.5	4.5	4.47
600I	4.4	4.2	4.4	4.33

(c) % Nitrogen

N/Irrig.	Start	Middle	End	Mean
0	0.174	0.172	0.172	0.173
200	0.167	0.141	0.170	0.159
400	0.170	0.169	0.170	0.170
600	0.162	0.155	0.162	0.160
0I	0.162	0.162	0.165	0.163
200I	0.169	0.163	0.163	0.164
400I	0.162	0.162	0.167	0.164
600I	0.162	0.163	0.166	0.164

(d) Phosphorus (p.p.m.)

N/Irrig.	Start	Middle	End	Mean
0	5	7	6	6.0
200	3	4	5	4.0
400	5	4	4	4.3
600	5	3	4	4.0
0I	6	4	5	5.0
200I	5	3	4	4.0
400I	7	6	4	5.7
600I	5	4	4	4.3

(e) Potassium (mg/100 gm)

N/Irrig.	Start	Middle	End	Mean
0	20	20	23	21.0
200	15	14	15	14.7
400	12	13	20	15.0
600	15	11	14	13.3
0I	15	18	19	16.7
200I	12	15	17	14.7
400I	11	11	14	12.0
600I	13	13	14	10.0

(f) Calcium (mg/100 gm)

N/Irrig.	Start	Middle	End	Mean
0	125	131	137	131
200	102	105	111	106
400	107	105	100	104
600	94	96	92	94
0I	100	89	100	96
200I	106	96	102	101
400I	95	97	99	97
600I	97	95	97	96

(g) Magnesium (mg/100 gm)

N/Irrig.	Start	Middle	End	Mean
0	35	34	34	34.3
200	32	30	31	31.0
400	31	29	30	30.0
600	24	26	24	24.7
0I	31	31	33	31.7
200I	32	30	32	31.7
400I	30	28	30	29.3
600I	27	30	28	28.7

(h) A guide to Kawanda routine soil analysis results

1. % Organic Matter

Low	3	(= 1.5% C or approx. 0.09% N)
Moderate	4	(= 2% C or approx. 0.12% N)
High	6	(= 3% C or approx. 0.18% N)

2. Available P p.p.m.

Low	5	(approx. 15 p.p.m. Truog P_2O_5)
Moderate	10	(approx. 30 p.p.m. Truog P_2O_5)
High	20	(approx. 60 p.p.m. Truog P_2O_5)

3. Available Ca mg/100g.

Low	35	(approx. 2 m.e./100g exchangeable Ca)
Moderate	80	(approx. 5 m.e./100g exchangeable Ca)
High	200	(approx. 12 m.e./100g exchangeable Ca)

4. Available K mg/100g.

Low	15	(approx. 0.3 m.e./100g exchangeable K)
Moderate	25	(approx. 0.5 m.e./100 g exchangeable K)
High	50	(approx. 1.0 m.e./100g exchangeable K)

Note

These figures are very tentative, and will be revised when more data becomes available.

Appendix 4. ANALYSIS OF VARIANCE

4.1 Mean daily liveweight gain during the dry seasons.

Source of variations	dF		M.S.	F
Total	31			
Replicate (seasons)	3		0.80	0.01 N.S.
Treatments	7		1.09	12.82 ***
Nitrogen		3	1.58	18.60 ***
Irrigation		1	2.19	25.80 ***
Nitrogen X Irrigation		3	0.23	2.70 N.S.
Error	21		0.085	

4.2 Mean daily liveweight - gain during the wet seasons

Source of variation		dF	M.S.	F
Total	31			
Replicates (seasons)	3		0.79	3.76 *
Treatments	7		1.77	8.63 ***
Nitrogen		3	3.93	19.17 ***
Irrigation		1	0.04	0.20 N.S.
Nitrogen X Irrigation		3	0.18	0.88 N.S.
Error	21		0.205	

4.3 Mean daily liveweight-gains for dry and wet seasons combined

Source of variation		dF	M.S.	F
Total		63		
Replicates (seasons)		7	0.68	4.5 N.S.
Treatments		7	2.47	15.67 ***
Nitrogen	3		5.09	31.90 ***
Irrigation	1		1.20	8.54 ***
Nitrogen X Irrigation	3		0.30	1.83 N.S.
Error		49	0.164	

N.S. = not significant

* = $P < 0.05$

** = $P < 0.01$

*** = $P < 0.001$

4.4 <u>Consolidation of data.</u>

Mean separation (mean daily liveweight gains) by Duncan's multiple range test.

Dry season	0	0I	200	400	600	200I	400I	600I
	d	d	d	cd	c	bc	ab	a
Wet season	0I	0	200	200I	400	400I	600I	600
	c	c	bc	ab	a	a	a	a
Dry + wet	0I	0	200	400	200I	600	400I	600I
season	c	c	c	b	b	ab	a	a

Within each season treatments bearing the same subscript letter are not significantly different at the 5% level.

4.5 Mean seasonal % C.P. from grazed irrigated and non-irrigated pasture at 4 levels of nitrogen fertilization

(a) <u>Dry seasons</u>

Source of variation	dF	M.S.	F
Total	31		
Replicates	3	6.33	4.4
Treatments	7	33.50	23.3 ***
Nitrogen	3	78.00	54.17 ***
Irrigation	1	0.12	0.07 N.S.
Nitrogen X irrigation	3	0.19	0.13 N.S.
Error	21	1.44	

(b) <u>Wet seasons</u>

Source of variation	dF	M.S.	F
Total	31		
Replicates	3	3.31	1.34
Treatments	7	46.65	18.89 ***
Nitrogen	3	102.20	41.38 ***
Irrigation	1	15.27	6.18 *
Nitrogen X irrigation	3	1.56	0.63 N.S.
Error	21	2.47	

4.6 Mean seasonal % C.F. from grazed irrigated and non-irrigated pasture at 4 levels of nitrogen fertilization.

(a) Dry seasons

Source of variation		dF	M.S.	F
Total		31		
Replicates		3	4.97	4.97
Treatments		7	5.03	5.03 **
Nitrogen	3		9.59	9.59 ***
Irrigation	1		0.41	0.41 N.S.
Nitrogen X Irrigation	3		2.01	2.01 N.S.
Error		21	1.00	

(b) Wet seasons

Source of variation		dF	M.S.	F
Total		31		
Replicates		3	1.03	
Treatments		7	6.51	4.31 **
Nitrogen	3		13.21	8.75 ***
Irrigation	1		1.00	0.66 N.S.
Nitrogen X Irrigation	3		1.66	1.10 N.S.
Error		21	1.51	

4.7 Consolidation of data. Mean separation for % C.P. and % C.F. by Duncan's multiple range test

(i) % C.P. Dry seasons

Means	4.2	4.4	6.1	6.3	8.4	9.0	11.4	11.6
	f	f	e	d	c	b	a	a
Treatments	0	0I	200I	200	400	400I	600	600I

(ii) % C.P. Wet seasons

Means	4.1	4.7	6.2	8.4	9.2	11.2	12.3	13.0
	h	g	f	e	d	c	b	a
Treatments	0I	0	200I	200	400I	400	600I	600

(iii) % C.F. Dry seasons

Means	29.0	29.9	30.1	31.1	31.1	31.4	31.5	32.7
	d	c	bc	abc	abc	abc	ab	a
Treatments	600	600I	400	400I	200	200I	0I	0

(iv) % C.F. Wet seasons

Means	28.9	29.5	30.0	30.2	30.6	31.7	32.2	32.3
	c	c	c	bc	abc	ab	a	a
Treatments	600	600I	400I	200I	400	200	0I	0

N.B. For each of (i) to (iv), means underscored by the same letter are not significantly different at the 5% level.

4.8 The t test for the average soil moisture obtained from irrigated and non-irrigated pasture at 4 levels of N fertilization.

Aver. % moisture for 52 weeks

Lbs N/ac.	Not irrigated	Irrigated
0	17.7	21.4
200	16.9	21.2
400	17.0	20.5
600	16.7	20.9
Mean	17.1	21.0

$$s^2 = \frac{0.44}{3} = 0.147$$

$$s = 0.3834$$

$$s\bar{x} = \frac{.3834}{\sqrt{3}} = 0.221$$

$$t = \frac{21 - 17.1}{0.221} = 17.6 \quad ***$$

Appendix 5. Pooled regression equations of levels of N per acre on (a) % C.P. and (b) % C.F. in herbage.

Levels of N (200 lbs/acre)	% crude protein	% crude fibre
0	4.2	32.7
0	4.7	31.5
0	4.4	32.3
0	4.1	32.2
1	6.3	31.1
1	8.4	31.4
1	6.1	31.7
1	6.2	30.2
2	9.0	30.1
2	11.2	31.1
2	8.4	30.6
2	9.2	30.0
3	11.4	29.0
3	13.0	29.9
3	11.6	28.9
3	12.3	29.5

(a) Crude protein

Analysis of variance

Source	df	S.S.	M.S.	F
Total	15	145.86	-	
Regression	1	133.90	133.90	173.67***
Residual	14	9.96	0.711	

$$SD = \sqrt{RMS} = \sqrt{0.711} = 0.84$$

Coefficient of determination, r^2 = 0.931

Correlation coefficient, r = 0.965

Regression equation: $Y = 4.275 + 2.59X \pm 0.84$

(b) Crude fibre

Analysis of variance

Source	df	S.S.	M.S.	F
Total	15	29.37	-	
Regression	1	16.93	16.93	18.81 ***
Residual	14	12.44	0.90	

$$SD = \sqrt{RMS} = \sqrt{0.90} = \pm 0.95$$

Coefficient of determination, r^2 = 0.5764

Correlation coefficient, r = -0.7592

Regression equation: $Y = 32.14 - 0.92X \pm 0.95$

(a) Crude protein

Analysis of variance

Source	df	S.S.	M.S.	F
Total	15	145.86	-	
Regression	1	133.90	133.90	173.67***
Residual	14	9.96	0.711	

$$SD = \sqrt{RMS} = \sqrt{0.711} = 0.84$$

Coefficient of determination, $r^2 = 0.931$

Correlation coefficient, $r = 0.965$

Regression equation: $Y = 4.275 + 2.59X \pm 0.84$

(b) Crude fibre

Analysis of variance

Source	df	S.S.	M.S.	F
Total	15	29.37	-	
Regression	1	16.93	16.93	18.81 ***
Residual	14	12.44	0.90	

$$SD = \sqrt{RMS} = \sqrt{0.90} = \pm 0.95$$

Coefficient of determination, $r^2 = 0.5764$

Correlation coefficient, $r = -0.7592$

Regression equation: $Y = 32.14 - 0.92X \pm 0.95$

Appendix 6. **THE PRICES OF INPUTS AND OUTPUTS**

1) **Fertilizer (at Kampala, 1970)**

Nitrogen	1/05 per actual lb N
Phosphate:	-/80 " " " P_2O_5
Potash:	-/72 " " " K_2O

2) **Irrigation**

The pump, motor and pipes altogether cost 16,000/-. If these had to last for, say, 10 years, their cost per year would be 1,600/-. The unit had a capacity to irrigate 10 acres per week. Since only 2 acres of pasture were irrigated, the total cost of irrigating them in 2 years was about

$$\frac{(2 \times 1600 \times 2)}{10} = 640/-$$

Therefore each irrigated treatment cost

$$\frac{640}{4} = 160/-$$

3) The price of beef in Kampala is Shs. 5/- per kg. or Sh. 2/27 per lb.

Appendix 7. Initial and final liveweights (lbs) of "tester" experimental cattle.

	1968/69 heifers		1969/70 steers	
No.	Initial wt.	Final wt.	Initial wt.	Final wt.
1	223	502	248	470
2	323	523	279	642
3	269	548	289	632
4	256	557	233	484
5	237	548	311	648
6	271	534	251	487
7	289	564	295	648
8	240	502	310	636
9	245	525	296	623
10	281	564	288	644
Mean	263	537	280	591