THE DEVELOPMENT OF CULTIVATED DRYLAND GRASS PASTURES FOR LIVESTOCK PRODUCTION IN THE HIGH RAINFALL AREAS OF RHODESIA.

by

MALCOLM GEORGE WISHART RODEL

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DECLARATION

This thesis is the result of the author's own original work and contains no other work accepted for any other degree or diploma in any university nor any material which has been previously published, except where due reference is made in the text of the thesis. The exception is Section 4.7 which was planned by K.B. Addison, Senior Pasture Research Officer at Henderson Research Station until 1963, and completed in 1975 by J.N. Boultwood, Senior Technical Research Officer, under the supervision of the author.

M.G.W. Rodel

The author

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1 INTRODUCTION

The collection and propogation of grasses for possible use by livestock started soon after the arrival of the Pioneer Column in Rhodesia in 1890. Organised pasture research began in 1909, but until the end of the second World War the development of a research infrastructure and increases in staff employed were hampered by internal and external problems. From 1945 notable progress was made and the present research facilities are adequate for the demands made upon them. Research is financed by Government and falls under the Division of Livestock, Veld and Pasture Research in the Department of Research and Specialist Services, Ministry of Agriculture.

Pioneer farmers and research workers soon discovered that although the veld (natural grazing) was rich in species composition cattle thrived only during the rainy season when the grasses were growing. During the dry season when the grasses were dormant and the herbage coarse and dry, cattle lost body mass and frequently died despite the fact that there was much dry herbage available for grazing. A search for grasses that would remain green into the dry season was started, and it continued for many years. In this search, several indigenous and imported temperate grasses were tested, all without success.

The feeding of hay, made from grasses in the late dry season, also failed to obviate the loss in body mass of cattle in the dry season. It was found however, that appropriate management and the application of small quantities of chemical fertilizers increased the crude protein content of veld grasses. For example, it was found that cutting or grazing grasses in mid growing season increased the crude protein content of the regrowth cut for hay in the late growing season. It was postulated that it was probably a lack of crude protein in the herbage that caused poverty and deaths in cattle during the dry season. This was confirmed during the late 1930's when it was shown that by feeding small amounts of protein-rich concentrates to cattle during the dry season their body mass was maintained. As a result cattle could be marketed at four to five years of age instead of the normal five to six years without protein supplements. Unfortunately for economic reasons the practice of feeding protein-rich concentrates to cattle during the dry season was not adopted at this time. This situation persisted until after World War II.

Much of the high rainfall areas of Rhodesia, with which this report is primarily concerned, is covered by sandy soils which rapidly decline in fertility when cultivated and are prone to erosion. There are also large areas of heavy clay soil that can be difficult to cultivate and that may cap after rain. About 1950, on the sandy soils, common farming practice was to cultivate the land for tobacco for one or two years, and then leave it fallow for a number of years clearing new land for tobacco as required. On the heavy clay soils where most of the maize was grown, the practice was to grow maize in alternate year rotation with annual legumes that were ploughed under as green manure in order to maintain soil fertility. Also at this time there was a universal interest in pastoral farming with emphasis on the use of grass leys. On the recommendations of an invited authority on this subject, pasture research in Rhodesia became centred on the use of grass leys in the hope that they would enhance crop and animal production from both sandy and clay soils. The ultimate objective was the evolution of stable mixed farming systems that would meet the future needs of an expanding human population.

Consequently, much research effort was spent over the next 16 years in developing grass leys for Rhodesian conditions. In general, the results of detailed investigations at two of the major research stations, namely, the Grasslands and Henderson Research Stations, the former on sandy soils derived from granite and the latter on heavy clay soils, were disappointing. The expected improvement in soil fertility and resultant increase in crop yields following grass leys did not materialise.

Despite the fact that fertilizers were applied to the leys it was still necessary to apply fertilizers directly to the crops to achieve satisfactory yields. On the sands there was some effect the first year and to a lesser extent during the second year after the ley, but this was mainly a physical one which reduced the erosion hazard. On the clays grass leys had no effect on following crops regardless of fertilizers applied to them and management imposed. Yields of maize after leys were no greater than yields where maize was grown in successive years and where adequate chemical fertilizers were applied and all crop residues were ploughed back into the soil. Furthermore, although the quality of herbage from grass leys was better than that from the veld, cattle still lost body mass when grazing on them as foggage during the dry season or if fed on hay or silage made from them.

The effects of feeding small amounts of protein-rich concentrates to cattle grazing on coarse dry roughages during the dry season was again investigated in 1960 and the great impact that this could have in practice was realised. Also it had become clear that cattle grazing the veld on clay soils were likely to gain body mass for only the first four months of the growing season, and that the more desirable grasses were replaced by unpalatable species. The reason for this was that cattle tended to concentrate on the desirable grasses because they were more palatable and the frequent defoliation during the growing season weakened and then killed them thus allowing the unpalatable species to multiply. Clearly if grazing during the growing season could be provided by grass leys the veld grasses could be rested, they would maintain their vigour and they would not be replaced by unpalatable species. The coarse dry herbage that accumulated from resting the veld could be efficiently utilized during the dry season by supplementing cattle with protein-rich concentrates.

The emphasis on the clay soils served by Henderson Research Station thus changed from using grass leys as sources of foggage or conserved foods for the dry season, to using them as grazing during the growing season. Grasses were selected for this purpose, the optimum fertilizer requirements in the prevailing economic circumstances were determined, stocking rates with cattle were investigated and production measured. Although it was found that the carrying capacity of grass leys was about six times greater than that of the veld during the growing season, the monetary returns could not rival those from cash crops. By 1963 there seemed to be no future for grass leys on the clay soils both from the point of view of maintaining soil fertility and therefore crop yields, or from the value of livestock products that could be obtained from them. Grass pastures could only be included in farming on the clay soils if they enabled the value of beef produced to rival the value of the cash crops. Maize was the principal cash crop and few cattle were being kept at the time. There was a great potential for using the maize for fattening beef cattle. However, it was recognised that the carrying capacity of maize farms based on veld and crop residues was too low to take advantage of the maize for fattening purposes. If permanent grass pastures could be introduced and used for grazing during the growing season the veld could be rested at this time and then grazed during the dry season together with maize stover, provided cattle were adequately supplemented with protein-rich concentrates. This would materially increase the carrying capacity of maize farms and greater advantage could be taken of maize for fattening beef cattle. Thus maize and grass pasture would be complementary to one another in a mixed farming system. There was adequate arable land for both maize and pasture on farms. The problem was to find ways of increasing productivity from grass pastures.

A clue as to how productivity from pastures could be increased was given by the results from two experiments, one carried out in 1953, and the other in 1961. In these experiments it was found that herbage production from grasses increased as nitrogen applications were increased up to at least 470 kg N per ha. With this application, up to 19 770 kg of dry herbage per ha was harvested in a growing season, indicating that grasses could support large numbers of cattle. For economic reasons this result was not pursued and in practice no more than 150 kg N per ha was recommended for pastures.

Because the great potential for producing beef on maize farms in the Mazoe Valley in particular, and in the high rainfall areas of Rhodesia in general was recognised, the research programme reported in this dissertation was started in 1963. The ultimate objective of this work, which continued until 1975, was to increase the carrying capacity and production of dryland grass pastures to a point where they could be profitably integrated into beef production systems on maize farms.

Clearly grasses capable of producing large amounts of herbage and therefore likely to have a high potential livestock carrying capacity, would have to be found. For this a large number of grasses were grown in a comparative trial and those apparently suitable for the purpose were selected.

The grasses selected on the basis of their herbage yielding ability were then tested for their responses to heavy applications of nitrogenous fertilizer. This was done both with and without grazing animals and on different sites, because it is well known that the return of dung and urine to pasture and the type of soil on which the pastures are grown can influence these responses.

The selected grasses were then subjected to different stocking rates and systems of management to determine the most productive stocking rates and the most suitable system of management. Of particular interest was the durability and profitability of grass pastures.

Finally, various ways of integrating pastures into intensive systems of beef production on maize farms in the Mazoe Valley were considered. In these systems the various roles that fertilized dryland grass pastures, the veld and the maize available would play, are outlined. The effect of integrating grass pastures into beef production systems on the carrying capacity of farms, the use of maize for fattening slaughter cattle, the output of beef and the overall profitability of farming systems are indicated.

2 DESCRIPTIONS OF THE HIGH RAINFALL AREAS OF RHODESIA AND OF HENDERSON RESEARCH STATION

2.1 The High Rainfall Areas

Rhodesia is situated in south central Africa, slightly north of the Tropic of Capricorn between latitudes 15° 40' and 22° 30' south, and longtitudes 25° 15' and 33° 05' east.

The topographical features of Rhodesia are shown in Figure 1. The topography is dominated by a central plateau extending from near the south-western border to the central area where it divides with one arm extending eastwards to the border with Moçambique and the other north-westwards ending on the escarpment of the Zambesi River Valley. The plateau ranges in altitude from 1150 m to 1700 m above sea level but, on the eastern border it rises to 2600 m as it merges into the mountainous area extending both northwards and southwards. The plateau is generally of gently undulating relief and is drained by two major river systems ; the Zambesi and the Sabi-Limpopo. The rivers of the former drain north-east into the Zambesi and those of the latter drain south-east into the Sabi or Limpopo. These two rivers flow east or south-east through Moçambique into the Indian Ocean.

The rainfall of Rhodesia (Figure 2) is influenced markedly by topographical features. For example the mountainous area along the eastern border has an annual rainfall of between 1000 and 2000 mm, the central plateau receives between 600 and 900 mm while low altitude areas in the south of the country receive less than 400 mm annually. Generally rainfall tends to become less from north to south and from east to west, as altitude decreases.

Since this dissertation concerns the development of dryland grass pastures, further descriptions of the Rhodesian environment are confined to the areas where these pastures are likely to be successful. The areas of the country

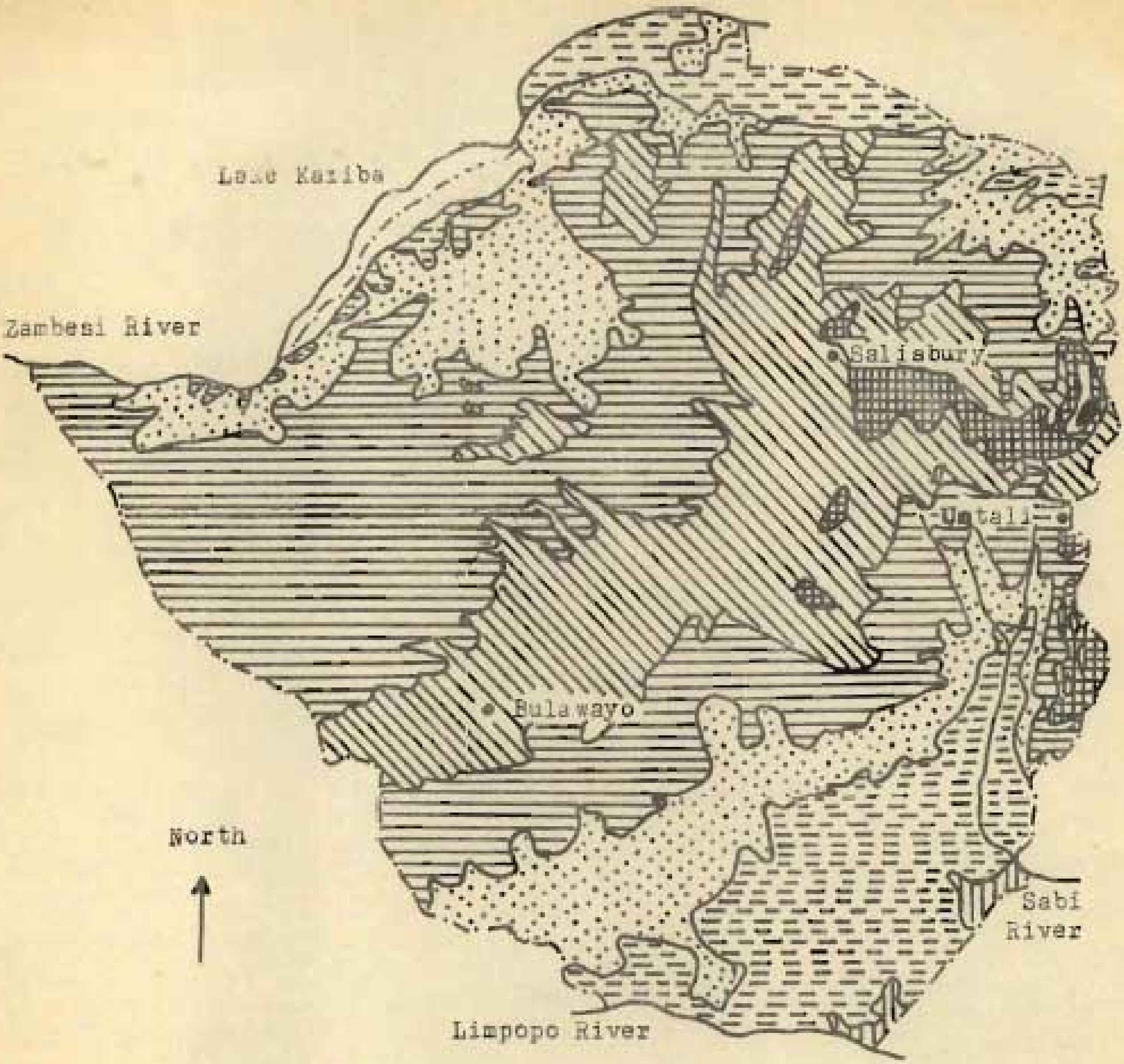
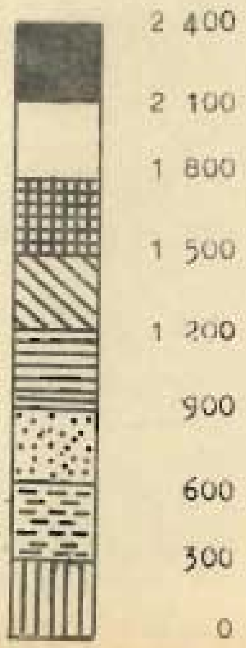


Figure 1. Topography of Rhodesia.
Altitude in m. Scale 1 : 5 000 000



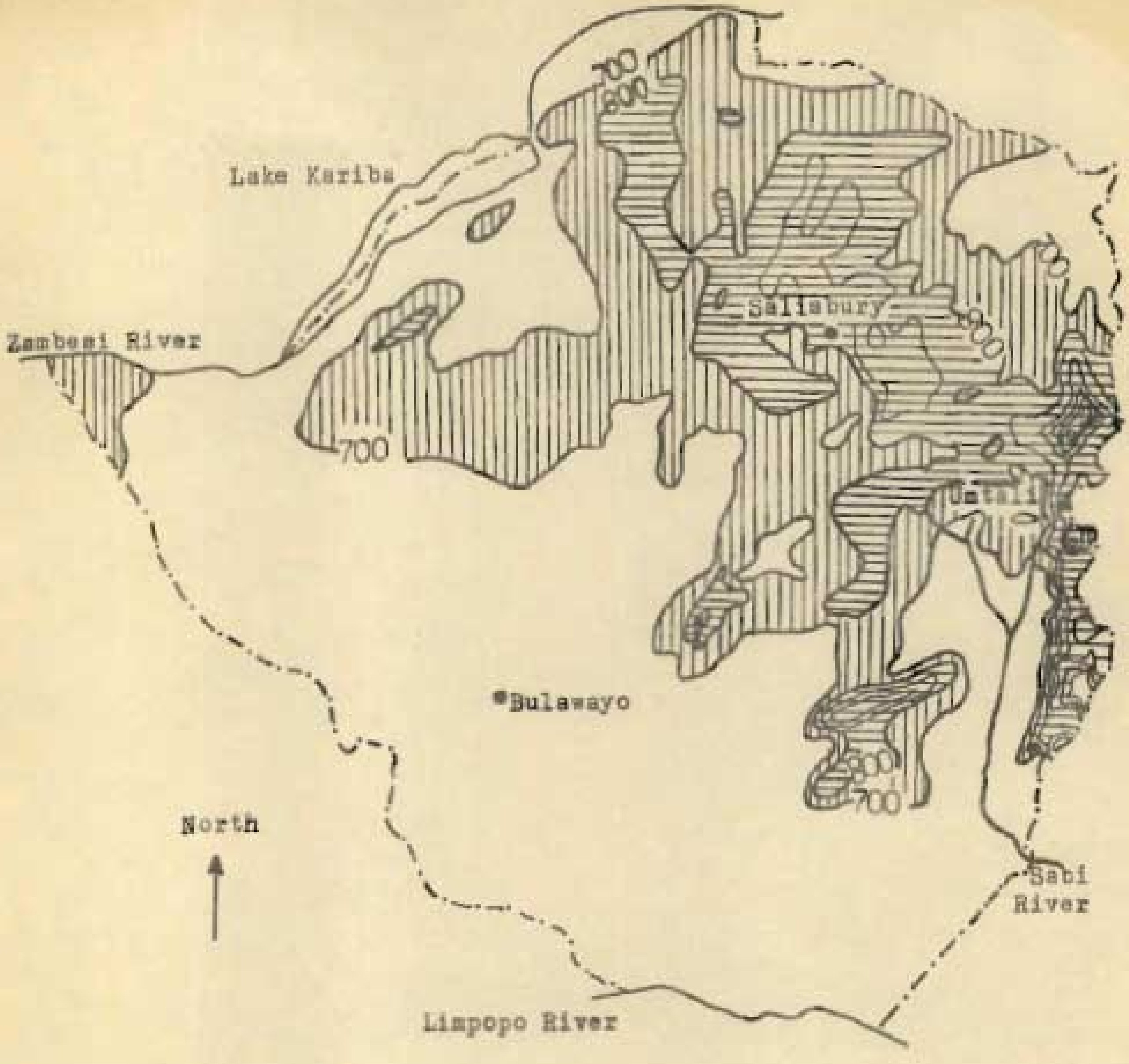
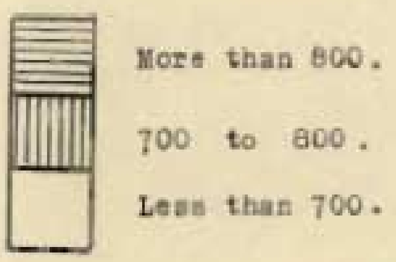


Figure 2. Mean annual rainfall of Rhodesia in mm. Scale 1 : 5 000 000. (Department of Meteorological Services, 1968).



having conditions favourable for pastures are mainly coincident with those suitable for intensive dryland crop production and these have been defined as Agro-ecological Regions I and II by Vincent and Thomas (1961). Region III, as defined by Vincent and Thomas (1961), has a less reliable rainfall than Regions I and II and is more suitable for semi-intensive crop and livestock farming systems. Therefore this Region is only marginally suited for dryland grass pastures.

Recognizing the importance of rainfall distribution in determining cropping potential, Ivy (1975a) prepared a map (Figure 3) showing rainfall distribution over the main cropping areas of Rhodesia using the method of rainy pentades as defined by Griffiths (1960). For this system the year is divided into five-day periods (pentades) and for each pentade rainfall totals are extracted. A rainy pentade is the centre one of three pentades which together received more than 38,1 mm of rain and not more than one of the three having received less than 7,6 mm. From the agricultural point of view the method allows for the build-up of moisture in the soil before conditions can be described as being wet. As no account is taken of how much over 38,1 mm the total group of three pentades may be, allowances are made for rainfall lost by run-off.

Using the distribution of rainfall by rainy pentades (Figure 3), Ivy (1975b) redefined the boundaries of Agro-ecological Regions I, II and III (Figure 4) as previously defined by Vincent and Thomas (1961).

Areas of Rhodesia which receive more than 16 rainy pentades per season (Figure 3) generally have an adequate, well-distributed rainfall that makes them suitable for dryland pastures and coincide approximately with Regions I and II (Figure 4). The area that has 14 to 16 rainy pentades (Figure 3) has a less reliable rainfall accompanied by frequent droughts and is approximately coincident with Region III (Figure 4). This area is only marginally suitable

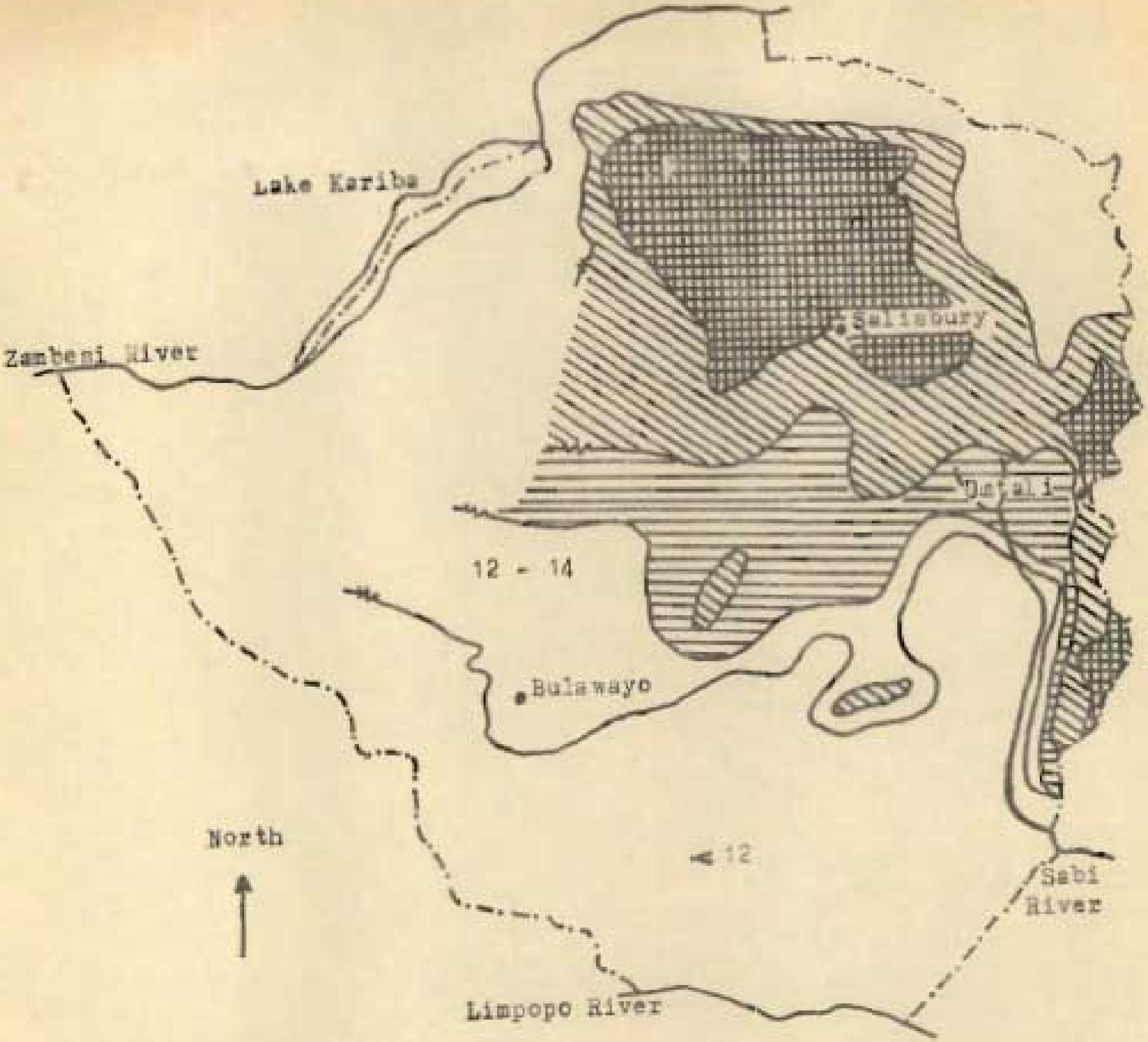
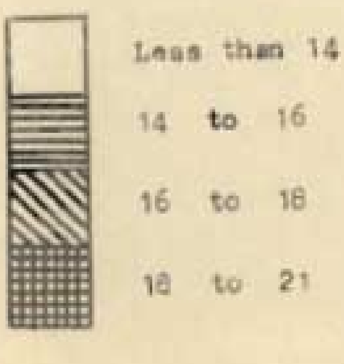


Figure 3. Areas of Rhodesia that receive more than 14 rainy pentades per annum. Scale 1 : 5 000 000 (Ivy, 1975a).



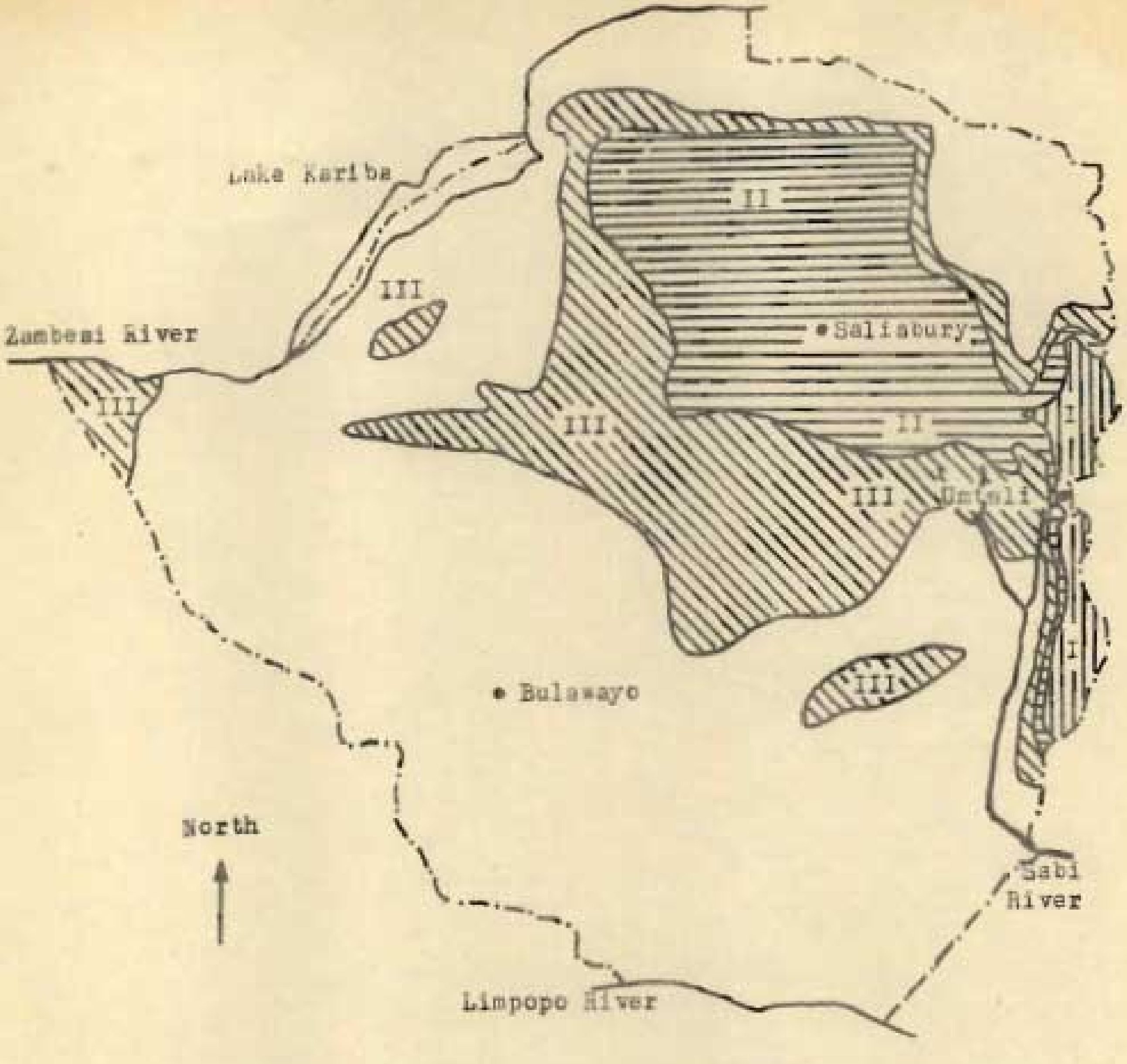
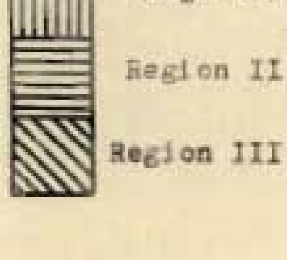


Figure 4. Natural Regions in areas of Rhodesia that receive more than 700 mm of rain per annum and that have more than 14 rainy pentades per annum. Scale 1 : 5 000 000 (Vincent and Thomas, 1961 ; Ivy, 1975b).



for pastures. The former fall mainly within those areas of Rhodesia receiving more than 800 mm of rain annually and the latter within areas receiving 700 to 800 mm of rain (Figure 2). In the Republic of South Africa Visser (1966) stated that the chemical fertilization of veld (natural vegetation used as grazing which may be composed of any number of growth forms and need not be climax vegetation) was economic where more than 625 mm of rain fell annually while Edwards (1966) stated that 760 mm of rain annually was required for the successful replacement of veld grasses by cultivated species.

The soils falling within those areas of Rhodesia suitable or marginally suitable for dryland grass pastures are shown in Figure 5 (Thompson and Purves, 1979).

2.1.1 Natural Region I

This region adjoins Mocambique in the east and runs both north and south of Umtali, the main town in the area. It is a mountainous area interposed with deep valleys and has an annual rainfall in excess of 1070 mm with some areas receiving more than 2540 mm. Most rain falls during the summer months (November to April) although drizzle or mist may occur in any month of the year. Except in the major valleys where the climate is sub-tropical, the climate is generally cool in summer and cold in winter with frequent frosts.

The northern part of this Region with altitudes up to 2600 m is generally higher than the southern part which has a mean altitude of about 1380 m. These northern high altitude regions have a distinctly temperate climate and so are suited to the cultivation of dryland pastures of temperate rather than tropical or sub-tropical species. Because of the limited extent of these areas and the limited scope for temperate pastures in Rhodesia, they are not given further attention in this dissertation. The lower elevations of the southern parts of this region, however, have a climate suited to the production of sub-tropical grass pastures.

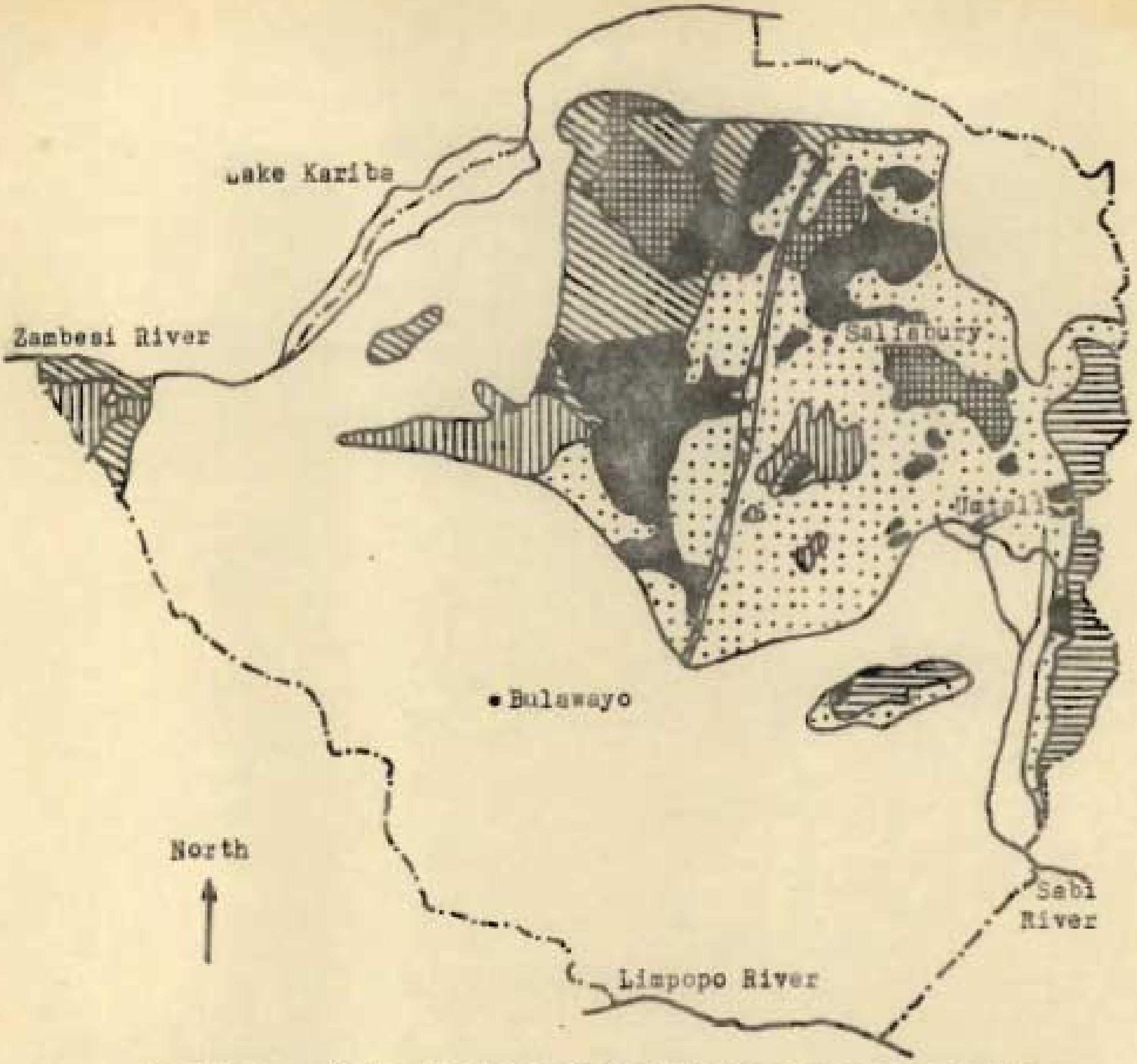
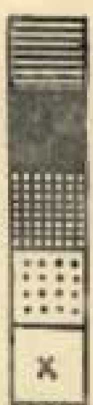


Figure 5. Soils in areas of Rhodesia receiving more than 700 mm of rain per annum and that have more than 14 rainy pentades per annum. Scale 1 : 5 000 000 (Thompson and Purves, 1979).



Highly leached acid orthoferrallitic soils.

Heavy textured fersiallitic soils.

Heavy textured paraferrallitic soils derived from granite.

Sandy fersiallitic soils derived from granite.

Dyke soils high in magnesium.

Shallow skeletal lithosol soils.

Sandy soils derived from Kalahari and Karroo sediments.

Soils

According to Thompson (1965) the soils in Natural Region I have the characteristics of those in the orthoferrallitic group of kaolinitic soils. Such soils are leached and acid in reaction, are highly porous and truly ferrallitic with very little or no reserves of weatherable minerals and with base saturations usually lower than 30%. They comprise red orthoferrallitic clays found on basic rocks, yellow orthoferrallitic silty-clays found on Umkondo shales and red and yellow orthoferrallitic sandy to medium textured soils on granites and Umkondo sandstones.

Vegetation

Originally the climax vegetation was a montane rain forest but today only small relic patches remain. In these forests, altitude determines the dominant species, with Widdringtonia whytei and Podocarpus milanjianus occurring at high altitudes; the evergreen, broad-leaved trees Cussonia umbellifera, Aphloia theiformis, Syzygium gerrardii, Macaranga mellifera, M. capensis, Chrysophyllum gorungosanum, Craibia brevicaudata, Ilex mitis, Pittosporum viridiflorum at slightly lower altitudes; and Uapaca kirkiana, Macaranga sp., Anthocleista zambesiaca and Adina microcephala in the hot, sub-tropical valleys (Vincent and Thomas, 1960).

According to Vincent and Thomas (1960) the remainder of the area is considered to be a fire pro-climax of four types; mountain grassland, shrubland, grassland with scattered trees, and woodland, while Rattray (1957) classified it simply as mountain grassland. Crook (1956) classified the vegetation of the Melsetter area into similar categories. The mountain grassland (Vincent and Thomas, 1960) consists of sour grasses such as Loudetia simplex, Elyonurus argenteus, Monocymbium ceresiiforme, Apochaete hispida, Bewsia biflora, Sporobolus sp., Alloteropsis semialata, Eragrostis spp. and others, and occurs at the highest altitudes.

The relatively homogenous mountain grassland changes abruptly into a shrubland comprising Smithia thymodora and Psoralea foliosa with Pteridium aquilinum and Helichrysum kraussii. Associated with these are tall Hyparrhenia, Cymbopogon and Setaria spp. This shrubland changes gradually into a grassland with scattered trees. The main trees found here are Parinari curatellifolia, Pterocarpus angolensis, Cussonia spicata, Dombeya rotundifolia, Ficus spp., Faurea saligna and Strychnos cocculoides while Syzygium cordatum occurs along stream banks. The tall grasses Hyparrhenia spp., Cymbopogon validus, Setaria spp., Pennisetum spp., and Beckeropsis uniseta grow between the scattered trees (Vincent and Thomas, 1960).

Woodland, comprising a dense cover of stunted and distorted trees with little grass beneath, covers large areas at all altitudes but especially on the warmer, westerly and northerly slopes. Brachystegia spiciformis is dominant but at lower altitudes gives way to Brachystegia utilis. Uapaca kirkiana is locally dominant on well-drained, frost-free sites. A poor, sparse grass cover occurs under the trees mainly comprising Loudetia simplex, Digitaria sp., and some Hyparrhenia spp.. The shrub Philippia benguelensis is common (Vincent and Thomas, 1960).

Land use

The most suitable areas for farming are in the south around Chipinga and in the valleys around Melsetter. These areas generally lie at a lower altitude, have potentially more arable land and are warmer than the rest of the Region which is more mountainous and therefore has less potential arable land. Vincent and Thomas (1961) described the area as being suitable for a system of crop production supporting intensive livestock, particularly dairying based on established pastures. While some crops are grown and livestock are kept, coffee has of recent years become increasingly important. Afforestation with softwoods is also important, and some deciduous fruit is grown.

The remainder of Natural Region I, which has a more mountainous terrain, is used extensively for afforestation, particularly for softwoods. This is also the main area of Rhodesia for deciduous fruits. In the warm valleys, which have a sub-tropical climate, tea and coffee plantations are increasing in area. Although Vincent and Thomas (1961) stated that the area was suited to semi-intensive dairy and semi-intensive beef production these have not developed to any great extent. A few wool sheep are kept.

2.1.2 Natural Region II

This is the most intensive farming area of Rhodesia. It comprises the central plateau which lies at altitudes of between 1150 m to 1700 m. The capital of Rhodesia, Salisbury, is in the centre of this Region. The mean annual rainfall is between 700 and 1060 mm most of which falls between mid-November and mid-April while the rest of the year is dry. Rainfall is fairly reliable, thus making the Region suitable for crop production. Generally the topography is gently undulating with the terrain sloping gradually away from the centre of the plateau but is broken in many parts by hills, particularly adjacent to the Mazoe River. These hills cause local variations in rainfall with south-easterly slopes often receiving above average rainfall while adjacent north-westerly slopes receive below average rainfall. River valleys, which are at a lower elevation than the plateau, are usually warmer and therefore rainfall is less effective. Mean annual temperatures range between 15° to 21° C but frosts are common over the whole area between June and September and are more severe at the higher altitudes (Vincent and Thomas, 1961).

Soils

The principal soils, which cover approximately two-thirds of the area, have coarse-grained sandy surface horizons overlying medium to heavy-textured sub-soils. They are derived from granite and belong to the paraferrallitic group of kaolinitic soils, which, although they have some ferrallitic characteristics, are not truly ferrallitic. These soils, together with the ferrallitic sandy soils derived from granite, are commonly known as granite sands (Figure 5).

Interspersed in the granite sands are heavy-textured, fersiallitic soils which are moderately to strongly leached with their clay fractions mainly kaolinitic and which contain appreciable amounts of free sesquioxides of iron and aluminium. They have considerable reserves of weatherable minerals and base saturations of 60 to 80 %. They comprise red, granular clays found on basic and ultra-basic rocks ; silt-rich soils formed mainly on sedimentary rocks ; highly micaceous soils formed from highly micaceous parent materials ; and weakly fersiallitic, red clays found on narrow dolerite dykes intrusive into granite (Thompson, 1965).

There are two other soil types which are of little importance from a pasture point of view. These are the Dyke soils and the sandy soils derived from Karroo sandstones.

The Dyke soils are either vertisols without appreciable free water, soluble salts or exchangeable sodium, found mainly on basic or ultra-basic rocks ; or fersiallitic, red, granular clays found on similar rocks (Thompson, 1965). The "Great Dyke" runs in a north-south direction for the length of the plateau and is a narrow band of steep, broken hilly country, rising out of the plateau.

The deep sandy soils derived from Karroo sandstones have a fine-grained sand fraction and overlie, at varying depths, medium textured sub-soils. Many of these soils are subject to a high water table.

Vegetation

The descriptions which follow have been taken from Rattray (1957), Vincent and Thomas (1960), Wild and Grandvaux Barbosa

(1967), to which the author's own knowledge of the vegetation has been added.

The principal vegetation occurring in Region II is a woodland dominated by a Brachystegia spp. in association with Julbernardia globiflora. In its natural state the woodland comprises trees 5 to 10 m tall, closely or widely spaced in a tall grass community whose density varies inversely with tree density. Little of the natural woodland remains today as much has been cleared for agricultural purposes or has been cut for firewood or for mining operations. The dominant tree species coppice freely when cut. Uncontrolled chopping frequently results in a dense thicket vegetation in which the herbaceous component is severely suppressed.

In Natural Region II the vegetation may be classified into two main communities based on the two major soil types that occur. While the grass species are influenced to some extent by changes in soil type the dominant tree species are influenced more by altitude than by soil changes.

The vegetation of the granite sands

The vegetation of the granite sands is dominated by Brachystegia spiciformis and Julbernardia globiflora. B. spiciformis is usually dominant in the wetter, higher areas. J. globiflora assumes dominance at the lower, slightly drier altitudes when Brachystegia boehmii also becomes common and may assume dominance at the lowest altitudes in this Natural Region. Of the many trees associated with the dominants, common are : Diplorhynchus condylocarpon, Pseudolachnostylis maprouneifolia, Strychnos spinosa, Uapaca kirkiana, Erythrina spp., Ficus spp., Protea spp., Monotes glaber, Terminalia sericea and Parinari curatellifolia.

Where the trees are dense the grass cover is sparse and comprises Hyparrhenia filipendula associated with the undesirable species Perotis patens, Microchloa kunthii, Sporobolus stapfianus, Schizachyrium jeffreysii, Aristida barbicollis, A. congesta, Trichoneura grandiglumis, Pogonarthria squarrosa and Eragrostis chapelieri. When the trees are removed or thinned the grass cover thickens up considerably with Hyparrhenia fillipendula and Hyperthelia dissoluta becoming dominant. In such cleared veld Stereochlaena cameronii, Digitaria milanjiana, D. pentzii, Schizachyrium semiberbe, Brachiaria serrata, Heteropogon contortus, Pogonarthria squarrosa and Cynodon dactylon (particularly on termitaria), are commonly found. Associated with the grasses are numerous herbs and small shrubs, notably Eriosema englerianum, Dolichos maloeanus, Lippia javanica, Psoralea sp., Tephrosia spp., Indigofera spp. and Borreria sp..

In the disturbed areas and on recently abandoned arable land Rhynchelytrum repens, Eragrostis aspera, E. viscosa, E. patens, E. cilianensis, Setaria pallide-fusca, S. verticillata, Aristida adscensionis and Eleusine indica generally occur. On reverted land these grasses are replaced after three to five years by Hyparrhenia filipendula and Hyperthelia dissoluta which become dominant and which are associated with similar grass species to those found on cleared veld.

Grassy vleis (poorly drained soils generally in depressions associated with drainage lines) are characteristic in granite sand areas and in places comprise up to 30 % of the land. Parinari curatellifolia, Syzygium guineense, S. huillense and Protea spp. often grow on vlei margins or scattered in semi-vlei land where the water table is near the soil surface. In the vleis unpalatable sedges such as Scleria spp. are frequently more common than grasses, particularly in the wetter parts of vleis. In the drier parts of vleis Loudetia simplex, Brachiaria filifolia, Eragrostis capensis, Monocymbium ceresiiforme, Aristida macilenta, Elyonurus argenteus, Alloteropsis semialata and Andropogon eucomus occur.

Boulder kopjes are common in the granite sands. On these Brachystegia glaucescens and B. spiciformis are usually the dominant trees, and are commonly associated with Julbernardia globiflora, Diplorhynchus condylocarpon, Pseudolachnostylis maprouneifolia, Ficus, spp., Cussonia natalensis, Swartzia madagascarensis, Strychnos spinosa, Lannea discolor, Pterocarpus angolensis, Erythrina abyssinica and Flacourtia indica.

The vegetation of the heavy soils

The heavy soils generally occur at lower altitudes than do most sands in Natural Region II. These zones are warmer and rainfall is slightly less than in the granite sand areas, but it is still adequate for intensive farming. Julbernardia globiflora and Brachystegia boehmii are co-dominant trees with the latter assuming dominance on north-westerly slopes. With decreasing altitude B. spiciformis occurs less frequently and at medium altitudes it is replaced by B. boehmii while on the shallow rocky soils of the hills B. glaucescens is commonly found in association with B. boehmii and J. globiflora. Diplorhynchus condylocarpon, Peltophorum africanum, Flacourtia indica, Bauhinia galpinii, Piliostigma thonningii, Uapaca kirkiana, Pterocarpus angolensis, P. rotundifolius, Strychnos spinosa, Monotes glaber, Ficus sp., Combretum spp., Terminalia spp. and Pseudolachnostylis maprouneifolia are common associates in these areas.

The dominant grasses are Hyperthelia dissoluta and Hyparrhenia filipendula which are associated with H. rufa, H. cymbaria, Themeda triandra, Brachiaria serrata, B. brizantha, Heteropogon contortus, Andropogon gayanus, Panicum maximum and Sporobolus pyramidalis. Cynodon dactylon is common on termitaria. On disturbed areas Setaria pallide-fusca, S. verticillata, Rottboellia exaltata, Tragus racemosus, Chloris pycnothrix, C. virgata and Cynodon dactylon are usually found while common weeds of arable lands are R. exaltata, Setaria pallide-fusca, Urochloa mosambicensis, U. panicoides, Pancium sp., Digitaria sp., Brachiaria sp. and Sorghum verticilliflorum.

Few grassy vleis occur on the heavy soils. In these Imperata cylindrica, Leersia hexandra, Hemarthria altissima, Allotaropsis semialta, Sporobolus pyramidalis, Paspalum urvillei, P. dilatatum, Setaria sphacelata and Phragmites communis are commonly found. Many grassy drainage lines occur. These are dominated by Hyperthelia dissoluta and Hyparrhenia fillipendula with Acacia polyacantha and A. sieberiana var. woodii as the principal trees. Syzygium cordatum, S. guineense, Ilex mitis, Celtis kraussiana, Chrysophyllum magliamontanum, Pittosporum viridiflorum and Combretum erythrophyllum are found on the banks of streams and rivers where alluvial soil occurs while A. karroo is found as a river valley tree.

Land use

Vincent and Thomas (1961) divided Natural Region II into ten different areas of potential intensity of farming based principally on rainfall and soils. For the present purpose a description of farming on the two main soil types will suffice.

The granite sands

The organic matter content of these soils is low and consequently the nitrogen content is low. The amounts of available phosphorus are variable but base exchange capacity and general base status are poor. Potash is generally available in amounts adequate for most crops. Once granite sands are cultivated organic matter decomposes rapidly. The organic matter, and therefore the nitrogen status, are difficult to maintain under cultivation. By using fertilizers and lime, crop rotations and grass leys, the stability and productivity of these soils can be maintained and even improved, resulting in excellent crops. These soils are particularly suitable for flue cured tobacco which is grown on land following three or four years of grass ley. The grasses used for these leys are usually resistant to the root knot nematode, Meloidogyne javanica, which causes serious damage to the roots of tobacco plants.

The average size of farms in the high rainfall granite sand areas is 1260 ha (Anonymous, 1977a), of which 51 % is potential arable land. At present 12,3 % of the total area of farms is cultivated. Before 1965 tobacco was the most important crop but today relatively little is grown. Maize is now the most important crop and with the development of short-season hybrids it can now be successfully grown above 1380 m where it is too cool for the long-growing-season hybrids. Cotton has become an important crop below 1400 m where burley tobacco and groundnuts are also grown. Where irrigation is available tobacco, maize, groundnuts or cotton may be grown with supplementary irrigation during summer followed by irrigated wheat in winter. In the higher, cooler parts of the granite sands, there has been some development of deciduous fruit and pyrethrum in recent years.

During the last decade the numbers of beef cattle have increased markedly. Many farms now have breeding herds and sell store cattle or slaughter stock. Cattle are mainly carried on the veld, utilising also limited areas of crop residues and grass leys. Some grass pastures have been established during the last ten years specifically for carrying beef cattle but further development is likely to be slow in view of the present high cost of fertilizer.

The clay soils

The heavy clay and silty clay soils are very suitable for sustained, intensive cash cropping provided their nutrient and base status are maintained by application of fertilizers and agricultural lime and provided crop residues are ploughed under to maintain a good physical structure which facilitates cultivation.

The mean size of farms is 1100 ha, of which 30 % is potential arable land but at present approximately only one-half of this is cultivated (Anonymous, 1976a). Maize and cotton are the most important crops of the area. While maize is grown throughout the area cotton is generally grown at altitudes below 1400 m. Burley tobacco, groundnuts and soyabeans are also grown. Where irrigation is available wheat has become an important crop. The general practice is to take two crops a year from irrigated land by growing either maize, cotton or soyabeans during the summer, supplementing rainfall with irrigation, followed by irrigated wheat during the winter.

As on the granite sands beef cattle have increased considerably in numbers during the last decade. Most farms now carry breeding herds and sell slaughter cattle. The fattening of slaughter cattle on high energy rations containing 70 % maize grain was becoming widespread but present economic circumstances do not favour this system. Cattle are carried largely on the veld, with crop residues, protein-rich supplements and maize grain. While there has been some development of both irrigated and dryland grass pastures for beef production the present high cost of fertilizers is restricting further expansion.

2.1.3 Natural Region III

This Natural Region is adjacent to Natural Region II (Figure 4) and lies mainly between altitudes of 980 m and 1290 m. Annual rainfall varies between 560 and 710 mm (Figure 2) and is often poorly distributed (Figure 3) within and between seasons. Consequently, most of the Region is only marginally suitable for cash crops and, for the same reason, for dryland grass pastures. Topography is similar to that found in Natural Region II since Natural Region III also occupies a large part of the central plateau. However, broken, hilly country does occur where the main rivers leave the plateau and in areas of heavy soil.

Mean annual temperatures range from 16° to 22° C while mean maximum temperatures may be as high as 28° C at the lower altitudes. Frosts occur from June to August over the entire area (Vincent and Thomas, 1961).

Soils

The soils in Natural Region III are similar in many respects to those in Natural Region II which have already been described. The boundaries demarcating the different soils in Natural Region III receiving more than 700 mm rain annually with more than 14 rainy pentades per season are included in those mapped in Figure 5. However, this Region also includes the weakly developed Kalahari sands. These are deep sands with less than 15 % silt and clay above 2 m and extremely low silt/clay ratios with little or no reserves of weatherable minerals (Thompson, 1965).

Vegetation

In contrast to Natural Region II vegetation in Natural Region III is affected more by soil changes than by rainfall and this becomes evident as rainfall diminishes. Julbernardia globiflora Brachystegia boehmii woodland occurs on granite sands while Brachystegia spiciformis and Baikiaea plurijuga are dominant on the Kalahari sands with J. globiflora a common associate. Small areas of poorly drained, sodium clays are scattered throughout the granite sands and on these Colophospermum mopane is dominant. On loams and clays Combretum spp. become dominant at the lower altitudes while B. boehmii and J. globiflora are dominant at the higher altitudes. Acacia karroo and other Acacia spp. are generally dominant on the heavy clays (Vincent and Thomas, 1960).

The grasses in Natural Region III are numerous and varied. On the granite sands Eragrostis jeffreysii, E. rigidior, *Aristida* spp., *Pogonarthria squarrosa*, *Schizachyrium semiberbe*, *Hyparrhenia filipendula* and *Hyperthelia dissoluta* are common while on the Kalahari sands *Aristida graciliflora*, *A. pilgeri*, *Apochaete rehmannii*, *Eragrostis* spp., *Digitaria* spp., *Andropogon schirensis* and some *H. filipendula* and *H. dissoluta* are found. On the heavy soils common grasses are *Themeda triandra*, *Heteropogon contortus*, *Bothriochloa insculpta*, *Cymbopogon plurinodis*, *Digitaria* spp., *Setaria sphacelata*, *H. filipendula* and *H. dissoluta* (Vincent and Thomas, 1960).

Land use

Vincent and Thomas (1961) divided Natural Region III into five areas (A to E) of potential use for farming. Natural Regions III A, B and C were classified as being suitable for semi-intensive livestock production based on veld, supported by small grains and other short-season, drought-resistant crops. Natural Regions III D and E were classified as semi-extensive ranching areas.

On the heavy textured soils cotton is the principal crop with sorghum, burley tobacco and short-season varieties of maize. Where irrigation is possible cotton or maize are grown under supplementary irrigation in summer, followed by irrigated wheat in winter. On the lighter soils sorghum and short-season varieties of maize are grown but conditions on these soils are less favourable for crop production than on the heavy soils. Dryland grass pastures are only a possibility in those areas of Natural Region III receiving more than 700 mm of rain annually with a distribution of more than 14 rainy pentades per season (Figures 2 and 3).

In Natural Region III beef cattle are generally the main farming enterprise. Store cattle are often produced for sale off the veld while slaughter cattle are also produced off the veld, supplemented to some extent with forage crops and grains.

2.2 Henderson Research Station

Henderson Research Station is 32 km north of Salisbury, the capital, and largest city of Rhodesia. The main road joining Salisbury with the farming centres of Bindura, Shamva, Mazoe, Concession, Glendale, Umvukwes, Centenary and Mount Darwin passes through the Station. It is situated at latitude 17° 35' south and longitude 30° 58' east. It is one of the largest research stations in the Department of Research and Specialist Services, Ministry of Agriculture, Rhodesia. Originally it was the property of Mr. Archibald Henderson who farmed it for 35 years, producing mainly flue cured tobacco. In 1947 the Great B Estate, as it was then known, was purchased by the Government as a Research Station. Since then the Station has seen various changes and developments and it is now the headquarters of the Division of Livestock, Veld and Pasture Research. The main research activities on the Station, which is situated in Natural Region II (Figure 4) are at present, animal nutrition, animal reproductive physiology, and a study of the use of nitrogen fertilized pastures and pasture legumes for beef production. In addition a poultry research unit is being developed and the Weed Research Unit, Division of Crop Research, has its headquarters here. The Weed Research Unit investigates effects of herbicides on crops and weeds, weed biology and related tillage practices.

Henderson is some 2 220 ha in extent and is bounded by the Iron Mask Range of hills in the west and by a range of granite hills in the east. It lies in the valley formed by these hills and the topography in the valley is undulating with slopes ranging from 3% in the central area to 8 % adjacent to the steep hills which flank the valley. The altitude is 1 290 m at the floor of the valley, rising to 1 540 m on the hills. The Station is situated at the head of the Mazoe River Valley and the Dassura River which runs through the Station joins with the Mazoe River in the Mazoe Dam whose waters extend onto the Station. The Mazoe Dam is used to irrigate a large citrus estate while the Mazoe Valley generally is one of the most intensively farmed areas in Rhodesia.

Climate

This is very similar to the rest of the high rainfall areas of Rhodesia. Henderson has a sub-tropical, summer rainfall climate, with the main rains starting in mid-to-late November and ending late in March or early April. The 45-year mean annual rainfall is 875,2 mm. There is an even probability that the annual rainfall will be above or below the mean and the standard deviation from the mean is 225 mm (Hannington, 1972). The distribution of rain during the season is good and the 45-year mean number of rainy pentades for Henderson is 20,3 per rainy season with a maximum of 28,0 and a minimum of 11,0 (Hannington, 1972). Rainfall data are presented in Table 1.

October and November are the hottest months of the year although temperatures seldom exceed 32°C. Frosts are common during June to August. Maximum and minimum temperatures and incidence of frost are also presented in Table 1.

The effective growing season for crops or pastures varies in length from 120 to 150 days. The climate is suitable for growing a wide range of summer crops such as maize, cotton, soyabeans, groundnuts, sunflowers and burley tobacco. Wheat and barley can be successfully grown under irrigation during the dry months of the year. Dryland grass pastures of tropical and sub-tropical species can be grown and the climate is ideal for raising cattle.

Table 1. Mean monthly and annual rainfall (45 years) in mm and mean monthly maximum and minimum temperatures (15 years) in ° C.

Month	Rainfall mm	Mean monthly temperature °C	
		Maximum	Minimum
July	0,3	22,5	3,2
August	3,4	25,0	4,8
September	4,3	28,1	7,5
October	27,0	30,1	11,5
November	93,0	28,0	14,5
December	189,4	27,0	15,7
January	211,9	26,6	16,1
February	185,0	26,7	15,7
March	111,6	27,2	13,9
April	33,4	26,4	11,5
May	12,6	24,6	6,6
June	3,3	22,7	3,8
Mean annual	875,2	26,3	10,4

During the last 15 years absolute minimum temperatures of below 0,0° C were recorded on an average of 34 days a year between 1 May and 30 September, inclusive.

Soils

The soils occurring on Henderson Research Station fall into two types according to Thompson's (1965) classification. The greater proportion of soils fall into the fersiallitic group and they have appreciable reserves of weatherable materials with a base saturation of over 40 %. They are mainly red, granular clays formed on basic and ultra-basic rocks ; and relatively silt-rich soils formed mainly on sedimentary rocks. The remaining soils, of which there is only a small area adjacent to the granite hills, fall into

Thompson's (1965) paraferrallitic group (Figure 5). These are predominantly sandy soils found mainly on siliceous rock. They are highly porous with very little reserves of weatherable minerals and have a base saturation lower than 40 %.

A detailed survey of the soils on Henderson was undertaken by du Toit (1965). He described the silty clay soils on which the majority of dryland grass pasture experiments have been carried out as being derived from metasediments. However, a more recent examination of this soil by Wells (1977) shows that the soil is derived from felsite and not from metasediments. The salient features of these soils which are on a 2 % slope, are shown in Table 2.

Table 2. Some chemical and physical properties of the silty clay soils (Wells, 1977).

	Soil depth cm			
	0-39	40-81	82-149	150-175
Gravel %	5	5	4	10
Coarse sand %	2	3	2	5
Medium sand %	3	2	2	2
Fine sand %	24	19	20	18
Silt %	31	25	25	27
Clay %	40	51	51	48
pH (CaCl)	5,15	5,80	5,55	6,00
Ex.Ca (me %)	4,12	4,01	4,06	3,60
Ex.Mg (me %)	1,89	3,11	3,45	3,71
Ex.Na (me %)	0,02	0,03	0,03	0,03
Ex.K (me %)	0,35	0,16	0,23	0,19
Ex.bases (me %)	6,38	7,31	7,77	7,53
Ex.cap.(me %)	6,38	7,33	7,91	7,59
Base saturation %	97	100	98	99
E/C value	16	14	16	16
S/C value	16	14	15	16
ESP	< 1	< 1	< 1	< 1
EKP	6	2	3	3
Free Fe_2O_3%	3,84	5,22	4,99	5,05

Note : Ex = Exchangeable
E/C = Exchange capacity per 100 g soil.
S/C = Sum of bases per 100 g clay.
ESP = Exchangeable sodium percentage.
EKP = Exchangeable potassium percentage.

From the surface the descriptions of the successive layers of soil (Table 2) are as follows (Wells, 1977) :

0-39 cm	dark brown clay loam of very hard consistence with a medium coarse subangular blocky structure and restricted permeability. Changes clearly to
40-81 cm	relatively silty clay with red to yellow red variegated colours with a very hard consistence and fine granular structure with moderately restricted permability. Some small ferromanganese concretions and occasional quartz gravel. Changes diffusely to
82-149 cm	dominantly red silty clay with yellowish red and reddish yellow mottles. Hard consistence with numerous ferromanganese stains and small concretions and occasional large felsite stones. Moderately restricted permeability. Changes abruptly to
150-155 cm	subrounded quartz horizon. Changes abruptly to
156-175 cm	diffuse but highly mottled relatively silty clay, mostly soil-like material of a moist friable consistence with some soft weathering rock. Massive to fine granular structure. Much ferromanganese staining and very small concretions. Moderately restricted permeability.

The subsoil colours are all very variegated and tend to become uniform upon wetting.

These soils are inherently fertile, but because of the high proportion of silt and clay they puddle easily when wet and cake hard when dry and are therefore difficult to cultivate.

The salient features of the granite sand soils on which only three pasture experiments were carried out and that lie on a 5 % slope are shown in Table 3.

Table 3. Some chemical and physical properties of the granite sand soils (Wells, 1977).

	Soil depth cm			
	0-15	40-45	90-105	130-145
Gravel %	9	9	14	22
Coarse sand %	35	36	39	33
Medium sand %	35	34	30	28
Fine sand %	20	17	23	28
Silt %	6	6	6	8
Clay %	4	7	2	3
pH (Ca Cl)	4,70	4,60	5,70	5,80
Ex.Ca (me %)	0,77	0,51	0,21	0,26
Ex.Mg (me %)	0,23	0,06	0,07	0,10
Ex.Na (me %)	0,02	0,02	0,01	0,02
Ex. K (me %)	0,16	0,06	0,03	0,03
Ex. bases (me %)	1,18	0,65	0,32	0,41
Ex. cap. (me %)	1,26	0,86	0,36	0,42
Base saturation %	94	76	89	98
E/C value	32	12	18	14
S/C value	30	9	16	14
ESP	2	3	3	5
EKP	14	9	9	7
Free Fe_2O_3%	0,25	0,23	0,11	0,11

Note : See Table 2 for abbreviations.

From the surface the descriptions of the successive layers of soil (Table 3) are as follows (Wells, 1977) :

0-35 cm — dark yellowish brown coarse-grained sand with a apedal single-grained structure and a dry solf consistence. Very permeable. Changes clearly to

36-74 cm — yellowish brown, similar loamy sand with a massive apedal structure and hard consistence. Very permeable. Changes clearly to

75-124 cm — light grey, similar sand with a single-grained apedal structure and loose consistence. Very diffusely mottled and very permeable. Changes clearly to

125-156 cm — light grey fine gravelly sand with faint, large yellow mottles and very friable consistence and single-grained apedal structure. Very permeable.

These sandy soils are not fertile but with correct cultural and fertilizer practices are capable of producing good crops.

Vegetation

Extensive areas of land on Henderson have been cultivated in the past and much of the vegetation is secondary. Relics indicate that it was originally a Brachystegia boehmii, Julbernardia globiflora and B. spiciformis woodland. Land which is not under the plough or established to grass pastures or Eucalypt plantations is at present grassland : the dominant species are Hyperthelia dissoluta and Hyparrhenia filipendula on both the heavy clay and sandy soils. The most common grass associates on the heavy soils are Hyparrhenia rufa, H. cymbaria, Heteropogon contortus, Brachiaria brizantha, B. serrata, Cynodon dactylon (on termitaria) and Sporobolus pyramidalis, the latter quickly becoming dominant with heavy grazing during the growing season. Rottboellia exaltata, Urochloa panicoides, Setaria pallide-fusca, Sorghum verticilliflorum and Eluesine indica are common weeds of arable lands.

On the sands the common associates with H. dissoluta and H. filipendula are Digitaria milanjiana, Stereochlaena cameronii, Perotis patens and Pogonarthria squarrosa. Common grass weeds on cultivated land are Eragrostis viscosa, E. patens, E. gummiflua and Eluesine indica. Acacia sieberiana var. woodii occurs as scattered large trees throughout the grassland on both soils, as do Dolichos malosanus and Eriosema anglerianum.

Vleis occur as open grassland on both soil types. Vleis on the heavy soils comprise mainly Hemarthria altissima, Leersia hexandra, Imperata cylindrica, Sporobolus pyramidalis, Paspalum urvillei and P. dilatatum. Aristida macilenta, Elyonurus argenteus, Andropogon eucomis, Paspalum urvillei, Eragrostis capensis, Sporobolus pyramidalis and various sedges are found in vleis on sandy soils.

The dominant trees on the Iron Mask Range are *Brachystegia boehmii*, *B. glaucescens* and *Julbernardia globiflora* with *B. spiciformis*, *Uapaca kirkiana*, *Cassia singueana*, *Cussonia kirkii*, *Erythrina abyssinica*, *Diplorhynchus condylocarpon*, *Pseudolachnostylis maprouneifolia* and *Parinari curatellifolia* being common. Associated with these trees are *Hyparrhenia* spp., *Themeda triandra*, *Diheteropogon amplectens*, *Brachiaria serrata* and *B. brizantha*.

The rugged granite hills have very little grass growing under the tree canopy which comprises mainly *Brachystegia glaucescens*, *B. spiciformis* and *Julbernardia globiflora* with *Diplorhynchus condylocarpon*, *Monotes glaber*, *Faurea saligna* and *Parinari curatellifolia* associated with them. At the base of the hills *Terminalia sericea*, *Burkea africana*, *Peltophorum africanum* and *Zizyphus mucronata* are found. *Aloe excelsa* and *A. chabaudii* are distributed throughout the hills.

Many other species occur in a narrow strip of riverine vegetation on either side of the Dassura River where *Acacia karroo* and *Combretum erythrophyllum*, are the principal constituents. *Panicum maximum* is the main grass species.

3 THE DEVELOPMENT AND PROGRESS IN CULTIVATED PASTURES AND PASTURE RESEARCH IN RHODESIA

3.1 The Period 1890 to 1947

It was stated in Section 2.1 that dryland grass pastures are only likely to be successful in Natural Regions I, II and III in Rhodesia (Figure 4). These Regions receive more than 700 mm of rain annually (Figure 2) and have more than 14 rainy pentades per season (Figure 3). However, in the early years attempts were made to develop dryland grass pastures in many parts of Rhodesia, including areas that are now recognised as being unsuitable. The progress made and the results obtained from all the work done on pastures in both suitable and unsuitable areas is pertinent to the historical development of dryland grass pastures in Rhodesia and is therefore included in this review.

European settlement of Rhodesia dates essentially from the arrival of the Pioneer Column in 1890. Interest in finding grasses superior to those commonly occurring in the natural veld in Rhodesia was evident from the earliest times. For example, in 1894 Menyharth, a Hungarian missionary, collected an ecotype of Pennisetum purpureum in the north-east of Rhodesia near the Zambesi River (Stapf, 1913). In 1908 the same grass was found growing near Gutu by Colonel Napier who cultivated it and chemically analysed the herbage. The grass became known as Napier Fodder (Stapf, 1913).

Cecil John Rhodes was also interested in grasses and in 1896 noticed that cattle were particularly partial to a grass growing near Bulawayo. He arranged for roots and seed of the grass to be sent to Capetown where the grass was multiplied at his house, Groote Schuur. From this developed the world-wide distribution of Rhodes grass (Chloris gayana)(Mundy, 1932a).

Although the Department of Agriculture was formed as early as 1897 as a sub-department of the Lands Department (Weinmann, 1972), agricultural progress in these early years was hindered by the Matabele War in 1893, the Mashona Rebellion in 1896 and the Boer War from 1899 to 1902. Any improvement in the development of grazing resources was further hampered by the Rinderpest epidemic between 1896 and 1898 and then by East Coast Fever. It was only in 1909 that the latter disease was brought under control and cattle numbers started increasing (Weinmann, 1972).

In his will Cecil Rhodes bequeathed Rhodes Matopos Estates (West, 1948) some 30 km south of Bulawayo, to the people of Southern Rhodesia with a proviso that a portion of the Estate be set aside for agricultural research. Thus, in 1902 the Matopos Research Station, known initially as the Matabeleland Experiment Farm, was established, but it was only in 1945 that pasture research was started (West, 1948 ; Rennan, 1956).

In 1909 the Botanical Experiment Station, presently Salisbury Research Station, was opened. Initially, the primary function of this Station was plant introduction and testing (Mundy, 1932 a,b) Grasses which showed promise at Salisbury were also tested at Gwebi Government Farm, now Gwebi College of Agriculture, which is approximately 30 km north-west of Salisbury (Nobbs, 1916).

The first organised attempts to carry out a grassland improvement research programme were sponsored by the Empire Marketing Board. The programme was based on a scheme put forward in 1927 by A.D. Husband, the Chief Chemist (Staples, 1948). More staff were recruited to carry out work in Matabeleland and in Mashonaland and two members of Staff underwent training at the Rowett Institute, Aberdeen (Meade, 1929). The Government acquired land on granite-derived sands near Marandellas for use as a demonstration farm which included tobacco, crops and pasture sections (Mundy, 1930).

While the economic depression during the early 1930's curtailed research and reduced interest by farmers in pastures because of the unfavourable economic circumstances (Staples, 1948), farmers began to show interest in pastures by the late 1930's. Timson (1938) wrote "It is pleasing to be able to record that greatly increased interest is being evinced by farmers all over the Colony in the question of laying down of improved summer pastures, both on dryland and on moisture retaining soils".

The Second World War of 1939 to 1946 seriously retarded agricultural research and caused staff shortages (Romyn, 1947). Research at Marandellas was stopped in 1940 and a Pasture Research Committee under the chairmanship of Dr. E.A. Romyn (Chief Animal Husbandry Officer) was formed as an interim measure to guide and foster pasture research with particular emphasis on the development of pastures on the poor sandy vleis of the area. Some progress was made with vlei pastures and body mass gains of cattle and milk production on pastures were assessed (Staples, 1948).

In 1942 Dr. I.B. Pole Evans of South Africa was invited to investigate the pasture problems of Rhodesia. He recommended that a Pasture Research Insitute be formed. This was not accepted but a Chief Pasture Officer was appointed in 1944 (Staples, 1948).

Dr. William Davies from the United Kingdom was invited to visit Rhodesia and to give his opinion on development of pasture research in the country. As a result of his visit surveys were made of the resources of veld, dryland and vleiland pastures, and water supplies. The research station at Marandellas was re-opened and named the Grasslands Research Station and pasture research was started at the Matopos Research Station. An Assistant Pasture Research Officer and two Technical Assistants were appointed in 1945 and a Pasture Research Chemist was appointed to the staff of the Chief Chemist (Staples, 1948). In 1947 the Government purchased the farm of Mr. Archie Henderson near Mazoe which was named the Henderson Research Station. A Senior Pasture Research Officer was appointed to take charge of the Henderson Research Station and a start was made with a nursery for introduced grasses (Staples, 1949).

Early use of the veld

Of the veld grasses in Rhodesia in general Sawer (1905) wrote that, "they were rich and with a great variety of species". Despite these attributes cattle frequently died during the normal dry season and not only during droughts. This was particularly the case in Matabeleland (areas surrounding and to the south of Bulawayo). Sawer (1905) suggested that the problem might be overcome by conserving the veld grasses as hay or silage, by introducing special crops capable of maintaining growth during periods of drought and frosts, that a study be made of veld grasses with a view to managing the veld so as to encourage the more desirable species and that forage crops be introduced into the veld to improve the quality of the herbage. However, the prevailing unfavourable economic circumstances limited the growing of forage crops for livestock (Sawer, 1906a) but hay was made from veld grasses during 1904 (Sawer, 1905).

About this time it was estimated that 12,0 to 16,0 ha of veld were required to carry one head of cattle year-round but that 1,5 to 2,0 ha were sufficient during the rainy season (Cameron, 1908b). It was common practice for farmers to trek their herds from Mashonaland (areas around and to the north of Salisbury) to lower lying areas where the grass was plentiful and nutritious during the dry months to try and overcome the body mass losses commonly occurring in cattle during this time of the year (Cameron, 1909b).

Farmers generally showed little interest in their veld and this is reflected in a statement made by Mundy (1920). He wrote that Rhodesia was often said to be cattle country and yet most cattle owners paid little attention to the veld on their land. A similar view was later expressed by Husband (1926) who drew attention to the fact that farmers did little to maintain and improve grasses on their farms and that it was generally considered that grassland required little or no attention. He pointed out that grassland could tolerate a considerable amount of abuse and still produce forage but that the forage might, by management, be considerably altered in composition and in feeding value for livestock.

Effects of fertilizers on the veld

Ammonium sulphate, nitrate of soda, superphosphate and muriate of potash were applied to veld on Salisbury Research Station. Subsequent analysis of the herbage showed that the herbage from fertilized plots contained 44 % more crude protein than that from unfertilized controls (Husband, 1928). In 1929 the effects of fertilizers on the mineral composition of veld herbage in the same experiment was investigated (Husband, 1929). The results showed that, except for calcium, veld grasses were considerably lower in minerals than grasses from Europe. It was found also that the crude protein content of grasses was much lower towards the end of the growing season than early in the season and it was postulated that a deficiency of protein was the cause of frequent deaths of cattle from poverty during the dry season. It was also concluded that it would be desirable to make hay for use during the dry season and that instead of cutting it early in the dry season as was so commonly done, it should be cut before April when it was of better quality.

In the 1930's, fertilizers were also applied to veld at Marandellas and at Matopos to observe their effects. At Matopos yields of grass were measured for five years on granite sands and for six years on black clays. During the last three years no fertilizer was applied because of successive droughts. On both sites the application of full fertilizer (nitrogen, phosphate and potash) gave the greatest yields of herbage (Husband, 1933, 1935) and in following years had the largest residual effect on herbage production compared with phosphate and potash alone or no fertilizer at all (Husband, 1936). At Marandellas, between 1931 and 1933, fertilizers were applied to veld from which the woody components had been removed. Nitrogen was found to have the greatest effect on amount of herbage produced and in the next two years, when no fertilizer was applied, it had a marked residual effect on herbage production (Husband, 1936). In 1936, 110 kg sulphate of ammonia per ha was applied to plots that had not previously received fertilizer. It was calculated that the resultant increase in herbage yield more than offset the cost of the fertilizer (Husband, 1937).

Samples of herbage from the veld experiments at both Matopos and Marandellas were analysed. These showed that where fertilizers were applied they influenced the crude protein, phosphoric acid, potassium oxide and chlorine contents of the herbage and, on all fertilized plots, these were higher than the unfertilized controls (Husband, 1936).

The use of protein-rich supplements on the veld

Murray, Romyn, Haylett and Erickeson (1936) reported experiments in which the reasons for cattle losing condition on veld grazing during the dry months of the year were investigated. Earlier (Husband, 1929) had found that the crude protein content of grasses declined rapidly after April and suggested that this might be the cause of this loss in condition in cattle. The work done by Murray, Romyn, Haylett and Ericksson (1936) and Murray and Romyn (1939 a,b) showed that young cattle grazing on veld during the dry season gained instead of losing body mass when fed small amounts of groundnut cake containing 45 % crude protein. Thus the time taken to grow a steer to slaughter-mass was reduced from five or six years, where it grazed on veld without being fed protein-rich supplements, to about three-and-a-half years where steers were fed with 680 g of groundnut cake per head daily. These findings had much practical application and significance because slaughtering cattle at an earlier age meant that more cattle could be carried due to the quicker turnover and profitability was therefore likely to be greater. Furthermore the number of deaths due to poverty as experienced before these findings could be reduced. However, it was only 21 years later that this practice was adopted by farmers when Elliott (1960) demonstrated that, with cows, maintenance and even small body mass gains could be achieved by feeding 910 g of cottonseed cake per head, daily. Supplementing cows with small amounts of cottonseed cake also had a marked effect on their reconception rate in that cows that received the supplement conceived more often than those that did not receive the supplement.

The unfavourable economic conditions prevailing at the time probably explains why the practice of feeding small amounts of protein-rich supplements to cattle during the dry season was not adopted earlier. This is indicated in a statement made by Arnold (1939a)who said, "the comparatively small monetary return received for animal products when they are exported from this Colony compel the use of feeding materials that are obtainable at low cost". The problem was to find inexpensive feeds for the dry months and even the feeding of small amounts of protein-rich supplements to cattle was uneconomic. However, it was generally recognised by farmers that there was a need to preserve fodder for cattle for the dry months as grass hay or silage and selected grasses planted in vleis were particularly useful (Arnold, 1939a).

The search for better grasses

Because cattle frequently died during the normal dry season and not only during droughts, the objectives in selecting and introducing grasses were initially to find those that would remain green and nutritious during the dry months of the year when the veld grasses did not provide nutritious forage.

Probably the first exotic grass to be introduced into Rhodesia was Paspalum dilatatum which was imported in 1900 (Mundy, 1920; Weinmann, 1972).

Systematic introduction of exotic grasses and the selection and testing of both exotic and indigenous grasses only began in 1909 with the establishment of the Botanical Experiment Station near Salisbury (Mundy, 1910). Despite an earlier statement by Sawer (1906b) that exotic grasses were not suited to Rhodesian conditions, they continued to be introduced in following years and grown at this Station. Various reports on the progress made with these grasses were prepared by Mundy (1910, 1920), Walters (1913a,b, 1914, 1915, 1916, 1917, 1918) and Stapf (1913). Grasses were also planted at the Matabeleland Experiment Station (Mundy, 1914). While most of the grasses investigated during this time were temperate species such as Dactylis glomerata, Festuca arundinacea, Holcus lanatus as well as various clovers, a start was made with the selection of indigenous grasses in 1913 (Mundy, 1922). Walters (1916) repeated an earlier observation made by Sawer (1906b) that the majority of exotic grasses tested were clearly not suitable to Rhodesian conditions.

The general technique used for selection purposes was to grow the grasses in small plots and to observe their growth. Particular attention was paid to vigour, winter greenness and resistance to drought and frost. Paspalum dilatatum was found to remain greener for longer into the dry season than most other grasses (Walters, 1912; Mundy, 1920) and to be resistant to frost (Hampton, 1911). Measurement of herbage yields of grasses as a criterion of selection was seldom used although Walters (1913a) reported that during 1912-13 Pennisetum purpureum (Napier Fodder) cut when it reached a height of 2 m yielded between 25 and 45 tonnes per ha of green herbage.

Despite a general lack of interest by farmers in grass pastures, research workers continued to grow new grasses with some emphasis on their chemical composition and nutritive value for livestock. Star grass (Cynodon aethiopicus) obtained from the Chief, Division of Botany, Pretoria, was introduced to Rhodesia in 1920 (Mundy, 1922). There was an awareness of the importance of high nutritive value in grasses and in 1922 chemical analyses of 24 grasses were done to assess their relative feed value for livestock (Blackshaw, 1922). Husband (1928) drew attention to the importance of quality, palatability, digestibility and nutritive value of grasses, the effect of fertilizing on these attributes, and their importance in livestock nutrition.

Arnold (1929a)reported that silage had been made successfully on an experimental scale from Rottboellia exaltata and Sorghum halepense. R. exaltata, a common weed of cultivated land, gave a three-year mean yield of 22,5 tonnes green herbage per ha compared with 8,3 tonnes per ha from S. halepense. It was stated that silage made from R. exaltata was of better quality than that made from Pennisetum purpureum but the statement was not qualified.

In an excellent report Arnold (1929b)summarised the results of a methodical screening programme on grasses extending over ten years. As Sawer (1906b) and Walters (1916) had done before him, he again drew attention to the fact that exotic grasses were not suited to Rhodesian conditions and had not grown as well as selected indigenous grasses. Although several of the indigenous grasses had grown well, notably Chloris gayana, Digitaria eriantha, Hemathria altissima, Digitaria milanjiana, Andropogon gayanus, Setaria phragmatoides and Panicum maximum, some, particularly the rhizomatous and stoloniferous ones, did not produce viable seed and therefore had to be propogated vegetatively. Later Arnold (1936) listed the grasses that had been selected and grown during the previous 16 years at Salisbury. He commented on type of growth, earliness or lateness of growth, yields of herbage, seeding ability, methods of propagation, drought resistance, persistency, aggressiveness in competition with other grasses, effects of close cutting at frequent intervals and response to fertilizers.

While Star grasses (Cynodon sp.) had been introduced in 1920 (Mundy, 1922) and by 1943 the No's 1, 2, 3 and 4 cultivars of Cynodon aethiopicus were being grown in Rhodesia, particularly at Salisbury, these grasses were not available to farmers (Timson, 1943). The reason for this was that S.J. van der Watt and D.C. Steyn had found at Onderstepoort, South Africa, that the prussic acid (HCN) content of these grasses constituted a grave danger to livestock, although by 1943 some Rhodesian farmers had grown and grazed Star grass pastures for up to three years without encountering problems (Timson, 1943). Nevertheless the Department of Agriculture did not recommend these grasses for the foregoing reason. Instead it was suggested that farmers grow 'safe' pastures of Pennisetum clandestinum, Paspalum dilatatum and Chloris gayana (Timson, 1943).

Fertilizer and management practices

The first record of fertilizer applications made to cultivated grass, in this case Sorghum halepense, was in 1919 (Anonymous, 1919). The fertilizer contained small amounts of nitrogen, phosphoric oxide and potash, namely, 1,6; 8,1 and 2,0 % respectively, and was applied at the rate of 225 kg per ha. Yields of fertilized and unfertilized grass were similar. It is of interest to note that fertilizers were applied to maize some ten years earlier, in 1907-08 (Cameron, 1908a,b), indicating that crops were considered more deserving of the financial investment associated with fertilization. At the time the market for crops was much more favourable than that for livestock. In addition there was then a relatively small livestock population and an abundance of veld grazing. There was thus little incentive to develop grazing resources.

It was realised that the selection and establishment of suitable grasses was not the only problem facing research workers but management and the fertilizer requirements of grasses were equally important. In view of this 60 grasses were grown at Salisbury from 1927-28 and were cut during the growing season in January each year and the aftermath grazed by cattle. It was found that by mowing grasses in January and then allowing them to grow out, quality of herbage for the dry season was improved (Arnold, 1929b).

Throughout the world there was a swing to pastoral farming during the early 1930's. The Acting Editor of the Rhodesian Agricultural Journal (Walters, 1931) wrote, "The subject of grass treatment is at present receiving a measure of attention more in proportion to its tremendous importance in agriculture". Romyn (1931) noted that in South Africa experimental results had demonstrated the potential of cultivated grass pastures for livestock production and described some of the recent results obtained in Rhodesia. In the latter country *Digitaria pentzii* and *Chloris gayana* had provided 250 and 292 grazing days per ha in 1931-32 (Mundy, 1932c). The *Digitaria pentzii* pasture received 27 tonnes per ha of manure the year before establishment and 225 kg per ha bonemeal and superphosphate when planted. *Chloris gayana* only received 450 kg per ha bonemeal and superphosphate when planted. In 1931 superphosphate was applied to each grass at the rate of 225 kg per ha and in addition one-half of each plot received 110 kg per ha ammonium sulphate. After the second year *Chloris gayana* had died out but *Digitaria pentzii* was still a complete sward (Mundy, 1932c). Arnold (1939b) reported that applications of phosphate (up to 900 kg per ha superphosphate) had no effect on the herbage yields of *Digitaria* sp., *Chloris gayana*, *Brachiaria dictyoneura*, *Paspalum dilatatum* and *Phleum pratense* while 110 kg per ha ammonium nitrate increased green herbage yields by 5 340 kg per ha.

Chloris gayana and *Paspalum dilatatum* were recommended for dryland while *Acroceras macrum*, *Hemarthria altissima* and *Paspalum dilatatum* were recommended for vleis. It was stated that pasture should not be established with less than 635 mm of rain per annum and various recommendations regarding the establishment and fertilization of grass pastures were given. For example, it was recommended that *Chloris gayana* be planted after a green manure crop (*Crotolaria juncea*) because this would reduce weed competition to the grass (Timson, 1937). It was suggested that on poor soils 60 to 110 kg per ha ammonium sulphate be applied before seeding the grass. Irrigated pasture grass it was recommended, should receive 16 to 22 tonnes per ha compost or 340 to 450 kg per ha of "grass fertilizer" (10% nitrogen) before planting. Vlei pastures should receive 170 to 280 kg per ha of a raw rock phosphate and superphosphate mixture. Pastures could be cut for hay or could be grazed (Timson, 1938).

Ley pastures

The grasses which showed promise at Salisbury were tested on a larger scale at Gwebi Government Farm. It had been noticed at Gwebi that yields of cash crops were becoming progressively smaller on land planted in successive years to cash crops. There was thought to be a need to plant grasses on such land in order to restore their productivity (Nobbs, 1916). Previously Cameron (1909a) had suggested that clovers might be suitable for maintaining the fertility of soils when grown in rotation with cash crops but attempts to achieve this with Egyptian and Cow clover (*Trifolium* spp.) failed.

Mundy (1924) stated that in the Marandellas area the general practice was to grow one or two crops of tobacco and then allow the land to revert back to veld. He suggested that a crop rotation system should replace this practice. In the rotation tobacco would be grown in the first and second years followed by maize, groundnuts and Sudan grass (*Sorghum halepense*) in the third, fourth and fifth years. The Sudan grass would be cut for hay or silage and the regrowth ploughed under. The rotation would then be repeated. A similar suggestion was made by African Explosives Ltd. (Anonymous, 1935) where it was suggested that *Chloris gayana* be grown in rotation with tobacco to maintain soil fertility and, in addition, to control soil nematodes that affected growth of tobacco.

Although these suggestions were not put into practice at the time they did anticipate research policy at the Grasslands Research Station from the early 1950's onwards when the development of a ley farming system was investigated in detail.

If research workers had concentrated their efforts during the period under review on finding grasses suitable for grazing during the growing season instead of trying to find ones that remained green into the dry season, and, if they had recognised the importance of applying fertilizers, particularly nitrogen, to grass, and, if they had realised the implications of feeding protein supplements to livestock during the dry season on veld grazing, they might have anticipated current pasture development by 20 to 30 years. In the event many factors contributed to the slow progress made in pasture research from the time of the arrival of the Pioneer Column in 1890 to 1947. The various wars during this period, livestock diseases and the economic depression during the 1930's retarded progress. In addition, there was an abundance of veld grazing for a small livestock population and land was available and inexpensive. During this time cash crops could readily be disposed of but it was more difficult to sell livestock and livestock products because of the great distances from ports and markets. Therefore pastures remained an unattractive proposition even though it had been shown that for a given number of cattle a smaller area of pasture than of veld was needed during the growing season (Romyn, 1943).

5.2 The period 1947 to 1963

The late forties saw the planning, establishment and consolidation of pasture research in Rhodesia. Between 1945 and 1947 a Central Veld and Pasture Station for Matabeleland was established at Matopos, the Grassland Research Station at Marandellas was re-opened, the Henderson Research Station near Mazoe was established and development of a pasture sub-Station started at Melsetter (West, 1946 ; Rattray, 1948 ; Staples, 1950).

Dr. William Davies, the well-known authority on grassland farming in the United Kingdom, visited Rhodesia to review the grassland problems in relation to future development. Following his visit in 1947 he wrote, "In the agricultural development of Rhodesia nothing is likely to be greater and of more fundamental importance than the establishment of sound systems of grassland farming. In such a development the place of the ley must be paramount. Not only does the ley build-up fertility, but a dense sward is also a soil binder which can play an important part in preventing soil erosion under such conditions as exist in Rhodesia. Grassland potential of Southern Rhodesia is great not only for beef but also for dairy. With an expanding population it is highly desirable that a system of mixed farming be developed. Natural fertility as occurs under woodland is not high, so farming is faced with the problem of building up fertility and maintaining it for crops and grass" (Davies, 1947).

While much had previously been done on the selection of grasses for pasture purposes, Davies (1947) emphasised the need to examine more grasses, legumes and herbs for leys as well as for erosion control. He stressed that veld should be integrated in systems of farming with the cultivated lands and the natural trees thinned to promote a good grass cover.

The pasture potential in the different parts of Rhodesia was recognised and the grassland problem was seen to be not only one of production of grass during the short growing season but also one of extending the total period of growth to provide for out-of- season pasturage. Davies (1947) foresaw special purpose leys designed to extend the growing season.

There was a universal interest in the development and use of grass or grass/legume leys about the time Davies visited Rhodesia and since he was one of the principal advocates of leys his visit influenced research in the country for the next 16 years, when much time and effort was spent developing leys for Rhodesia.

Pasture research at the various Stations developed along similar general lines, but differed in detail because the work of each Station was orientated to the farming problems found within the areas each Station served. In these circumstances it is appropriate that the research done at each station be briefly reviewed.

Matopos Research Station

Matopos Research Station is situated approximately 30 km south of Bulawayo at an altitude of 1 370 m and has a mean annual rainfall of 600 mm. According to Vincent and Thomas' (1961) classification Matopos falls into Natural Region IIIB but Ivy's (1975b)more recent classification indicates that it falls outside Natural Region III. Therefore Matopos is not suitable for dryland grass pastures but this was not realised until the late 1950's. Before this much work on pastures was done at this Station and for this reason is briefly reviewed. Most of the work was done on sandy soils derived from granite and some on black and grey clay soils. The object of this work was to develop leys for Rhodesian conditions (West, 1952).

In 1945 a nursery was started with 250 grasses and legumes, most of which were obtained from the Prinshof Grass Breeding Station, Pretoria (West, 1948). Several annual and perennial grasses were planted at different espacements and received 130 kg N and 45 kg P_2O_5per ha. The annual grasses outyielded the perennial grasses over two years (Kennan, 1950). The Gold Coast and Cameroon cultivars of Pennisetum purpureum were later found to be useful for providing feed for livestock for the dry months. In the third year of establishment no fertilizer was found to be necessary, but in subsequent years 130 kg N and 45 kg P_2O_5 per ha were recommended (Kennan, 1952).

Kennan (1956) reviewed the work of the Matopos Research Station. The Gold Coast and Cameroon cultivars of Pennisetum purpureum and the Bambatsi and Zhilo cultivars of Panicum coloratum var. makarikariense had proved the most suitable grasses for pastures. A disadvantage was that the grasses required heavy dressings of nitrogenous fertilizer and it was doubtful whether this practice was profitable because of the high cost of nitrogen and the unreliable rainfall (Kennan, 1956). Similar fertilizer experiments with Pennisetum purpureum continued until 1959 (Anonymous, 1957, 1958, 1959).

Fertilizers were also applied to veld in an attempt to increase herbage produced by the veld grasses and so increase livestock carrying capacity. In these experiments which lasted for nine years, up to 270 kg per ha N were applied with various basic dressings of phosphate and potash to three veld types on three different soils. Effects of fertilizers on herbage production and quality were assessed. On all these veld types annual herbage yields were greatest where 130 to 200 kg per ha N were applied annually while crude protein content of the herbage was greatest where 200 or 270 kg per ha N were applied (Mills, 1964, 1966, 1968).

Grasslands Research Station

The Grasslands Research Station falls into Natural Region II (Ivy, 1975b) and is therefore in an area suitable for dryland grass pastures. It is situated near Marandellas, approximately 60 km east of Salisbury at an altitude of 1 550 m and has a mean annual rainfall of 920 mm, falling mainly between mid-November and the end of March. Mean annual temperatures range from 18 to 20°C and from mid-May to late-August frosts are common. The soils are derived from granite, are easily leached, and are acid in reaction.

The Station serves the region with sandy soils derived from granite in the higher rainfall areas where the principal cash crops are flue cured tobacco and maize. Initially, general farming practice was to stump the Brachystegia spiciformis/Julbernardia globiflora woodland, crop the land for two or three years and then let it recover for about 15 years under a natural veld fallow. With increasing land settlement this became impracticable and it was necessary to investigate alternatives. In these circumstances grass leys appeared to offer a way of developing sound mixed farming systems with crops and livestock (Corby, 1955).

At Grasslands, grasses for leys were selected primarily for their resistance to the root knot nematode, Meloidogyne javanica, and their ability to produce seed. By planting a grass resistant to root knot nematode infestation in the subsequent tobacco crop by nematodes was substantially reduced. With a seeding grass the establishment of the ley immediately after the tobacco crop was facilitated. Cynodon aethiopicus (cv. No. 2 Star) was not considered to be ideal for use in rotation with tobacco. For nematode control only Eragrostis curvula (cv. Ermelo), Chloris gayana (cv. Katambora Rhodes), and later Panicum maximum var. trichoglume (cv. Sabi) were recommended. Cenchrus ciliaris (cv. Grasslands), Setaria sphacelata (now S. anceps)(cv. Kazungula) and Panicum coloratum var. makarikariense (cv. Babatsi) were also suitable ley grasses but were never grown on any significant scale in rotation with crops (Corby, 1955, Anonymous+, 1956, 1957, 1958, 1959, 1960, 1961, 1962, 1963).

Many fertilizer experiments on grasses were carried out by Weinmann (1950), Corby (1955) and Barnes (1960a), but with one exception, nitrogen applications did not exceed 200

Note : The reference Anonymous+ indicates Grasslands Research Station Annual Reports (see REFERENCES pg. 327).

kg per ha. There were two main reasons for this. Firstly, it was believed that for economic reasons no more nitrogen should be applied in practice, and, secondly, residual nitrogen remaining after heavy dressings of nitrogenous fertilizers to grass leys would cause undesirable rank growth in the tobacco which followed the grass (Anonymous† 1961).

In the experiments herbage production of grasses increased as the amount of nitrogen was increased but the response depended in most instances on there being adequate applications of phosphate. Generally, no responses to applications of potash or lime were detected (Anonymous† 1953, 1954, 1955).

Applying a given amount of nitrogen as a single dressing or in two, four or eight dressings had little effect on the amount of herbage produced by grasses. Also the form that nitrogen was applied in had little effect on herbage yields and with all forms used herbage yields increased as nitrogen applied was increased up to 106 kg per ha. Weinmann (1950) also found that herbage yields of Cynodon aethiopicus increased linearly with nitrogen applications of up to 180 kg per ha. He noted that the herbage from grass plots receiving the greatest amount of nitrogen was greener and leafier than that from plots without applied nitrogen. In the one exceptional experiment, up to 470 kg N per ha were applied to Cynodon aethiopicus (cv. No. 2 Star) in 1952-53 on soil of known high fertility (Anonymous† 1953). The nitrogen was applied in six equal dressings but no other fertilizers were applied. The grass was cut three times during the growing season. The yields obtained are shown in Table 4.

Table 4. Effects of heavy dressings of nitrogenous fertilizer on the herbage yield of Star grass at Grasslands Research Station during 1952-53.

Nitrogen kg per ha	94	188	282	376	470
Dry matter kg per ha	9 640	10 630	12 940	16 450	19 770

The response to increasing dressings of nitrogen was marked, the yields of herbage increasing steadily to 19 770 kg per ha with the largest amount of applied nitrogen. No particular significance was attached to the results and the experiment was not repeated. The principal reason for this was that it was generally believed that it was uneconomic to apply such heavy dressings of nitrogen to grass pastures. Furthermore, as the experiment had been done on a soil of exceptionally high fertility it was thought unlikely that similar results could be obtained on soils less fertile.

Grass leys were seldom grazed because it was believed that the nitrogen dropped onto the ley in the dung and urine of animals might cause rank growth in the tobacco that followed. Most experiments where the effects of fertilizers on grasses were assessed were done without the grazing animal (Anonymous+, 1955). Comparisons were made, however, between cattle grazing on pasture and on veld. West (1956) noted that throughout the year the carrying capacity of Brachystegia spiciformis/ Julbernardia globiflora veld was 1 livestock unit (1 livestock unit (LU) is equal to 500 kg of live body mass of cattle) on 6 to 12 ha in dense woodland and 1 LU on 3 to 4 ha where trees were cleared. In the growing season cleared veld would support 1 LU on 1,2 ha with a body mass gain of 103 kg per ha, and pasture fertilized with 120 kg N and 50 kg P_2O_5 per ha would support 1 LU on 0,4 ha with a body mass gain of 495 kg per ha over 150 days from November to April. This clearly demonstrated the greater productivity of fertilized pasture over veld.

The value of grass leys, and in particular Star grass leys, for dairy production was assessed over a number of years. It was found that one hectare of Star grass fertilized with 90 to 110 kg N per ha per growing season produced 13,6 litres of milk per cow, daily, for three months during the growing season (West, 1956).

Beef production from Setaria anceps (cv. Kazungula) pastures was assessed over three years at three stocking rates viz. 0,486; 0,348 and 0,267 ha per steer during the growing season.

The pastures were fertilized annually with 45, 80 and 135 kg N per ha at the respective stocking rates with a basic dressing of 45 kg P_2O_5 per ha. In the first year additional steers were brought in to control the grass but in the second and third years the stocking rates were kept constant at the scheduled levels throughout the season. In all three seasons body mass gains per ha of steers increased with increasing amounts of nitrogen and in each season the increase resulted from carrying more steers per ha rather than from greater gains per head. Mean body mass gains for the first, second and third years were 186, 237 and 322 kg per ha for the 45, 80 and 135 kg N per ha treatments, respectively. Grazing during the late growing season appeared to damage the swards and by the end of the third season grass growth was poor and weed growth profuse (Anonymous, 1957, 1958, 1959).

By 1957 it was realised that to develop sound principles of management for grass leys a knowledge of the seasonal growth of perennial grasses, changes in their underground carbohydrate reserves and the effects of defoliation on them were necessary. Also, this knowledge might help to explain the observed decrease in production of fertilized pastures which occurred from the second year after establishment. Two grasses with contrasting growth habits, namely, Panicum maximum var. trichoglume (cv. Sabi), a tufted grass, and Cynodon aethiopicus (cv. No. 2 Star), a stoloniferous grass, were selected for study. Both grasses had proved suitable as ley pastures for the high rainfall granite sands. During 1957-58 and 1958-59 the effects of different amounts of nitrogen and of defoliation of the grasses on shoot and root mass, and the total available carbohydrates (TAC) in the roots and stem bases were studied (Barnes, 1960b).

When Sabi Panicum fertilized with 90 or 180 kg N per ha was allowed to grow unchecked throughout the growing season (23 December 1957 to 29 May 1958) changes in shoot mass were sigmoidal, whereas the mass of the underground parts in the top 15 cm of soil increased in the first few weeks of shoot growth, remained constant until the end of February and then once again increased markedly. Where 180 kg N per ha were applied this increase was greater than where 90 kg N per ha were applied. In the underground parts where 90 kg N per ha were applied the TAC content was 6,9 % at the start of the season, falling off to 2,8 % by mid-January, where it remained for six weeks, following which it rose to 8,8 % by late May. The TAC concentration in the underground parts was slightly less where 180 kg N per ha were applied but the trends were similar. The seasonal shoot growth cycle of Sabi Panicum appeared to be related to the cycle of depletion and accumulation of reserve carbohydrates and the changes in the roots and stembases and was in agreement with the results of other workers. When the grass was cut in mid-season the mass of roots and stembases did not increase in the late growing season as it did with grass left to grow unchecked (Barnes, 1960b).

Where Star grass was allowed to grow unchecked growth was initially slow and after increasing to a maximum at the end of February it remained at this level until growth rate declined in the late growing season. Where 90 kg N per ha were applied the TAC content of the underground parts increased from 8,6 % at the beginning of the growing season to 11,4 % by late January, at which level it remained until late May. Where 180 kg N per ha were applied the TAC concentration was generally lower, but followed similar trends, to where 90 kg N per ha were applied. It was not known whether the changes in TAC content in Star grass were characteristic since no previous work had been done on this grass (Barnes, 1960b).

In the ensuing dry season and the following growing season the effects of the differential defoliation and nitrogen treatments on the two grasses were assessed. This was done by measuring root and stembase mass and carbohydrate reserves during the dry season and recovery growth in the following growing season (Barnes, 1960c).

The greatest recovery growth in terms of herbage yields was recorded when grass was left to grow unchecked through the previous growing season. All other cutting schedules reduced recovery growth significantly compared with uncut grass. The reductions in yields were associated with reductions in root and stembase mass and carbohydrate reserves, indicating that the loss of vigour was primarily a result of the effects of the defoliation on organic reserves. The results suggested that Star grass was more tolerant of frequent defoliation than Sabi Panicum (Barnes, 1960c).

In further studies on Sabi Panicum, 70, 140, 210 kg N per ha were applied to the grass which was either cut once in mid-January, cut seven times at 28-day intervals or left to grow unchecked (Barnes, 1961). The results confirmed previous findings (Barnes, 1960b,c) that Sabi Panicum was sensitive to defoliation and that the root system and carbohydrate reserves were reduced by it. The amount of nitrogen in the roots was reduced in a similar manner. The mass of roots in the top 15 cm of soil varied from 9,0 to 15,5 tonnes per ha and it was concluded that rapid soil regeneration under grass depended on liberal applications of nitrogen and use of defoliation systems that maintained vigour (Barnes, 1961).

In later work Barnes and Hava (1963) found that although both the content and to a lesser extent the amount of carbohydrate in the roots increased after mid-season even in Sabi Panicum cut at monthly intervals, the root system was progressively reduced compared with uncut grass. The level of carbohydrate was lower at the end of the season compared with the beginning. The nitrogen content of the roots was constant, which indicated that it was not a constituent of reserve substances. In the previous studies (Barnes, 1960b,c, 1961) applied nitrogen was found to increase root mass and the nitrogen content in the roots and also caused a large residual effect on herbage yield the next season. In Sabi Panicum, as in other grasses, there was a marked decrease in nitrogen content in shoots from shortly before flowering to senescence. The results made it clear that vigour of nitrogen fertilized Sabi Panicum could only be maintained if it was rested from mid-February to late-May.

Studies on the seasonal growth changes in Sabi Panicum indicated that vigour of this grass could be maintained if it was rested from mid-growing season to early dry season. Such management could be applied in practice because the herbage could be grazed off as foggage. This provided at least maintenance forage for growing beef cattle from June to September when cattle usually lost body mass on veld (Barnes and Hava, 1963 ; Barnes, 1966).

A comparison of selected grasses for dry season foggage grazing during 1959 showed that steers grazing either Sabi Panicum or Setaria anceps (cv. Kazungula) gained 23 kg body mass per head over a four month period (June to September) while those grazing Chloris gayana (cv. Katambora Rhodes)and Eragrostis curvula(cv. Ermelo) lost 16 and 36 kg per head, respectively. The four grasses were also grazed during the 1959-60 growing season when fertilized with 90 kg N and 45 kg P_2O_5per ha.

The grasses were grazed individually and collectively for periods ranging from 36 to 60 days up to mid growing season by a basic group of steers to which extra steers were added or removed according to grass growth. Sabi Panicum was the most satisfactory grass and steers grazing on it gained 345 kg body mass per ha (Anonymous+, 1960).

Since the general research policy of the Grasslands Research Station was based on the belief that ley farming would be a sound system for the high rainfall granite sands in Rhodesia, a number of ley experiments were carried out between 1955 and 1962 (Anonymous+, 1955 to 1962). In these experiments Cynodon aethiopicus (cv. No. 2 Star), Chloris gayana (cv. Katambora Rhodes) and Eragrostis curvula (cv. Ermelo) were used. The leys, whose duration was constant in some experiments and varied in others, were either not grazed or grazed at different intensities, fertilized with various amounts of nitrogen for the whole life of the ley or for various periods during the life of the ley and, ultimately, were ploughed under either early (March-April) or late (September-October). The effects of all these treatments of the ley were then assessed by growing test crops of maize and tobacco, the main cash crops of the area, after the ley was ploughed under. The leys received annual applications of nitrogen varying from 45 to 135 kg N per ha with basic dressings of 50 kg P_2O_5 per ha.

In 1956 the first experimental maize crop following a well-fertilized Star grass ley was reaped. A yield of 64 bags grain (91 kg) per ha was obtained without fertilizer being applied to the maize while adjacent land which had been continuously cropped yielded only 24 bags per ha. This result led to the belief that the success of ley farming had been demonstrated (Anonymous, 1956). Generally results showed that nitrogen applied to the ley sometimes increased grain yields of the following maize crop and sometimes did not. Nitrogen applied directly to the maize resulted in larger yields of grain by comparison with similar amounts of nitrogen applied to the ley. For example, the residual effect of applying 90 kg N per ha annually to a ley for four years resulted in a maize yield of 44 bags per ha without further applied nitrogen, whereas 90 kg N per ha applied directly to the maize yielded 65,0 bags maize per ha (Anonymous, 1962).

Increasing the duration of leys from two to four years increased maize yields from 34,1 to 46,9 bags per ha. Similarly, heavy grazing of leys increased yields from 34,1 without grazing to 43,0 bags per ha with grazing. Also, where herbage was removed from the ley in the form of hay, maize yields were 8,2 bags per ha lower than where the ley was grazed. Clearly cattle excreta deposited on grazed leys increased the plant nutrients in the soil and these were available to the maize following the ley (Anonymous, 1962).

Management of leys had little effect on yields of flue cured tobacco but tobacco following Katambora Rhodes grass yielded 110 kg per ha more than that following Ermelo Love grass and was also of a higher grade index (Anonymous+, 1962).

Increasing the nitrogen applied to the ley from 45 to 90 kg N per ha increased yields of tobacco by 110 kg per ha. Greater amounts of nitrogen applied to the ley had a negligible effect on tobacco yield. Late ploughing (September-October) of the ley reduced yields of tobacco compared with early ploughing (March-April). Also, whereas 13,4 kg N per ha increased tobacco yields by more than 110 kg per ha where the ley was ploughed early, 36,0 kg N per ha were needed on late ploughed ley to obtain similar increases in tobacco yield (Anonymous+, 1962).

The effect of the perennial grass leys was to provide a protective cover which reduced soil erosion and the leaching of nutrients and when grazed there was a much lower drain of nutrients than where the soil was cropped and the crops removed. While the leys maintained both the stability of the soil and it's physical structure and reduced soil erosion, the expected improvement in soil fertility under grass did not materialise, and the yields of crops following them were lower than expected. These findings confirmed the views expressed by Ellis (1953) that the main justification for the inclusion of grass leys was for the control of soil erosion, the improvement of soil structure and the attainment of balanced farming systems. The building-up of the chemical fertility of the soil under grass appeared to be illusory and this would be better achieved by proper management and by correct manurial and rotational practices.

Henderson Research Station

A detailed description of Henderson Research Station has already been given under Section 2.2. Henderson falls within Natural Region II (Ivy, 1975b)and serves those parts of the high rainfall areas of Rhodesia having heavy clay soils.

When pasture research started at Henderson in 1947, farmers in the area relied mainly on cash crops, principally maize, for a livelihood. The general practice was to grow maize in alternate year rotation with Crotolaria juncea (Sunnhemp). The Salisbury Experiment Station (Anonymous, 1940 to 1952) had shown that satisfactory yields of maize could be maintained indefinitely by rotating cash crops with green manure crops. Cash cropping of land in successive years also appeared to be feasible provided crops were rotated and adequate fertilizers and compost were applied (Rowland, 1953). Through the years maize has remained an important cash crop but during the last 15 years cotton, and more recently soyabeans, have also become important crops. In 1947 there were few cattle in the farming areas served by Henderson but since then there has been a steady increase in numbers with a particularly rapid increase during the last decade.

Rowland (1953) noted that the clay and silty clay soils occurring in the areas served by Henderson had been found to become extremely difficult to cultivate after a few years of annual cropping. These soils tended to puddle if cultivated when wet and to become very hard with a compact crust when dry. Grass leys were known to improve the physical structure of these soils making cultivation easier. Simultaneously leys could be used to replace the green manure crops grown in rotation with cash crops. He suggested that the forage produced from grass leys could be used for silage during the growing season, for hay during the late growing season, and finally for grazing during the dry season. This order was suggested since it was easier to make silage than hay during the growing season when rain frequently falls, while grazing would puddle the soil and compact it. It would be better to graze the veld or cultivate permanent grass pastures during the growing season for this reason.

Herbage conserved from grass leys could be used to feed cattle during the dry season when cattle commonly lost body mass on veld grazing (Addison, 1963). Since there were large resources of roughage available on maize farms in the form of maize stover, which was of similar quality to the veld at this time of the year, the veld could be used almost exclusively for grazing during the growing season and the stover for the dry season.

The usefulness of grass leys were assessed in ley research units which were simulated small farms where leys could be tested in practical farming situations. Observations were made to see whether they could replace the green manure crops grown in alternate year rotation with cash crops. It was also hoped that these investigations would indicate what problems there were and then these could be investigated elsewhere in greater detail (Anonymous*, 1953).

Pennisetum purpureum (cv. Gold Coast)(Napier Fodder) was selected in 1950 for use as a four-year pasture in a ley research unit (Addison, 1956a,b). It was the most productive grass at this time and provided large amounts of herbage for feeding cattle in the dry months (Anonymous*, 1953).

Of ten grasses evaluated later in field trials seven were found to be similar in herbage yielding ability and in value for grazing. These grasses were Cynodon aethiopicus (cv. No. 2 Star), a local and Australian selection of Chloris gayana (cv. Giant Rhodes), Setaria anceps (cv. Kazungula), Panicum coloratum var. makarikariense (cv. Makarikari) and the Nyasaland and Gold Coast cultivars of Pennisetum purpureum. The grasses received 45 kg N and 45 kg P_2O_5 per ha and they were grazed at a stocking rate of 2,5 steers per ha with a mean initial body mass of 360 kg per steer. Grazing continued for 120 days between December and March and a mean body mass gain of 280 kg per ha was recorded on the grasses. If an additional 45 kg N per ha were applied in mid-season the grazing period was extended into April and May, resulting in a further body mass gain of 60 kg per ha. Alternatively, if pastures were not grazed after the mid-season application of nitrogen, sufficient grass could be harvested to make 6,7 tonnes of silage per ha (Anonymous*, 1957).

Note : The reference Anonymous* indicates Henderson Research Station Annual Reports (see REFERENCES pp. 127)

Because the productivity and grazing value of these seven grasses was similar, these factors were discounted in selecting ones for leys. Instead, selection was based on practical considerations such as ease of establishment, management and ease of ploughing out. For these reasons Chloris gayana (cv. Giant Rhodes) was chosen as most suitable and in ensuing years was the principal grass used (Anonymous, 1957). It had also been found that there was little difference between grasses in their effectiveness in preventing soil erosion (Hudson, 1957).

Addison (1956a,b, 1958a,b) reported the results of several experiments with Napier Fodder that were initiated by Bumpus in 1950-51 and continued by Addison until 1955. Variables in these experiments were fertilizers and organic manures, plant espacement and cultivation.

In one experiment different amounts of nitrogen (up to 220 kg N per ha) were applied with various amounts of phosphatic fertilizer (up to 85 kg P_2O_5 per ha), annually. Effects of treatments on herbage yields were assessed by cutting the herbage twice each growing season. Three-year mean yields of green herbage increased as applied nitrogen was increased from 0 to 220 kg N per ha resulting in yields of 26 540 and 59 730 kg per ha, respectively. Similarly, increasing phosphorus applications raised green herbage yields from 29 460 kg with none to 44 540 kg per ha with 85 kg P_2O_5 per ha. The crude protein content of dry herbage was increased by applied nitrogen but was decreased by applying increasing amounts of phosphorus. The nitrogenous fertilizer used in this experiment was ammonium sulphate and this lowered the pH of the soil from pH 5,60 (water method) without fertilizer to 4,05 with 220 kg N per ha, applied annually for three years (Addison, 1956a).

Increasing the distance between the rows of Napier Fodder from 0,60 to 2,44 m decreased green herbage yields from 63 440 kg to 52 230 kg per ha. By increasing applied nitrogen, herbage yields were increased at each spacing but nitrogen was most effective at the closest spacing of plants (Addison, 1956b).

In another experiment nitrogen was applied to Napier Fodder in combination with agricultural lime. Agricultural lime did not effect green herbage yields significantly but yields increased as the amount of nitrogen applied was increased to 270 kg N per ha, the maximum applied (Addison, 1958a). Other treatments involved the deep cultivation between rows of Napier Fodder with disc harrows, tyne cultivators and sub-soilers. All cultivations had a negligible effect on herbage yields, which declined progressively over the first three years of the experiment when nitrogen was not applied. In the fourth year 110 kg N per ha was applied. This resulted in greater yields of herbage but the cultivation treatments still had little effect (Addison, 1958b).

In the ley research units various management systems were imposed on the grass leys. These included combinations of grazing during the growing season, late growing season and making silage for the dry season. For example, grass leys were left to grow unchecked until January, when they were cut for silage and the regrowth was grazed off as foggage during the late growing season and the dry season. Chloris gayana (cv. Giant Rhodes) was found to be suitable for this purpose and had the advantage over Napier Fodder in that it could be sown. Also it was easier to plough out. Giant Rhodes herbage was finer and of better quality than that of Napier Fodder (Anonymous*, 1954).

By 1955 Cynodon aethiopicus (cv. No. 2 Star) was also being used for ley pastures. Giant Rhodes grass and Star grass were fertilized with 45 kg N and 45 kg P_2O_5 per ha and were grazed during the growing season by steers of mean body mass 300 kg per steer, at a stocking rate of 2,5 steers per ha. Body mass gains were 118 and 161 kg per ha, respectively. In the next year Giant Rhodes, Star grass and Napier Fodder gave 337, 352 and 322 kg body mass gain per ha when grazed at a similar stocking rate and fertilized with 90 kg N and 45 kg P_2O_5 per ha (Anonymous*, 1956).

Of the grasses tested in experiments no differences were found between a three herd four paddock rotational grazing system, rotational grazing with an electric fence or a two paddock system. In the latter, steers grazed both paddocks early in the growing season but when grass growth was rapid one paddock was rested to allow for a silage cut. Also it was noted that while the stoloniferous grasses persisted under grazing the tufted ones lost vigour and after three years their swards were weedy (Anonymous*, 1957).

Canavalia ensiformis (Jack Bean), Crotolaria juncea (Sunnhemp) and Vigna parviflora had been found satisfactory as cover crops for establishing grasses (Anonymous*, 1957) and in addition Jack Bean provided a protein-rich bean meal and hay which were fed to cattle during the dry months (Addison, 1957). Elliott (1960) had found that an adequate protein intake was conducive to efficient food utilization by cattle and it was known that the dry roughages being used in the dry season were low in protein.

Later, many experiments were done on the establishment of Giant Rhodes grass under maize. The grass established well when 10 kg of seed were sown per ha under a maize population of 37 000 plants per ha. Desmodium discolor (Horse Marmalade), which had proved suitable as a browse plant in the late growing season, was also successfully undersown in maize while it in turn could be undersown with Giant Rhodes grass (Anonymous*, 1960). During the development of the ley research units it had been observed that cattle grazing on the veld, which comprised mainly coarse Hyparrhenia spp. and Hyperthelia dissoluta, gained body mass for only 10 to 12 weeks during the growing season and this coincided with the period of growth when herbage was immature. Once mature, grasses were of little value for grazing. Attempts to keep the veld grasses short and in a nutritious condition by heavy grazing resulted in rapid invasion by Sporobolus pyramidalis, which is a coarse and unpalatable perennial grass. A three herd to four camp system with rotational burning had been found satisfactory on this veld. Body mass gains in cattle could be expected from

December until the end of March at a stocking rate of 1 LU to 1,6 ha without supplements. After this time much herbage remained and it was clear that investigations would be necessary to determine the nature of the factors that limited further productive grazing (Anonymous*, 1957).

The carrying capacity of fertilized Giant Rhodes pastures had been observed to be considerably greater than unfertilized veld grasses during the growing season but no comparisons had been made between them with similar fertilizer applications. Between 1961 and 1965 up to 90 kg N and 45 kg P_2O_5 per ha, annually, were applied to both Giant Rhodes and veld grasses and their herbage yields compared under cutting frequencies of one to 12 times a growing season. Herbage yields increased as nitrogen was increased from 0 to 90 kg per ha with both Giant Rhodes and veld. In the first two seasons veld herbage yields were greater than those of Giant Rhodes but thereafter yields of both were similar. Herbage yields were progressively smaller with increasing cutting frequencies and were greatest where only one or two cuts a season were taken (Boultwood, 1969). While Giant Rhodes was no more productive than the veld it had earlier been observed that with heavy grazing during the growing season the veld became rapidly invaded with <u>Sporobolus pyramidalis</u>, which was of little value for grazing purposes (Anonymous*, 1957).

From the observations made up to 1957 on the use of leys and of veld, modifications were made in the ley unit experiments that led to the development of forage flow sequences for different classes of livestock. In 1957 two different forage flow studies were initiated for beef breeding cows and for beef steers while similar studies were started for beef weaners and dairy cows in 1959-60. In these studies veld and vlei grazing were used for the late dry season, growing season and early dry season while ley pastures were used during the dry season principally as foggage grazing together with maize stover. The pastures were rotated every three years with maize which was also grown for three consecutive years.

By 1959 veld grazing had not proved satisfactory for grazing during the growing season since body mass gains in cattle could only be expected from December to mid-April (Elliott, 1960a,b; Anonymous*, 1960). Elliott (1960) had proved by this time that the efficient use of coarse veld herbage by cattle during the dry season could be achieved by feeding small amounts of protein-rich concentrates. Since there were large amounts of roughage in the form of maize stover on maize farms in addition to veld, the problem was to find alternative sources of grazing for the growing season. From 1959 the emphasis in research changed from using ley pastures as a source of dry season roughage to one where they were used for grazing during the growing season (Anonymous*, 1960).

The forage flow studies continued until 1964. During this time a number of experiments were done on the management of grass leys as sources of winter roughage which all showed that productivity of these pastures depended largely upon the amount of nitrogen applied to them. Annual applications of 25 to 45 kg N per ha proved most satisfactory and pastures fertilized at this level provided foggage grazing for 90 days for beef cows stocked at a rate of 2,5 cows per ha (Anonymous*, 1959). It had also been noted that even when fertilizers were applied a marked reduction in herbage production occurred with advancing pasture age. It was postulated that this might be due to a build-up of organic matter in the soil under grass and a consequent nitrogen deficiency (Anonymous*, 1961).

Perhaps the most significant experiment of all between 1947 and 1963 at Henderson, and one that influenced research from then onwards, involved the application of large amounts of nitrogenous fertilizers to Giant Rhodes grass. It had been observed (Anonymous*, 1961) that Giant Rhodes grass pastures declined in productivity with advancing age and that after three years productivity was at a low level compared with that of the first year. In an attempt to rejuvenate such a pasture heavy dressings of nitrogenous fertilizer were applied in one, four or eight equal dressings during the growing season to an old Giant Rhodes grass pasture that was harvested four times at four-week intervals (Table 5)(Clatworthy, 1967).

Table 5. Mean effects of applied nitrogen on the herbage yield of an old Giant Rhodes pasture (Clatworthy, 1967).

Nitrogen kg per ha	0	112	225	450	900
Dry matter kg per ha	7080	9820	12220	13470	13610

Herbage yields increased as applied nitrogen was increased from 0 to 450 kg N per ha. Doubling the applied nitrogen from 450 to 900 kg per ha did not affect yields further. At any one level of nitrogen, herbage yields were similar whether the nitrogen was applied in four or eight dressings, but yields were reduced when it was all applied in one dressing (Clatworthy, 1967).

The results of this experiment showed that old Giant Rhodes grass pastures could be rejuvenated by heavy dressings of nitrogenous fertilizers, resulting in greater yields of herbage being produced than had hitherto been obtained with smaller amounts. They also indicated that as greater yields of herbage were produced it was possible that more livestock could be carried per unit area and this could lead to greater output and profitability from pastures. From 1963 to the present time effects of heavy dressings of nitrogenous fertilizers on grasses have been investigated in detail and the reports of this work form the basis for the present dissertation.

Maize yields following three years of grass ley did not exceed 64 bags (91 kg) per ha when 90 kg N and 45 kg P_2O_5 per ha were applied to the maize (Anonymous, 1961). By comparison, the mean maize yield for 12 years from land cropped to successive maize crops where 150 kg N, 55 kg P_2O_5 and 60 kg KCl per ha were applied, annually, and all stover ploughed under, was 67 bags per ha (Anonymous, 1966). One of the principal objectives of the ley pastures, namely to improve the fertility of the soil and thereby raise the yields of following crops, was therefore not achieved.

Addison (1965) summarised the practical implications of the results from the ley research units and the forage flow sequence studies for beef cattle done between 1950 and 1965. He compared the carrying capacity and output of the current farming system in the area with that of a hypothetical system based on the experimental results obtained.

In the first system maize was grown in alternate year rotation with a green manure crop. Carrying capacity was based on grazing the available veld year-round and supplementing cattle with stover and protein-rich concentrates in winter. All maize grain produced was sold. In this system the overall carrying capacity of farms was estimated to be 1 LU to 4,5 ha and slaughter cattle were sold when three years old.

In the second system maize was grown in a three-year rotation with grass leys. Cattle grazed the leys during the growing season, and the veld and stover in the dry season while receiving protein-rich supplements. In addition an annual legume (Jack Bean) and a perennial legume (Horse Marmalade) were grown to provide hay and a protein-rich bean meal and early dry season grazing. Of the maize produced 80 % was sold and 20 % retained as corn and cob meal for fattening cattle. In this system the carrying capacity was estimated to be 1 LU to 2,5 ha compared to 1 LU to 4,5 ha in the first system (Addison, 1965).

Although Addison (1965) had estimated that by using ley pastures for the growing season and the veld supplemented with maize stover for the dry season, the carrying capacity of maize farms could be increased by some 80 %, the system was not adopted in practice. There were several reasons for this.

(i) Farmers generally were making a comfortable living from cash crops and there was therefore little incentive to diversify into livestock.

(ii) There was no need to rotate grass leys with cash crops to maintain the productivity of soils. Continuous cash cropping was feasible provided adequate chemical fertilizers were applied and all crop residues were ploughed back into the soil annually. In fact, maize grain yields on land cropped annually were similar to those obtained following a three-year grass ley. Also the previous practice of growing cash crops in alternate year rotation with green manure crops fell away because productivity could be maintained by applying adequate fertilizer and ploughing under crop residues annually.

(iii) Returns from ley pastures in monetary terms did not compare favourably with those from cash crops.

(iv) There were relatively few cattle in the farming areas served by Henderson and there was adequate veld and crop residues to satisfy their forage needs. It was therefore unnecessary to establish grass pastures to increase carrying capacity of farms.

These facts indicated that pastures were unlikely to find application in practice unless returns from them could be substantially increased and rival those from maize. For many years it has been apparent to research workers that the areas served by Henderson Research Station were potentially suited to intensive livestock production and it was to this end that all the work reviewed was orientated.

Eastern Highlands Research Station

In 1949 the Eastern Highlands Research Station was opened to serve the mountainous eastern districts of Rhodesia which falls into Natural Region I (Ivy, 1975b). This area has a cool climate with a mean annual rainfall of 1 140 mm, most of which falls during summer although some falls every month of the year.

It is rather remote from the principal markets for agricultural products and for this, and other reasons, the Station was closed down in 1965.

The Station concentrated on finding grasses and legumes suitable for intensive farming with dairy and beef cattle and sheep (Elias, 1965). Many grasses and legumes were grown and observed for their adaptability to local conditions both on dryland and under irrigation and experiments were done to determine the effects of fertilizers on them (Williams, 1953). Of the grasses tested the most productive on dryland were Pennisetum clandestinum (Kikuyu) and P. purpureum (cv. Cameroon). Applying fertilizers, particularly nitrogen, to the grasses resulted in greater herbage yields (Williams, 1953) but grass clover pastures were less costly (Atkinson, 1963). Conditions in the area were found particularly suitable for Trifolium repens (New Zealand White), T. semipilosum (Kenya White) and T. ruepellianum (Kenya Red) and these grew well in association with Kikuyu. On such pastures two-year-old beef steers were carried during the growing season at a stocking rate of 3,7 steers per ha and gained 247 kg per ha in body mass (Atkinson, 1963).

Salisbury Research Station

The Salisbury Research Station which falls into Natural Region II (Ivy, 1975b), was principally concerned with cash crops but an experiment was done there on a heavy clay loam between 1955 and 1965 which concerned the effects of a grass ley on the following crops of maize (Anonymous, 1962; Fenner and Rattray, 1966). A Panicum coloratum var. makarikariense (cv. Makarikari) ley was either grazed, cut for hay or cut and the grass left in situ, each summer for five years. In addition, various amounts of nitrogenous fertilizer were applied to the ley. No herbage yields were taken on grazed plots but on the cut plots they were found to increase as nitrogen was increased to 180 kg per ha, the maximum applied. There was a significant decrease in herbage yields with advancing age of the ley and in the fifth year yields were approximately only 25 % of those obtained in the first year.

No differences were found in the residual effects of management of the ley on maize yields. While there was a small response in the first crop of maize following the ley due to the residual effect of nitrogen applied to the ley, this response became progressively less with successive crops and by the fifth crop it had disappeared. The conclusion reached was that greater returns could be obtained by applying nitrogen directly to maize rather than to the ley (Fenner and Rattray, 1966). The results agreed with the findings of similar work done at the Grasslands and Henderson Research Stations.

Gwebi College of Agriculture

At the Gwebi College of Agriculture which is in Natural Region II (Ivy, 1975b), some experiments were done on the effects of fertilizers on veld defoliated by either cutting or grazing. Application of fertilizers, particularly nitrogen, resulted in greater production of herbage and increased carrying capacity but changes in the species composition was caused by fertilizers, resulting in the natural dominants being replaced by Sporobolus pyramidalis (Barnes, 1955 ; Bate, 1962).

4 PASTURE RESEARCH AT HENDERSON RESEARCH STATION BETWEEN 1963 AND 1975 FOR WHICH THE AUTHOR WAS RESPONSIBLE

During the period 1963 to 1975 various fertilizers and weights and measures were used at Henderson Research Station for experimental purposes.

Fertilizers

Unless otherwise stated the fertilizers used in all the experimental work were as follows :

Nitrogenous fertilizers
- 1963 to 1970 Calcium ammonium nitrate containing either 20,5 or 26,0 % N.
- 1971 to 1975 Ammonium nitrate containing 34,5 % N.

Phosphatic fertilizers
- Single superphosphate containing 20,0 % P_2O_5 and 12,0 % S.

Potassic fertilizers
- Muriate of potash containing 60,0 % K_2O.

Units of measure

All experimental details and results are reported in metric units as follows :

Mass - grams (g), kilograms (kg) and tonnes (t).
Volume - millilitres (ml) and litres (l).
Linear measurements - millimetres (mm), centimetres (cm), metres (m) and kilometres (km).
Area - hectares (ha).
Draught-Newtons (N).
Force - kilopascals (kPa).

Metrication was only introduced into Rhodesia in 1969. Prior to this English weights and measures were used. Consequently when converting stocking rates from the English to the Metric System fractions of cattle per ha often result.

4.1 The Species of Grass and Effects of Fertilizers on Grasses

4.1.1 The effects of fertilizers on herbage production of grasses

It is well known throughout the world that applying nitrogenous fertilizers to grasses grown on most agricultural soils causes marked increases in herbage production and Rhodesia is no exception. During the 44 years ending in 1963 nitrogenous fertilizers were applied at various times to natural grassland (veld) and to cultivated grasses ; experimentally and in practice. The amounts of nitrogen applied seldom exceeded 140 kg of N per ha because it was believed that it was uneconomic to apply more. Generally herbage yields increased as the amount of nitrogen applied was increased to 470 kg per ha (Husband, 1929, 1933, 1937; Husband and Taylor, 1931; Weinmann, 1950; Anonymous, 1953 to 1963; Corby, 1955; Addison, 1956a,b, 1958a,b; Kennan, 1950; Barnes, 1960a,b,c, 1961; Anonymous, 1960; Bate, 1962; Mills, 1964, 1966,1968; Boultwood, 1969; Clatworthy, 1967). In only one experiment was more than 470 kg N per ha applied and in this case Clatworthy (1967), at Henderson Research Station, applied up to 900 kg N per ha to <u>Chloris gayana</u> (cv. Giant Rhodes). The response of this grass to applied nitrogen was linear up to 450 kg per ha and thereafter additional nitrogen had a negligible effect. Earlier, at Grasslands Research Station, up to 470 kg N per ha had been applied to <u>Cynodon aethiopicus</u> (cv. No. 2 Star) (Anonymous, 1953). Herbage yields of the Star grass increased linearly with increasing amounts of nitrogen up to the maximum applied.

These two experiments at Henderson and at Grasslands, showed that grasses responded markedly to nitrogen applications in excess of 140 kg per ha and the indications were that applications of 450 kg per ha might be economic in practice. Because more herbage was produced on heavily fertilized pastures compared with lightly fertilized ones, more cattle per unit area could be carried and greater body mass gains per unit area should result. This could have great practical significance in the farming areas served by Henderson by increasing the numbers of cattle carried on farms, particularly during the growing season.

It had already been found that the veld was not satisfactory for grazing during the growing season and body mass gains in cattle could only be expected from December to mid-April (Elliott, 1956a,b; Anonymous*, 1960).

While a large number of grasses had previously been tested with low levels of applied nitrogen there was only limited knowledge on the responses of grasses in Rhodesia to heavy dressings. Therefore it was clear that many of the grasses previously tested should be tried again because their productivity with heavy rates of applied nitrogen was unknown. A large number of grasses were therefore included in fertilizer experiments designed to test this.

Experimental Objectives

To determine the effects of heavy dressings of nitrogenous fertilizer on the productivity of a number of grasses (see Table 6) in terms of herbage yield.

For this purpose, 30 grasses were given heavy applications of nitrogenous fertilizer for several years. After this time the intention was to select some of the highest yielding grasses and to test their ability to withstand intensive grazing by beef cattle. Many of the grasses selected for testing had previously been tested with relatively low nitrogen applications and had shown an ability to respond to applied nitrogen. A few were newly selected grasses of unknown productivity.

Materials and Methods

The 30 grasses (Table 6) were established in a silty clay soil of pH 5,3 (calcium chloride) during February 1965 in 3,66 x 3,66 m plots, replicated three times in a randomised blocks design. Before planting the grasses 90 kg P_2O_5 per ha was deeply ploughed into the soil.

Chloris gayana (cv. Giant Rhodes), Panicum maximum var. trichoglume (cv. Sabi) and Eragrostis curvula (cv. Ermelo) were sown in drills 45 cm apart while the other grasses were established vegetatively in 45 cm rows.

During the next four years the grasses were topdressed annually with 450 kg N, 90 kg P_2O_5 and 65 kg K_2O per ha. The nitrogen was applied in four equal monthly dressings starting with the first good rains in November while the phosphate and potash were applied before the rains started.

Each growing season the grasses were cut by hand with a sickle to a height of 5 cm above ground level whenever they reached early anthesis. Freshly cut herbage was weighed and dry matter contents determined from oven-dried samples.

Cutting the grasses whenever they reached early anthesis was the criterion used because it was believed that it was the fairest way in which to compare a large number of grasses having diverse growth forms. Cutting the grasses at a certain time interval or at a set height would have favoured the stoloniferous or rhizomatous grasses and might have damaged the tufted ones.

Crude protein contents of the grasses were determined during the 1965-66 growing season by the Kjeldahl method. Following the 1967-68 season, a season of low rainfall, the grasses were assessed for survival before the 1968-69 season.

Rainfall during 1965-66, 1966-67 and 1968-69 approached the 45-year mean of 875 mm while in 1967-68 only 412 mm was recorded (Appendix 1).

Results

The herbage yields of the grasses are presented in Table 6.

The 30 grasses differed markedly in their productivity. For example the highest producing grass, Bushman Mine Panicum, yielded a mean of 17 890 kg dry matter per ha and the lowest producing grass, Mtarazi Falls Setaria, only 1 700 kg dry

Table 4. Annual and four-year mean herbage yields in kg dry matter per ha of thirty grasses fertilized with 450 kg N, 90 kg P_2O_5 and 45 kg K_2O per ha, annually, arranged in descending order of mean yield (analysis of variance table Appendix 2.1).

Grass	Cultivar	Dry matter kg per ha 1965-66	1966-67	1967-68	1968-69	Means	Significant levels 5% 0,1%	Crude protein means 1965-66 % D.M.	Estimated recovery of grasses following 1967-68 drought %
Panicum coloratum	Bushman Mine	16500(3)	21770(3)	15330(2)	18320(3)	17890		13,0	96
Cynodon nlemfuensis var. nlemfuensis	[illegible] Star	16090(4)	19750(4)	16370(3)	18010(3)	17750		14,9	90
C. aethiopicus	No. 2 Star	12420(3)	19036(4)	18990(3)	19034(3)	15750		13,5	100
C. aethiopicus	Lake [illegible] Star	13560(4)	16650(4)	12550(3)	18134(3)	15130		16,5	100
C. dactylon	[illegible] Couch	7000(2)	17000(3)	16470(2)	16930(2)	14450		14,7	98
C. aethiopicus	[illegible] Crater Star	11000(3)	16060(4)	12560(2)	17340(3)	14380		17,4	100
Paspalum notatum	Paraguay	3060(2)	20450(4)	11220(2)	21180(2)	14110		14,0	92
Cenchrus ciliaris	[illegible]	8000(4)	15620(4)	10000(3)	16340(3)	13000		14,9	98
Chloris gayana	Giant Rhodes	10020(3)	19454(3)	9770(2)	17960(2)	13050		19,5	60
Cynodon dactylon	[illegible] Couch	10640(3)	14440(4)	11710(3)	11110(3)	11900		15,3	67
[illegible]	Natal	8060(3)	17000(3)	9260(2)	10450(2)	11450		14,1	45
Digitaria milanjiana	[illegible]	13200(3)	12800(2)	7940(2)	11370(2)	11230		14,7	53
D. milanjiana	[illegible]	7440(3)	15790(4)	6650(2)	15020(2)	11250		14,6	78
D. pentzii	Pangola River	8030(2)	12010(3)	8620(2)	14600(2)	10990		13,8	82
Panicum repens	Victoria Falls	8290(2)	20890(3)	6430(2)	6100(2)	10430		14,5	13
Digitaria milanjiana	[illegible]	7500(2)	12590(3)	7600(2)	13670(2)	10300		15,4	90
Panicum coloratum	[illegible]	6250(3)	14870(4)	8330(2)	10730(2)	10050		17,1	85
Digitaria milanjiana	[illegible]	8920(2)	11710(2)	4810(1)	9360(1)	8700		14,1	10
Panicum maximum	Sabi	7270(3)	12800(4)	3910(2)	9300(2)	8280		19,4	60
Pennisetum clandestinum	Kikuyu	6520(3)	11140(3)	6110(2)	8440(2)	8050		20,5	25
Digitaria pentzii	Nelspruit	4490(2)	12300(3)	5880(2)	8070(2)	7690		16,0	30
Paspalum plicatulum	CP [illegible]	3240(3)	12710(3)	6330(3)	8120(3)	7510		12,8	37
Panicum coloratum	Coloured Guinea	7940(4)	9730(4)	5290(3)	6410(3)	7340		14,9	21
Acroceras macrum	G [illegible]	4700(2)	11790(3)	4530(2)	7800(2)	7060		22,1	20
Paspalum plicatulum	CP[illegible]	6970(2)	10070(3)	3580(2)	4860(2)	6360		15,6	19
P. dilatatum	[illegible]	5720(2)	9800(3)	3320(2)	5020(2)	5960		13,4	16
Eragrostis curvula	Ermelo	4940(3)	8000(5)	4060(2)	5030(2)	5710		14,3	37
Paspalum guenoarum	CP [illegible]	4800(2)	11300(4)	3460(2)	2430(2)	5570		11,5	8
Setaria sphacelata	[illegible]	6030(3)	7410(4)	4630(2)	2880(3)	5290		14,9	19
Setaria sphacelata	[illegible] Falls	3950(3)	1900(3)	700(2)	280(2)	1700		16,5	1
Means		8170	13960	8080	11020	10310		15,0	35
Standard errors ±		1560	1570	1150	1860	1060			
Least significant differences → P=0,05		3900	4430	1540	2280	3020			
→ P=0,001		5700	7470	3780	3440	5230			
Coefficient of variation %		19,1	19,4	8,5	25,0	16,0			

Note : Number of times grasses were cut each year are shown in parentheses. Means joined by a common line are not significantly different at $P < 0,05$ (lines nearest means) and $P < 0,001$.

matter per ha. Bushman Mine Panicum and Muguga Star, the two highest producing grasses, yielded significantly more herbage ($P < 0{,}05$) than 26 of the other grasses. These two grasses were also amongst the highest producing grasses in each of the four test seasons and Bushman Mine Panicum produced the greatest amount of herbage (21 270 kg dry matter per ha) in any one year. The Cynodon spp. tested generally produced large amounts of herbage while those of the genus Panicum were more variable.

During 1967-68, the year of low rainfall (Appendix 1), herbage yields were generally lower than those in the second and fourth years but were similar to those of the first year. The four highest yielding grasses, Bushman Mine Panicum, Muguga Star, No. 2 Star and Lake Manyara Star were hardly affected by the drought and produced large amounts of herbage in all years.

Certain grasses, notably Paraguay Paspalum and Victoria Falls Panicum, were slow to establish as indicated by a comparison of their herbage yields in the first and second years.

Crude protein content of the grasses varied from 11,5 to 22,1 % of the dry matter during 1965-66 while survival of grasses following drought in 1967-68 ranged from 1 to 100 %.

Discussion

The four-year mean herbage yields of eight of the grasses, namely : Bushman Mine Panicum, Muguga Star, No. 2 Star, Lake Manyara Star, Mondorro Couch, Henderson Couch, Paraguay Paspalum and Mondorro Cenchrus were all greater than 13 470 kg dry matter per ha. This yield was obtained previously by Clatworthy (1967) from Giant Rhodes grass to which similar amounts of fertilizer had been applied. Furthermore, Bushman Mine Panicum had produced annual yields in excess of 19 770 kg dry matter per ha, a yield achieved with No. 2 Star grass at Grasslands with similar applied fertilizer in 1952-53 (Anonymous, 1953).

None of the eight grasses whose mean herbage yields were greater than 13 470 kg dry matter per ha had a tufted growth form. Most were stoloniferous while Paraguay Paspalum and Mondorro Cenchrus were rhizomatous and Mondorro Couch was both stoloniferous and rhizomatous. The highest yielding tufted grass was Sabi Panicum with a mean yield of 8 080 kg per ha which was less than half that of Bushman Mine Panicum.

Ability of the grasses to withstand drought conditions in 1967-68 varied considerably and this variation appeared to be related to growth habit. For example, the four most productive grasses, Bushman Mine Panicum, Muguga Star, No. 2 Star and Lake Manyara Star, all stoloniferous, produced only 3 670 kg per ha less herbage on average in 1967-68 than the previous year. By comparison, the four highest yielding tufted grasses, Sabi Panicum, the CP 21380 and CP 11826 strains of Paspalum plicatulum and Mangwende Paspalum, were 7 350 kg per ha lower, on average, than the previous year. The rhizomatous grasses, Paraguay Paspalum, Victoria Falls Panicum, Mondorro Cenchrus and Natal Beckeropsis were also seriously affected by drought. Survival rate of stoloniferous grasses assessed in the year following the drought was high, while amongst the tufted grasses and some of the rhizomatous grasses survival was low. This was reflected in both the herbage yields and estimated percentage recovery of plants in 1968-69 (Table 6).

Crude protein contents of the dry herbage of the grasses in 1965-66 varied from 11,5 to 22,1%. Because approximately 13,0% crude protein is required by ruminants for them to digest herbage efficiently it must be assumed that nearly all the grasses contained adequate protein for ruminants.

The herbage yields obtained with the most productive grasses in this experiment compare favourably with yields obtained in other countries with similar amounts of applied nitrogen. For example in the Republic of South Africa, I'ons (1974) reported yields of 15 030 kg per ha with Muguga Star, 12 920 kg per ha with No. 2 Star and 15 640 kg per ha from another Star grass

(*Cynodon aethiopicus* cv. unknown). In Hawaii, Whitney and Green (1969) recorded yields of 16 390 kg per ha with *Digitaria decumbens* (cv. Pangola) while in America, Scarsbrook (1970) obtained yields of 16 .00 kg per ha with the Cynodon hybrid, Bermuda grass.

The results of this experiment provided a useful guide to the selection of grasses for intensive grazing. For this purpose it is desirable that grasses produce large amounts of nutritious herbage, withstand intensive defoliation by either cutting or grazing and survive unfavourable weather conditions. On the basis of the first two years results, 1965-66 and 1966-67, three grasses, Bushman Mine Panicum, Muguga Star and Victoria Falls Panicum were selected for further trial for grazing purposes. Bushman Mine Panicum and Muguga Star were both stoloniferous grasses easily and quickly established by planting rooted runners and even in 1965-66, the first growing season after establishment, they produced considerably more herbage than any of the other grasses. In all four years these two grasses produced consistently high yields of herbage, even in the dry season of 1967-68. This is an important factor in selecting grasses for grazing purposes because consistent herbage production is necessary for planning production systems for animals successfully. Furthermore they both formed dense swards and should therefore withstand intensive grazing well.

Victoria Falls Panicum was planted from rhizomes but established slowly compared with Bushman Mine and Muguga Star. In the first growing season after establishment Victoria Falls Panicum produced less than half the herbage produced by Bushman Mine and Muguga Star. But in 1966-67, the second season after establishment, it produced 20 890 kg dry matter per ha, the third highest yield recorded in the four years of the experiment. Earlier, in 1964-65 and also during 1965-66 and 1966-67 in observation trials, well establisbed pastures of Victoria Falls Panicum at Henderson Research Station had been heavily fertilized and intensively grazed by beef cattle and had withstood grazing well. Furthermore this grass gave greater body mass gains both per head and per ha than Beckeropsis uniseta (cv. Natal), Chloris gayana (cv. Giant Rhodes) and Cynodon aethiopicus (cv. No. 2 Star), all treated in a similar manner. At a stocking rate of 12 yearling steers per ha Victoria Falls Panicum produced 810 kg of body mass gain per ha, the highest gain recorded in Rhodesia up to this time. It was for these reasons that it too was selected for further trial under grazing.

4.1.2 The methods of applying nitrogen

Nitrogenous fertilizers are expensive. Therefore when they are applied to grass pastures the method of application should be one that will maximise the effect of the nitrogen on growth of the grass and consequently on the amount of herbage produced. Clearly, the greater the amount of herbage produced by a pasture the greater it's potential livestock carrying capacity. This will effect output of livestock products and therefore profitability.

On sandy soils derived from granite, Barnes (1960a) found that greatest yields of herbage were obtained when a given quantity of nitrogen was applied in not more than one or two dressings during the growing season. Somewhat contradictory results were obtained by Clatworthy (1967) on a silty clay soil. On this soil, the application of a given quantity of nitrogen in four or eight equal dressings produced greater amounts of herbage than the same amount applied as a single dressing. Clearly further investigation was needed to confirm the number of split dressings a given quantity of nitrogen should be applied in to give maximum herbage production. Also, as the final assessment of selected grasses would be made in terms of products obtained from livestock grazing them it was opportune to determine the effects on herbage production of animal excreta voided onto pastures. The plant nutrients, particularly nitrogen, contained in the dung and urine of animals grazing pastures might affect the growth and consequently herbage produced by the pasture. On heavily grazed pastures considerable amounts of plant nutrients would be deposited onto the pasture in dung and urine which might allow amounts of chemical fertilizers applied to be reduced without decreasing the productivity of the pasture. This could materially effect the profitability of pastures.

Experimental Objectives

The experiment ran concurrently with the experiment described in Section 4.1.1. At this time (1965) Chloris gayana (cv. Giant Rhodes) grass was still the most widely grown grass on Henderson Research Station and the potentialities of the other grasses tested in the experiment described in Section 4.1.1 were unknown. It was for these reasons that Giant Rhodes grass was used in this experiment.

The main objective in this experiment was to further investigate the effects of applying a constant quantity of nitrogen to Giant Rhodes grass in various split applications and at different time intervals on herbage production. In addition nitrogen was applied with and without cattle manure to simulate effects on herbage production of plant nutrients contained in animal excreta voided onto intensively grazed pastures.

Materials and Methods

During February 1965 Giant Rhodes grass was sown into a well-prepared silty clay soil with pH 5,3 (calcium chloride) to which 90 kg P_2O_5 per ha had been applied. The seeding rate was 13,5 kg seed per ha sown in drills 7 cm apart. Plots were 3,66 x 3,66 m and treatments were replicated three times in a randomised block design. Soon after seedling emergence 22 kg N per ha was topdressed on all plots. During August 1965 all growth since establishment was cut and removed from the plots.

Six methods of applying 450 kg N per ha were tried with or without an application of 22,4 tonnes per ha of well rotted kraal manure. These methods are shown in Table 7.

Table 7. Methods of applying 450 kg N per ha to Giant Rhodes grass (nitrogen applied with or without 22,4 t kraal manure per ha).

Method	Proportion of nitrogen applied: Beginning of growing season	No. of weeks after first application at beginning of growing season: 4	8	12	Mid growing season	End of growing season
i	All					
ii	½				½	
iii	½	¼	¼			
iv	¼	¼	¼	¼		
v	½					½
vi						All

The kraal manure applied contained 1,8 % N in 1965-66 and 2,0 % N in 1966-67 and therefore amounted to 403 and 448 kg N per ha for these two years, respectively. The manure was applied in October as a topdressing and the first dressings of nitrogen were applied in mid-November in both years followed by further dressings according to the experimental schedule (Table 7). In addition to the nitrogen and manurial treatments, 90 kg P_2O_5 and 65 kg K_2O per ha were applied annually during October/November, as a basic dressing to all plots.

The herbage was cut by hand with a sickle to 5 cm above ground level whenever growth reached early anthesis. Using this criterion the plots were harvested three times in both years. Immediately after cutting, herbage was weighed and dry matter contents determined from oven-dried samples. Regrowth which accumulated during the dry season of 1966 (from 5 April) was cut on 9 September 1966 and weighed. No such harvest was taken in 1967.

Rainfall during both years was similar in amount and distribution ; 816 mm falling in 1965-66 and 803 mm in 1966-67. Rainfall between 5 April and 9 September 1966 amounted to 105 mm (Appendix 1).

Results

The effects of the various treatments on the production of Giant Rhodes grass herbage are presented in Table 8.

In both years largest yields of herbage were obtained where the nitrogen was applied in four equal dressings at four-weekly intervals and smallest yields were obtained when all the nitrogen was applied at the end of the growing season. In the first year however, valid comparisons could not be made between all the methods of application because Method(vi) had no nitrogen applied during the growing season and Method(v) had only half the nitrogen applied during the growing season whereas the other four methods had all of the nitrogen applied during the course of the growing season. Therefore only Methods(i) to (iv) could be compared and of these Method(iv) produced more herbage ($P < 0,05$) than the other three methods.

In the second year all methods of application could be compared. No differences were detected between Methods(ii),(iii) and (iv) but all three produced more herbage ($P < 0,05$) than the other three methods.

Applying 22,4 t kraal manure per ha increased herbage yields in both years. The mean effect over all nitrogen treatments was to increase herbage yields by 2 240 kg per ha in 1965-66 and by 1 840 kg per ha in 1966-67.

Regrowth which accumulated between 5 April and 9 September 1966 and was harvested is shown in Table 9.

Table 8. Effects of applying 450 kg N per ha in various split dressings with or without 22,4 t of kraal manure per ha on herbage yields of Giant Rhodes grass in kg dry matter per ha (Analysis of variance table Appendix 2.2).

Method of applying nitrogen	1965-66			1966-67		
	Kraal manure t per ha		Means of method of applying N	Kraal manure t per ha		Means of method of applying N
	0	22,4		0	22,4	
i	14730	17950	16340 Bab	15670	18690	17180 BCa
ii	15500	16040	15770 Babc	16660	18960	17820 ABCa
iii	13690	16900	15300 Babc	17020	20450	18740 ABa
iv	17670	19420	18550 Aa	19430	19020	19230 Aa
v	12450	13960	13210 Cbcd	16700	18310	17510 BCa
vi	6210	9460	7840 De	15870	16900	16390 Ca
Means of kraal manure	13380 Bb	15620 Aa		16890 Bb	18730 Aa	
SE ±	Method 710	Kraal manure 410		Method 560	Kraal manure 320	
LSD P = 0,05	2090	1210		1640	950	
LSD P = 0,001	3820	2210		3010	1740	
Coefficient of variation %			12,1			7,0

Note : Means with similar letters next to them are not significantly different, i.e. capital letters indicate $P < 0,05$ and small letters $P < 0,001$.

Table 9. Effect of applying 450 kg N per ha in various split dressings with or without 22,4 t kraal manure per ha during the growing season of 1965-66 on herbage yields in kg dry matter per ha of Giant Rhodes regrowth obtained in the 1966 dry season. (Analysis of variance table Appendix 2.3).

Method of applying nitrogen	Kraal manure t per ha		Means of method
	0	22,4	
i	2550	2200	2360 Cbc
ii	2550	1660	2110 Cc
iii	2010	1940	1980 Cc
iv	2340	2370	2360 Cbc
v	2730	4210	3470 Bb
vi	4330	6240	5290 Aa
Means of kraal manure	2750 Aa	3100 Aa	
SE ± Method	220		
SE ± Kraal manure	130		
LSD	Method	Kraal manure	
P = 0,05	630	370	
P = 0,001	1160	670	
Coefficient of variation %	18,06		

Note : Means with similar letters next to them are not significantly different, i.e. capital letters indicate $P < 0,05$ and small letters $P < 0,001$.

Greatest yields in the residual harvest taken on 9 September 1966 were obtained where all the nitrogen was applied in a single dressing at the end of the 1965-66 season.

Discussion

Valid comparisons could only be made between all the methods of applying nitrogen in the second year because of the delayed effects of applied nitrogen in Methods (v) and (vi) due to late application of half, or all, of the nitrogen in the first year. With these two methods there was clearly a carry over of nitrogen from the first to the second year as indicated by the much greater yields of herbage in the second year. This was particularly obvious with Method (vi) where all the nitrogen was applied in a single dressing at the end of the first growing season. In the first year comparisons could, however, be made between Methods (i), (ii), (iii) and (iv) and results showed that applying nitrogen in four equal four-weekly dressings (Method (iv)) produced more herbage ($P < 0{,}01$) than Method (i) and also more ($P < 0{,}001$) than Methods (ii) and (iii). In the second year the amount of herbage produced by this method of applying nitrogen was only slightly, and not significantly more, than Methods (ii) and (iii). These three methods((ii), (iii) and (iv)) produced more herbage than the remaining three methods and of these, Method (vi) was the least efficient for producing herbage. The results are in agreement with Clatworthy (1967) who found that applying a given amount of nitrogen in four equal dressings produced more herbage than applying the same total amount of nitrogen in few dressings. Similar results have been obtained by Morris and Celecia (1964) and by Burns, Gross, Woodhouse and Nelson (1970). Reports that applying a given quantity of nitrogen in three or more dressings compared with few dressings, result in greater herbage production, have also been made by Birch (1967), Scarsbrook (1970), 't Mannetje and Shaw (1972) and Olsen (1974).

These results are contrary to Barnes (1960a) findings which showed that greatest yields of herbage were obtained by applying a given amount of nitrogen in one or two topdressings. But, whereas Barnes (1960a) applied only a total of 90 kg N per ha Clatworthy (1967) applied a range of nitrogen from 0 to 900 kg per ha and in the experiment being described 450 kg N per ha was applied and no single dressing of nitrogen was less than 110 kg N per ha in the present experiment. The results indicate that if small amounts of nitrogen (perhaps less than 100 kg per ha) are applied to grasses it should be applied in not more than two dressings. If large amounts (more than 400 kg N per ha) are to be applied then four equal dressings at four-weekly intervals will result in greater efficiency of nitrogen usage for herbage production than few dressings.

The most inefficient method of applying 450 kg N per ha for production of herbage during the growing season was where it was all applied during the late season (mid-March). This was expected as the growth rates of grasses decline during the late growing season and therefore fertilizer applied at this time is likely to be less effective than dressings earlier in the season. This method of application did produce the greatest residual harvest of herbage during the 1966 dry season. It apparently also affected yields the following growing season, which were 6 550 kg per ha more than in the previous season. As little rain fell between mid-March 1966 and the beginning of the 1966-67 season (Appendix 1) most of the nitrogen would only have become effective with the commencement of the 1966-67 rains. Clearly this accounts for the greater yield in 1966-67.

Applying 22,4 t per ha of kraal manure in addition to 450 kg N in chemical form improved herbage yields. The manure applied in 1965-66 and 1966-67 contained 403 and 448 kg N per ha, respectively. This indicated that possibly more than 450 kg N per ha should have been applied in chemical form without kraal manure to obtain maximum amounts of herbage. It also indicated that on pastures that are heavily grazed the excreta of the animals does affect the productivity of the pasture. Therefore the amount of chemical nitrogen applied to heavily grazed pastures to achieve maximum production would be less than that on ungrazed pasture. Barnes and Clatworthy (1969) concluded that where large dressings of compost were applied to _Panicum maximum_ var. _trichoglume_ (cv. Sabi) in addition to fertilizer nitrogen, the response in herbage yield to increasing amounts of nitrogen was linear up to 350 kg N per ha. Further evidence that cattle excreta affects production of grass herbage is indicated by Gillard's (1967) results in the Republic of South Africa. He found that cattle grazing on veld excreted 34 kg N in their dung and 7 to 8 kg N in their urine over a six month grazing period. Provided coprophagus beetles were present to bury the dung with their burrowing, 30 kg N in the dung was returned to the soil and was therefore available for plant growth.

4.1.3 The response of grasses to applied nitrogen on different soils

Many of the experiments done in Rhodesia on the effects of applied nitrogen on herbage production of grasses were done either at the Grasslands Research Station near Marandellas or at the Henderson Research Station near Mazoe. While these two Stations have similar rainfall (875 and 920 mm per annum, respectively) they are at different altitudes (1 670 and 1 260 m above sea level, respectively) and are situated on different soils. Experiments at Grasslands were done on sandy soils derived from granite while those at Henderson were done on grey, silty clay loams.

Results of experiments reported by Addison (1956a,b, 1958a,b), Barnes (1960a, b, c, 1961), Barnes and Clatworthy (1969), Clatworthy (1967), Anonymous[+](1953, 1954, 1955), Mills (1962) and Weinmann (1950, 1964), at these two Stations showed that grasses responded in a similar way on both soils to nitrogen applied in amounts up to 220 kg per ha.

In one experiment at Grasslands on the site of an old cattle kraal (Anonymous[+], 1953) up to 470 kg N per ha was applied to <u>Cynodon aethiopicus</u> (cv. No. 2 Star) which yielded 19 770 kg dry herbage per ha. Later Barnes and Clatworthy (1969) showed that large dressings of compost, in addition to the application of fertilizer nitrogen, resulted in large yields (18 170 kg per ha) of <u>Panicum maximum</u> var. <u>trichoglume</u> (cv. Sabi). They concluded that where compost and nitrogen were applied together the response in herbage yield to increasing amounts of applied nitrogen was linear up to 350 kg N per ha. In other experiments on granite sands where no animal manures or compost were applied it was found that herbage yields of Star grass diminished markedly when more than 220 kg N per ha were applied and even where 560 kg N per ha was applied, only 11 950 kg per ha dry matter was harvested (Anonymous, 1954, 1955).

On the silty clay soils at Henderson, Clatworthy (1967) had found that herbage yields of Chloris gayana (cv. Giant Rhodes) increased as nitrogen applied was increased up to 450 kg per ha, resulting in a yield of 13 470 kg dry herbage per ha. In the experiment reported under Section 4.1.1 herbage yields of over 19 000 kg dry matter per ha were harvested from six grasses to which 450 kg N per ha had been applied.

These results indicated that the degree of response of grasses to applied nitrogen on the two soils was inconsistent. Furthermore, observations on Henderson Research Station between 1963 and 1966 showed that the growth of grasses on granite sands was not as vigorous as on clay soils even where similar amounts of nitrogen were applied to the same grass. There was a need to determine the responses of grasses to applied nitrogen on different soils within the same environment.

Experimental Objectives

While results of experiments before 1963 indicated that the degree of response of grasses to applied nitrogen was similar up to 220 kg N per ha on different soils, results were inconsistent when heavier dressings were applied. No comparisons had been made on the responses of grasses to nitrogen on different soils in the same environment. The only comparisons that could be made were between Grasslands and Henderson Research Stations, some 70 km apart. The object of the present experiment was to compare the response of grasses to applied nitrogen on different soils in the same general climatic environment.

Materials and Methods

(i) Soil characteristics

One experiment was done on a deep, very permeable and well-drained sandy soil derived from granite. This soil was of a series that comprises very coarse-grained, greyish-brown sands over reddish-brown sandy sub-soils. They are atypical of most granite sands in Rhodesia because of their unusual depth relative to the rather steep slopes on which they occur, and the very coarse sand fractions (du Toit, 1965). The pH of the soil was 5,7 (calcium chloride).

The second experiment was done on a yellow-brown, silty clay soil derived from metasediments (du Toit, 1965) which has a marked tendency to form a hard surface crust and therefore has a lower water infiltration rate than the sand. The pH of this soil was 5,3 (calcium chloride).

(ii) Design of experiments

Cynodon nlemfuensis var. nlemfuensis (cv. Muguga), Panicum coloratum (cv. Bushman Mine), P. repens, (cv. Victoria Falls) and Eragrostis curvula (cv. Ermelo) were established on both soils during February 1967. Muguga Star was known to grow well on both sands and on heavy clay soils, Bushman Mine Panicum had been found to grow more vigorously on heavy soils than on sands while Ermelo Love was known to grow well on sands. Victoria Falls Panicum had grown well on heavy soils but had not been tried on sands. Therefore the grasses had apparent soil preferences which might bring out the effects of applied nitrogen on the two soil types more clearly. The grasses were planted in 3,66 x 3,66 m plots, replicated three times, in a randomised block design. Before planting, 90 kg P_2O_5 and 110 kg K_2O per ha were ploughed deeply into the soils. Also, 220 kg per ha of calcitic lime were applied to the granite sand site and 1 120 kg per ha to the silty clay site to equalise pH on both soils.

After soil preparation, Ermelo Love grass was sown in drills 45 cm apart while the other three grasses were established from transplants spaced 45 x 30 cm apart. As soon as the seed had germinated and the transplants had taken root, 110 kg N per ha were applied to all plots.

During the next three years 0, 225, 450 and 675 kg N per ha and basic dressings of 90 kg P_2O_5 and 70 kg K_2O per ha, were applied annually to grasses on both soils. Although the experimental results in Section 4.1.2 had shown that statistically there were no differences in herbage yields of Chloris gayana (cv. Giant Rhodes) where nitrogen was applied in two, three or four dressings, greatest yields were produced with four equal dressings at four-weekly intervals. For this reason the nitrogen in this experiment was also applied in four equal monthly dressings, starting with the first good rains in November, in an attempt to obtain the greatest possible effect of applied nitrogen on herbage production. The phosphate and potash were applied during October, before the rains started.

Each growing season the grasses were cut by hand with a sickle to a height of 5 cm above ground level whenever they reached early anthesis. Consequently the time and frequency of cutting varied between grasses and between soil types. The herbage was weighed soon after cutting and the dry matter contents were determined from oven-dried samples. Samples of dry herbage were also analysed for nitrogen content by the Kjeldahl method and the crude protein content calculated. By subtracting the amount of nitrogen contained in the herbage of the grasses where no nitrogen was applied from that where nitrogen (225, 450 or 675 N per ha) was applied, the proportions of applied nitrogen recovered in the herbage were calculated.

The effects of the two soils on the three-year mean herbage yields of the grasses were assessed by standard F-tests using a split-plot analysis in which soils were compared with a whole-plot error term comprising the mean square for soils x replications within soils, and the other effects were compared with a sub-plot error term comprising the mean square for soils x nitrogen x grasses x replications.

Results

The effects of applying different amounts of nitrogen on the herbage yields of the four grasses grown in the sandy soil derived from granite are shown in Figure 6.

On the granite sand, Muguga Star produced the greatest mean amount of herbage (7 450 kg per ha) followed closely by Ermelo Love (7 230 kg per ha) then Victoria Falls Panicum (5 630 kg per ha) and Bushman Mine Panicum (5 580 kg per ha). The former two grasses produced significantly more herbage ($P < 0{,}001$) than the latter two.

The mean effect of applying nitrogen to the grasses was to increase herbage production although increments in yield diminished with each successive increment in nitrogen applied. Yields of the individual grasses tended to increase with successive increments of nitrogen applied and the responses of Muguga Star and Ermelo Love were greater ($P < 0{,}05$) than those of Victoria Falls Panicum and Bushman Mine Panicum.

Responses of the grasses in 1967-68 and in 1969-70 to applied nitrogen were very similar to the three-year mean responses. Yields of the individual grasses tended to increase with successive increments of applied nitrogen though yield increases tended to decrease with each additional increment of nitrogen. In 1967-68 and in 1968-69 the responses of Muguga Star and Ermelo Love were greater ($P < 0{,}05$) than those of Victoria Falls Panicum and Bushman Mine Panicum.

Herbage yields in 1967-68, the year following establishment of the grasses and also a year of low rainfall (Appendix 1) were generally lower than in 1968-69 and 1969-70. The greatest herbage yield in any one year was produced by Victoria Falls Panicum with a yield of 13 930 kg per ha.

The effects of applying different amounts of nitrogen on the herbage yields of the four grasses grown in the silty clay soil are shown in Figure 7.

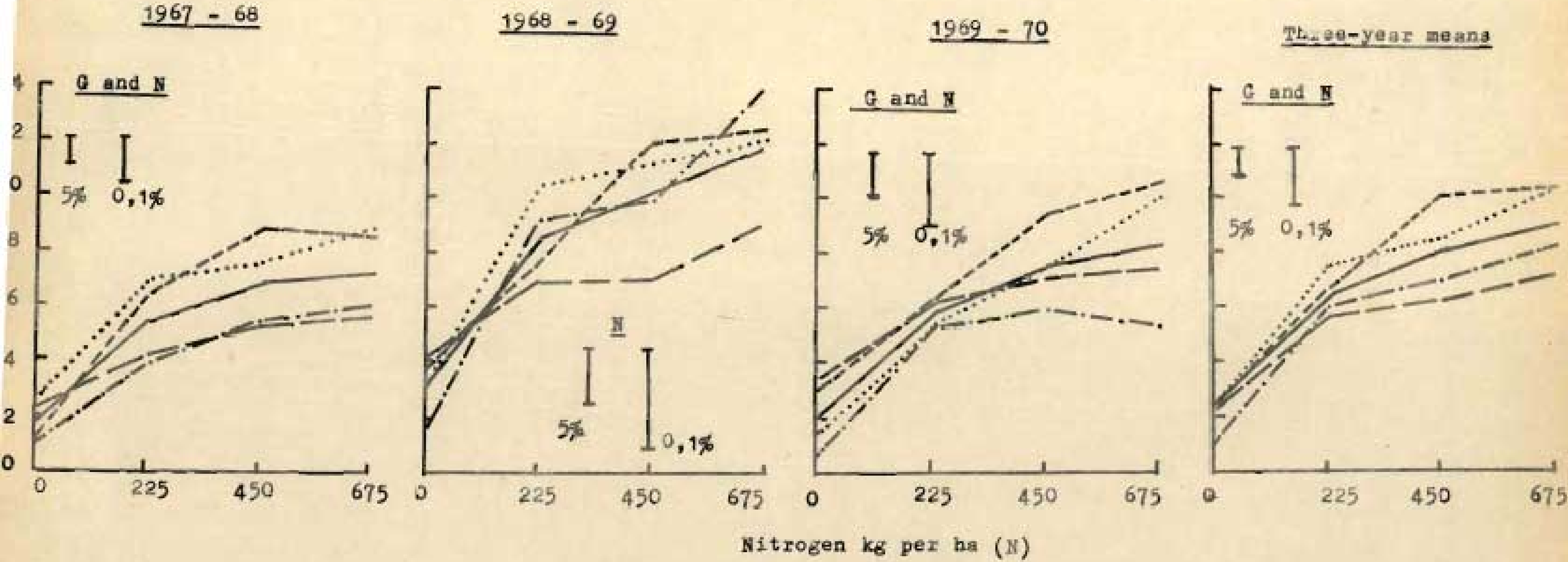


Figure 6. The effects of applied nitrogen (N) on the herbage yields in kg dry matter per ha of four grasses (G) grown in a sandy soil derived from granite. Least significant differences P = 0,05 and P = 0,001 indicated by vertical bars. (Analysis of variance tables Appendix 2,4; 2.6; 2.8 and 2.10).

Grasses (G)

- - - - - - Muguga Star
— — — Bushman Mine Panicum
.... Ermelo Love
·—·—·— Victoria Falls Panicum
———— Means grasses

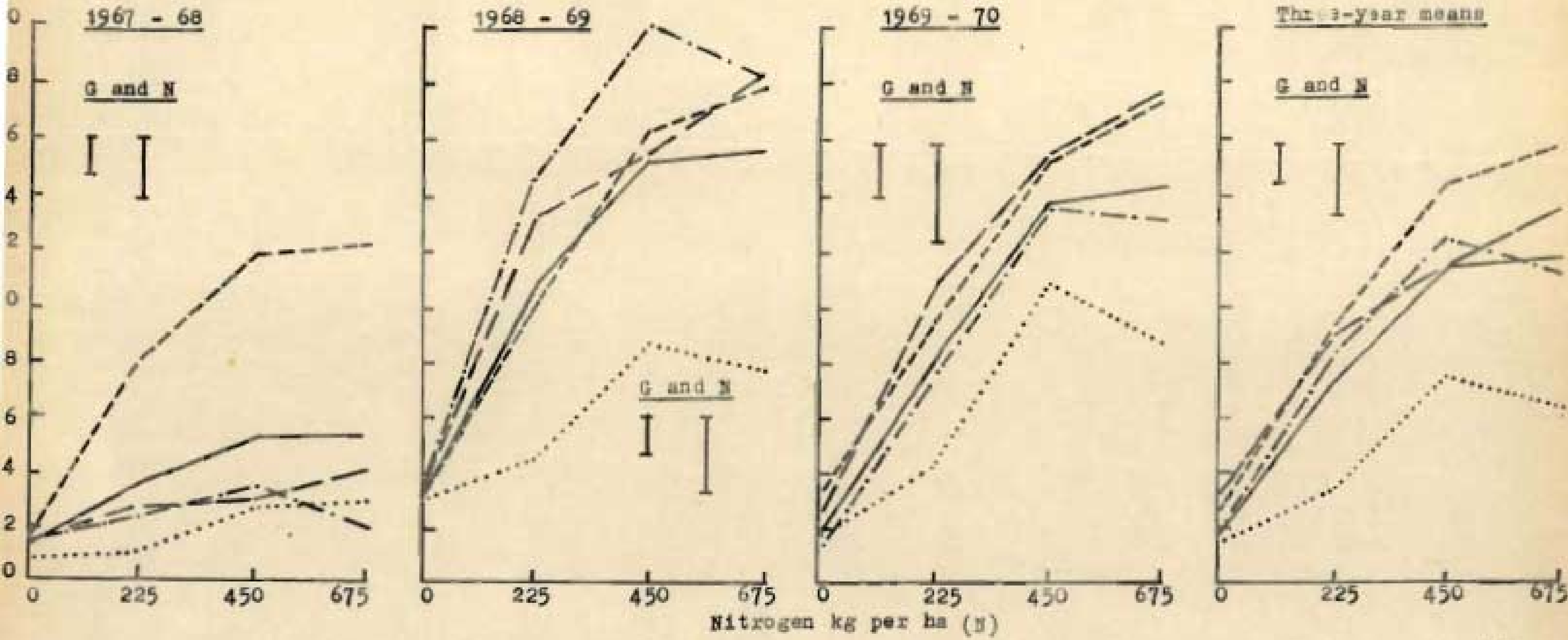


Figure 7. The effects of applied nitrogen (N) on the herbage yields in kg dry matter per ha of four grasses (G) grown in a silty clay soil. Least significant differences P = 0,05 and P = 0,001 indicated by vertical bars. (Analysis of variance tables Appendices 2.5; 2.7; 2.9 and 2.11).

Grasses (G)

- - - - - - - Muguga Star
.... Ermelo Love
———— Means grasses
— — — Bushman Mine Panicum
.—.—.— Victoria Falls Panicum

On the silty clay soil the mean yield of Muguga Star (10 460 kg per ha) was significantly greater ($P < 0,05$) than that of Bushman Mine Panicum (8 960 kg per ha) and of Victoria Falls Panicum (8 060 kg per ha) and significantly more ($P < 0,001$) than the yield of Ermelo Love (4 730 kg per ha). Bushman Mine Panicum and Victoria Falls Panicum produced significantly more ($P < 0,05$) herbage than Ermelo Love.

The mean effect of applying nitrogen to the grasses was to increase herbage yields markedly up to the 450 kg per ha level. Statistical analysis showed that up to this level of application herbage yields increased linearly to applied nitrogen but thereafter the increment diminished. Yields of Muguga Star and Bushman Mine Panicum increased with each successive increment of applied nitrogen but yields of Victoria Falls Panicum and Ermelo Love decreased with the last increment of nitrogen. The response of Ermelo Love was smaller ($P < 0,001$) than the responses of the other grasses.

Responses of the grasses to applied nitrogen in 1968-69 and in 1969-70 were similar to those of the three-year mean except that in the latter year no differences in the responses between grasses were detected. In 1967-68, the year following establishment of the grasses, differences in responses ($P < 0,001$) between Muguga Star and the remaining three grasses were detected but in this year herbage yields were considerably lower than in the other two years. This was due mainly to low rainfall although Muguga Star was not affected as severely as were the other three grasses.

The effects that soil type had on the three-year mean yields of the grasses are shown in Figure 8.

The mean yield of all the grasses on the silty clay were greater ($P < 0,01$) than their mean yield on the granite sand. Three grasses, namely Muguga Star, Bushman Mine Panicum and Victoria Falls Panicum produced more herbage on the silty clay while Ermelo Love produced more on the sand than on the silty clay.

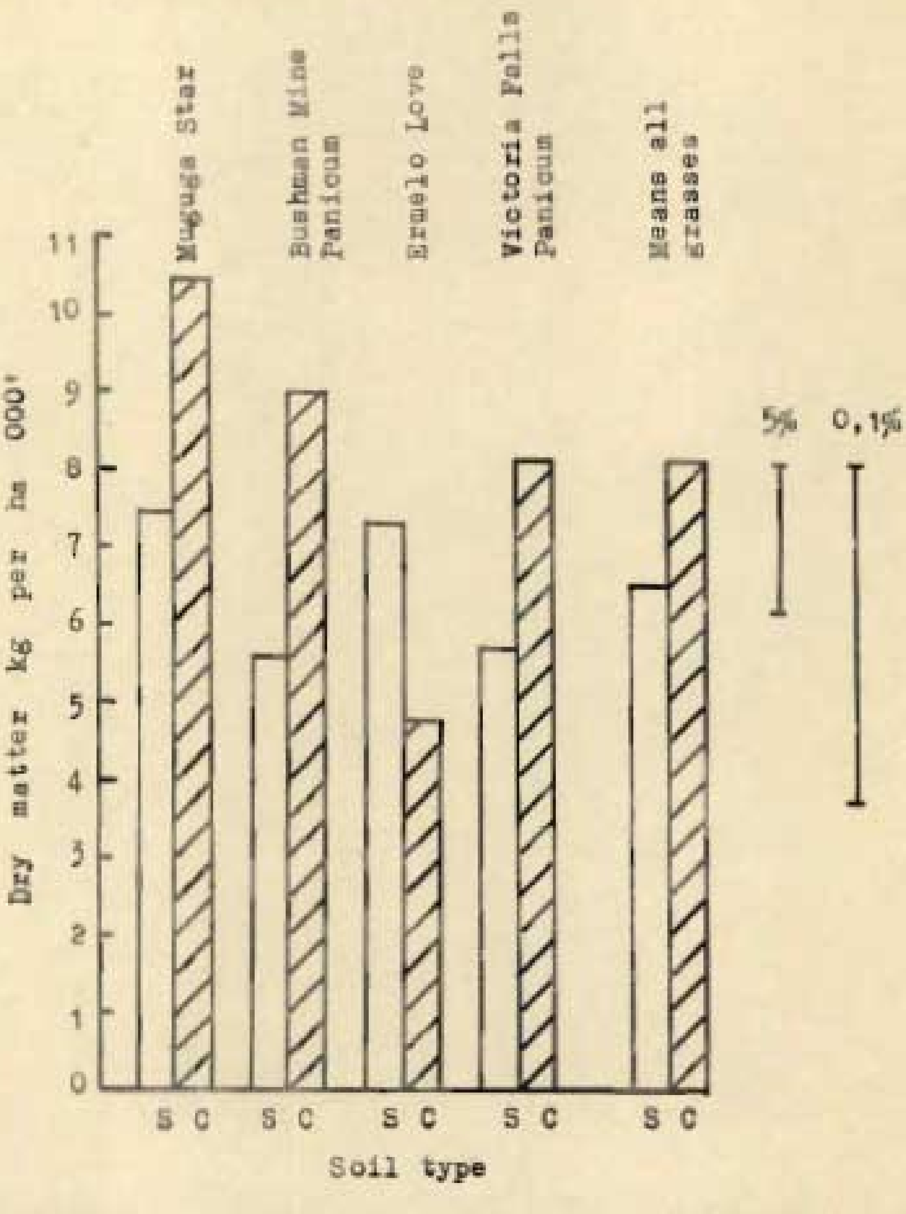


Figure 8. The effects of soil on the three-year mean herbage yields of four grasses in kg dry matter per ha grown in a sandy soil (S) and in a silty clay soil (C). Least significant differences indicated by vertical bars. (Analysis of variance table Appendix 2.12).

The three-year mean response of the grasses to applied nitrogen on the granite sand and on the silty clay are shown in Figure 9. Also shown are their estimated responses calculated from the quadratic regression model

$$Y = a + b N - c N^2 \quad \text{where}$$

Y is the herbage yield, a, b and c are constants and N is the amount of nitrogen applied.

The actual mean response of the grasses to applied nitrogen was greater ($P < 0{,}001$) on the silty clay than on the granite sand. However, on both soils herbage yields of the grasses increased ($P < 0{,}001$) with each increment of nitrogen applied although the increases diminished ($P < 0{,}001$) with each increment of nitrogen (Figures 6 and 7).

The calculated responses of the grasses to applied nitrogen on both soils were very close to the actual responses (Figure 9). Using the regression models in Figure 9 the amounts of nitrogen (N) theoretically required to produce maximum herbage yields on the sand (YS) and on the clay (YC), were calculated

$$YS = 2324 + 20{,}64\ N - 0{,}01716\ N^2$$

Therefore YS is at a maximum when $N = \frac{20{,}64}{0{,}03432}$

$$N = 601 \text{ kg N per ha}$$

$$YC = 1994 + 29{,}60\ N - 0{,}02224\ N^2$$

Therefore YC is at a maximum when $N = \frac{29{,}60}{0{,}04448}$

$$N = 665 \text{ kg N per ha}$$

The theoretical herbage yields with 601 kg N per ha on the sand and 665 kg N per ha on the silty clay were 8 530 and 11 843 kg dry matter per ha, respectively.

The crude protein contents of the grasses on the two soils with the various amounts of nitrogen applied, are shown in Figure 10.

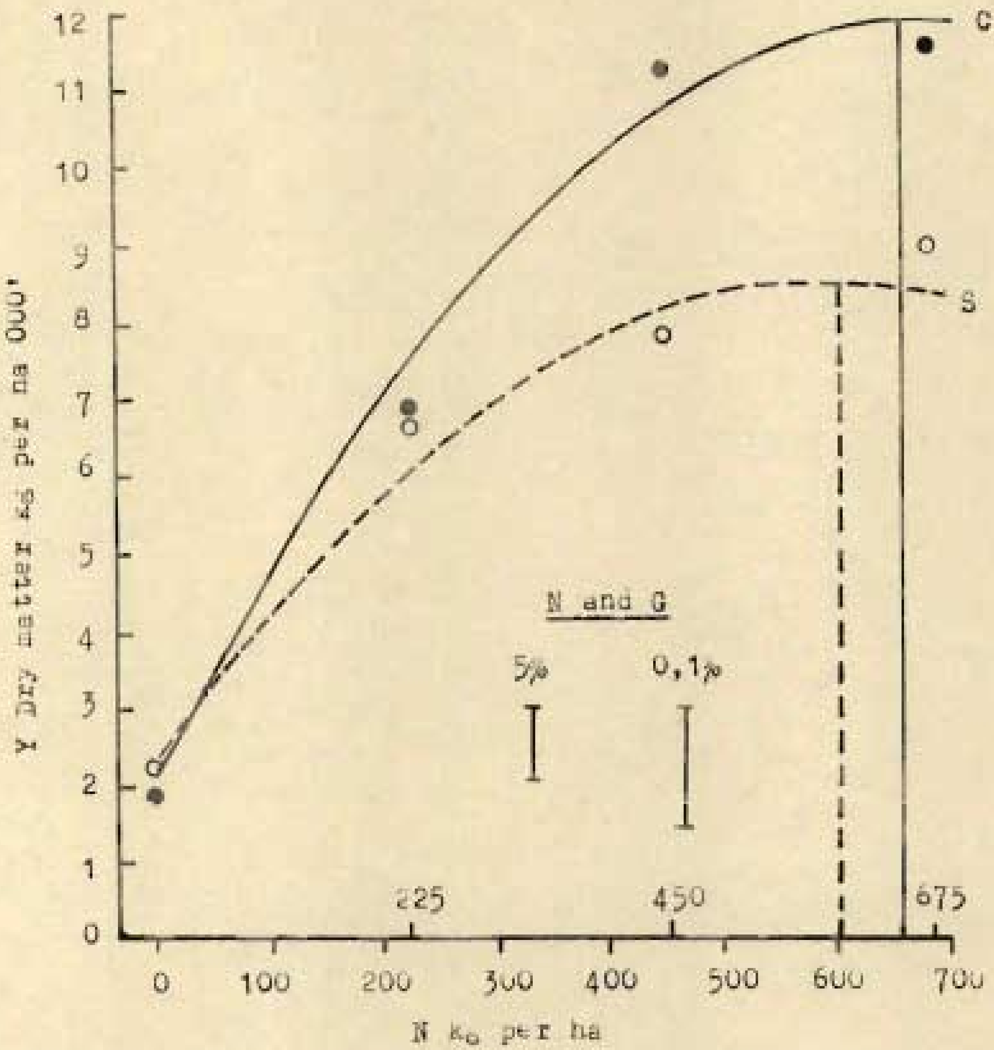


Figure 9. The actual and calculated mean effects of applied nitrogen (N) on the three-year mean herbage yields (Y) in kg dry matter per ha of four grasses (G) grown in a sandy soil derived from granite (S) and in a silty clay soil (C). Least significant difference for actual yields indicated by vertical bars. (Analysis of variance table Appendix 2.12).

o S
● C
Actual yields

------ $YS = 2524 + 20{,}64N - 0{,}01716\ N^2$
$R^2 = 0{,}9812$

——— $YC = 1994 + 29{,}60\ N - 0{,}02224\ N^2$
$R^2 = 0{,}9885$

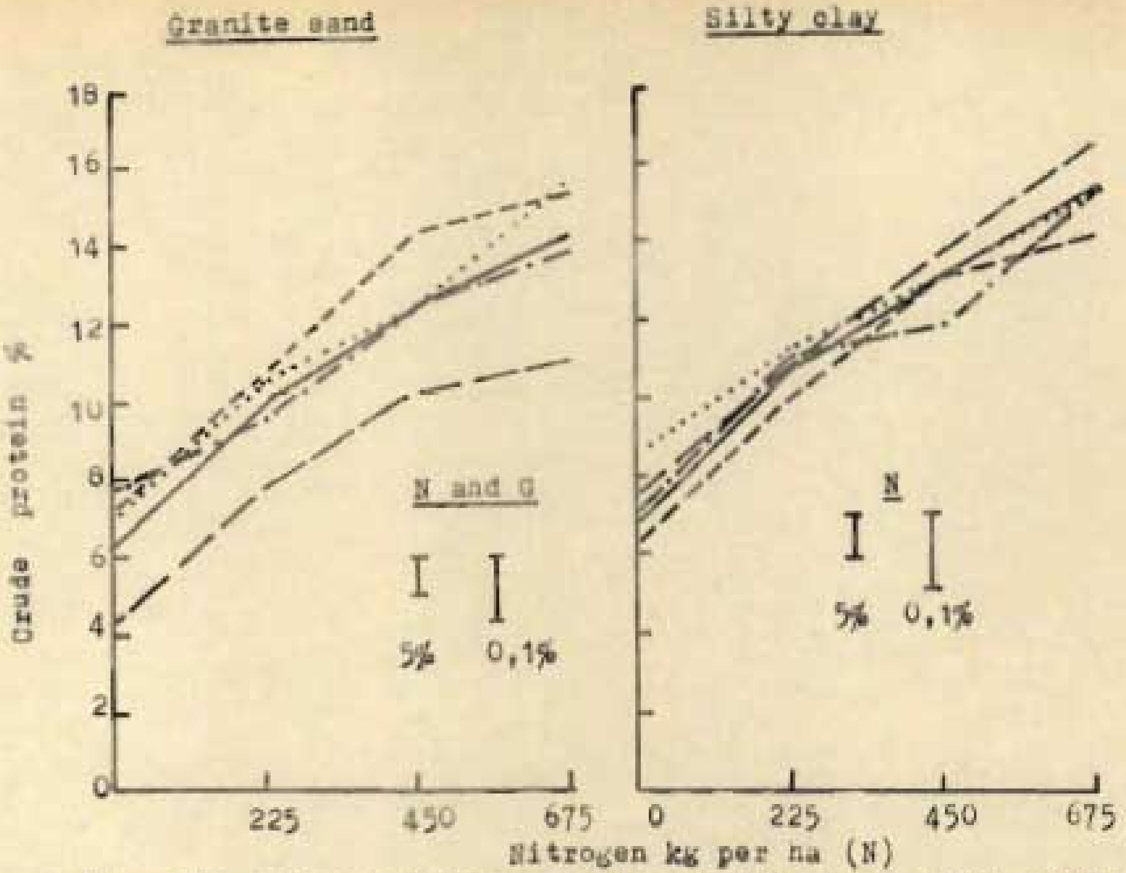


Figure 10. The effects of applied nitrogen (N) on the three-year mean crude protein content of four grasses (G) expressed as a percentage of dry matter. (Analysis of variance table Appendices 2.13 and 2.14).

Grasses (G)

------ Muguga Star
—·—·— Victoria Falls Panicum
— — — Bushman Mine Panicum
———— Means grasses
·········· Ermelo Love

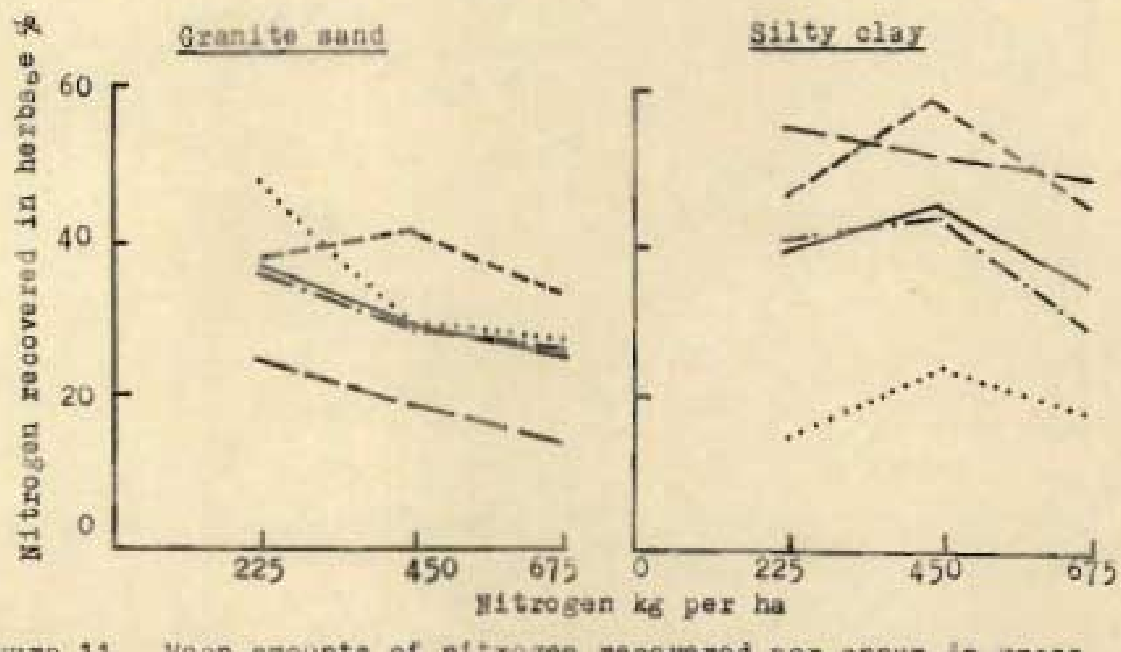


Figure 11. Mean amounts of nitrogen recovered per annum in grass herbage expressed as a percentage of that applied.

Grasses (G)

------ Muguga Star
—·—·— Victoria Falls Panicum
— — — Bushman Mine Panicum
———— Means grasses

The crude protein content of all the grasses increased in proportion to the amount of nitrogen applied on both soils. Also, the mean crude protein content of all the grasses was similar at each level of nitrogen application on both soils. For example where no nitrogen was applied it was 7,2% on the sand and 7,4 % on the silty clay, and where 675 kg N per ha was applied it was 14,2 % and 14,9 % on the sand and silty clay, respectively. Differences between grasses were detected on the sand in the relationship between crude protein content and applied nitrogen. This difference was due to the lower crude protein content of Bushman Mine Panicum compared with the other three grasses. There were no such differences between the grasses on the silty clay.

The amount of nitrogen recovered in the herbage of the grasses expressed as a percentage of that applied is shown in Figure 11.

The amount of applied nitrogen recovered in the grasses on the silty clay was generally greater than on the sand. On the sand the greatest mean recovery of nitrogen in the grasses was 37,5 % where 225 kg N per ha were applied. On the silty clay the greatest mean rate of recovery was 45,6 % where 450 kg N per ha were applied. There was one exception to the general result on the sand and one on the silty clay. On the sand Muguga Star recovered most nitrogen (42,0 %) where 450 kg N per ha were applied while on the silty clay Bushman Mine Panicum recovered most nitrogen where 225 kg N per ha were applied.

Discussion

The experimental results clearly show the well known effect that applied nitrogen has on production of grass herbage and the results are in keeping with the findings of other workers elsewhere in the world (Fribourg, Edwards and Barth (1971), Olsen (1972, 1974), Edwards and Mappledoram (1972), Ng (1972) and Mathias, Bennett and Lundberg (1973)). The results are also similar to those of other workers in Rhodesia, notably Weinmann (1950,1964), Anonymous+ (1953,1954,1956), Addison (1956a,b, 1958 a,b) Barnes (1960a, b,c), Mills (1962) and Clatworthy (1967). The

The crude protein content of all the grasses increased in proportion to the amount of nitrogen applied on both soils. Also, the mean crude protein content of all the grasses was similar at each level of nitrogen application on both soils. For example where no nitrogen was applied it was 7,2% on the sand and 7,4 % on the silty clay, and where 675 kg N per ha was applied it was 14,2 % and 14,9 % on the sand and silty clay, respectively. Differences between grasses were detected on the sand in the relationship between crude protein content and applied nitrogen. This difference was due to the lower crude protein content of Bushman Mine Panicum compared with the other three grasses. There were no such differences between the grasses on the silty clay.

The amount of nitrogen recovered in the herbage of the grasses expressed as a percentage of that applied is shown in Figure 11.

The amount of applied nitrogen recovered in the grasses on the silty clay was generally greater than on the sand. On the sand the greatest mean recovery of nitrogen in the grasses was 37,5 % where 225 kg N per ha were applied. On the silty clay the greatest mean rate of recovery was 45,6 % where 450 kg N per ha were applied. There was one exception to the general result on the sand and one on the silty clay. On the sand Muguga Star recovered most nitrogen (42,0 %) where 450 kg N per ha were applied while on the silty clay Bushman Mine Panicum recovered most nitrogen where 225 kg N per ha were applied.

Discussion

The experimental results clearly show the well known effect that applied nitrogen has on production of grass herbage and the results are in keeping with the findings of other workers elsewhere in the world (Fribourg, Edwards and Barth (1971), Olsen (1972, 1974), Edwards and Mappledoram (1972), Ng (1972) and Mathias, Bennett and Lundberg (1973)). The results are also similar to those of other workers in Rhodesia, notably Weinmann (1950,1964), Anonymous+ (1953,1954,1956), Addison (1956a,b, 1958 a,b) Barnes (1960a, b,c), Mills (1962) and Clatworthy (1967). The results of the Rhodesian workers showed that herbage production from grasses grown at Grasslands and Henderson Research Stations were similar despite the fact that soils were different and one Station is at a higher altitude than the other. The experiments now being discussed were done on two different soil types in a similar environment. The results showed that the responses of the four grasses to applied nitrogen differed between the two soil types. On the granite sand the grasses produced smaller amounts of herbage than they did on the silty clay soil, but differences only became apparent when more than 225 kg N per ha were applied.

Results indicated that not more than 225 kg N per ha should be applied to dryland grass pastures on granite sand and this agrees with Anonymous* (1954, 1955) findings. With such applications of nitrogen, between 6 000 to 7 000 kg dry herbage per ha are likely to be harvested annually, containing approximately 10 % crude protein and therefore resulting in approximately 36 % of the applied nitrogen being recovered.

On the silty clay the grasses responded significantly to nitrogen applications of 450 kg N per ha and the results agree with those of Clatworthy (1967), Fribourg, Edwards and Barth (1971), Edwards and Mappledoram (1972) and Olsen (1972, 1974). Herbage yields of three grasses, Muguga Star, Busman Mine Panicum and Victoria Falls Panicum, particularly in 1968-69 and 1969-70, were similar to those obtained in other experiments reported in Section 4.1.1. These grasses produced a mean of 11 370 kg dry herbage per ha which contained 13,2 % crude protein, resulting in 36 % of applied nitrogen being recovered. These results compare favourably with those of workers elsewhere. For example Whitney and Green (1969) and Olsen (1974) reported crude protein contents of 10,6 and 11,1 % respectively, in grasses fertilized with approximately 450 kg N per ha while Ng (1972) and Mathias, Bennett and Lundberg (1973) reported apparent nitrogen recoveries in herbage of 25,9 and 42,0 % respectively, at similar levels of applied nitrogen.

The effect that drought can have on growth of newly-established grasses is indicated by the much larger amounts of herbage harvested from older pastures, particularly on heavy soils. For example in 1967-68, the year of low rainfall, three-year-old pastures of Muguga Star and Bushman Mine Panicum fertilized with 450 kg N per ha on the silty clay soil, yielded 16 370 and 15 330 kg dry herbage per ha, respectively (Section 4.1.1), while in these experiments the one-year-old pastures produced only 11 750 and 2 850 kg per ha, respectively (Figure 7).

When the experimental results were analysed no explanation could be advanced for the generally lower herbage yields of the grasses on the sand as compared with the silty clay. Possible reasons were thought to be differences in the water relationships between the two soils and differences in the general plant nutrient status of the soils.

4.1.4 The effects of minor elements on herbage production of grasses

The soil type in which a grass is grown may effect the magnitude of response of the grass to applied nitrogen. This was shown in the experiment in which the responses of <u>Cynodon nlemfuensis</u> var. <u>nlemfuensis</u> (cv. Muguga Star), <u>Panicum coloratum</u> (cv. Bushman Mine), <u>P. repens</u> (cv. Victoria Falls) and <u>Eragrostis curvula</u> (cv. Ermelo) to applied nitrogen were measured on two soils(Section 4.1.3). The first three grasses yielded considerably more herbage on a silty clay soil compared with their yields on a granite sand. The exception was Ermelo Love grass which yielded more on the sand.

Differences in herbage yields of grasses grown on various soils but receiving similar amounts of applied fertilizers would generally be ascribed to the inherent fertility of the soils. In the experiment described in Section 4.1.3 large amounts of nitrogen and normally adequate amounts of phosphorus and potash for grass growth were applied to the grasses on both soils. It was therefore logical to assume that it was not a deficiency of one or more of these plant nutrients that caused the differences in herbage yields of grasses on the two soils. Clearly some other factor, or factors, were responsible.

On the granite sand minor element plant deficiencies had been observed in crops (Rodel, 1968a,1969; Rodel and Hopley, 1970). This indicated that minor element deficiencies might have been responsible for the low herbage yields of Muguga Star, Bushman Mine Panicum and Victoria Falls Panicum on the sand. No reason could be advanced for Ermelo Love grass yielding more herbage on the sand compared with the silty clay, but it is well known that this grass favours sandy soils.

Experimental Objectives

The object of this experiment was to test the hypothesis that certain minor elements in addition to major plant nutrients, nitrogen, phosphorus and potash, might be necessary on the granite sand for large herbage yields (more than 15 000 kg dry matter per ha) to be obtained from grasses.

Materials and Methods

Cynodon aethiopicus (cv. No. 2 Star) was selected for the experiment. In experiments (Section 4.1.1) on silty clay soils it had yielded 12 620 kg and 16 030 kg dry matter per ha in 1965-66 and 1966-67, respectively. During the same years on granite sands adjacent to the experiment described in Section 4.1.3 No. 2 Star grass pastures had been observed to grow poorly on small farms where systems of farming suitable for application in African Tribal Areas were being investigated (Rodel and Hopley, 1970).

The Star grass was established on granite sand in 3,35 x 3,35 m plots with 0,60 m pathways between them in November 1966. During the 1966-67 growing season 170 kg N, 90 kg P_2O_5 and 60 kg K_2O per ha were applied to aid rapid establishment. In 1967-68 and 1968-69 sulphur (S), boron (B), zinc (Zn) and magnesium (Mg) were applied separately and in combination and the effects of these on herbage production of Star grass were compared with an untreated control. Treatments were applied in all their combinations in three replicates of four randomised blocks with treatments arranged in a 2^4 factorial according to Cochran and

and Cox's (1950) plan (6.4, replications 1, 2 and 3). In this design certain treatments were partially or completely confounded as follows :

Replication 1. SB, S Zn Mg were partially confounded
Replication 2. S Zn, S B Mg were partially confounded
Replication 3. S Mg, S B Zn were partially confounded

The treatment B Zn Mg was totally confounded in all three replications and the sum of squares for this treatment was included in the error sums of squares. Three and four factor interactions in this experiment were not of great importance because of the difficulties of interpretation. However, for all the treatments that were partially confounded the unconfounded portions of the sums of squares were calculated and are included in the analysis of variance (Appendices 2.15 and 2.16) so that as much information as possible could be retrieved from these treatments.

Sulphur was applied to appropriate plots as single superphosphate (20 % P_2O_5 and 12 % S) at 450 kg per ha. Plots not receiving sulphur were dressed with an equivalent amount of phosphoric oxide as triple superphosphate (45 % P_2O_5) containing negligible quantities of sulphur. Boron was applied as fertilizer borate (14,3 % B) at 11 kg per ha and zinc sulphate (22,7 % Zn) at 22 kg per ha. Plots that received no magnesium were dressed with calcitic limestone while those to which magnesium was applied were given a similar amount (560 kg per ha) of dolomitic limestone (12 % Mg) of equal neutralizing value. In addition all plots received 450 kg N per ha as calcium ammonium nitrate and 55 kg K_2O per ha. All fertilizers and trace elements were applied annually at the rates stated. Nitrogen was topdressed each year in four equal monthly dressings while the other fertilizers and trace elements were broadcast over the plots during November when the rains started.

In 1967-68 and 1968-69 the herbage above 5 cm was harvested whenever growth attained early anthesis. In the first growing season, only 412 mm of rain fell (Appendix 1) and only one harvest was taken, on 17 February 1968. In the second growing season 852 mm of rain fell and harvests were taken on 24 January and 31 March 1969. At all harvests the freshly cut herbage was weighed and the dry matter contents determined from oven-dried samples.

Results

The herbage yields obtained during the two years are shown in Table 10.

Table 10. The effects of sulphur (S), boron (B), zinc (Zn) and magnesium (Mg) on the herbage yields of Star grass (cv. No. 2) in kg dry matter per ha during 1967-68 and 1968-69. (Analysis of variance table Appendices 2.15 and 2.16).

Element	1967-68			1968-69		
	Absent	Present	Significant effects	Absent	Present	Significant effects
S	4440	4660	All non	8270	9710	S **
B	4380	4770	significant	8790	9330	
Zn	4650	4460		8850	9290	
Mg	4550	4570		8810	9320	
S E ±	270			610		
Coefficient of variation %	16,9			19,2		

The F-test (Appendix 2.15) revealed that in 1967-68 the four minor elements had no effect on the herbage yields of Star grass when applied separately or in all their combinations. In 1968-69 however, sulphur had a significant effect ($P < 0,01$) on herbage yields, increasing the yield from 8 270 kg per ha without sulphur to 9 710 kg per ha with sulphur. No other elements or combinations of elements affected yields.

In 1967-68 when little rain fell (Appendix 1) the mean yield over all treatments was 4 560 kg per ha while in 1968-69, a year of average rainfall, it was 9 040 kg per ha.

Discussion

Of the four minor elements applied to Star grass only sulphur affected the growth of the grass, increasing herbage yields by 1 440 kg per ha in the second year. The herbage yield with sulphur was 9 710 kg per ha in this year.

On the silty clay soils on Henderson Research Station herbage yields of Star grass which received similar amounts of fertilizers during the same two years were much higher than those obtained in this experiment. Yields of 14 690 kg and 19 830 kg dry herbage were harvested from Star grass on the silty clay in 1967-68 and 1968-69, respectively (Section 4.1.1).

The differences in herbage yields of Star grass on the granite sands and on the silty clays during 1967-68 and 1968-69 shows that despite the effect of sulphur on herbage production on the sands in 1968-69, herbage yields were still 10 030 and 10 120 kg per ha lower on the sand compared with yields in the silty clay for these two respective years. Clearly, factors other than sulphur were limiting yields on the sands.

It may be argued that silty clay soils are inherently more fertile than granite sands and also have a better moisture holding capacity. Therefore grasses growing in them are therefore likely to produce more herbage. Also, that minor elements other than sulphur, boron, zinc and magnesium might have been deficient although from observations in 1968-69, molybdenum, copper, iron, calcium and manganese had no visible effect on growth of Star grass on granite sand when applied separately or in all their combinations (Rodel and Hopley, 1969).

The fact that adequate amounts of nitrogen, phosphate and potash were applied for grass growth and that there were apparently no minor element deficiencies other than sulphur which increased herbage yields by 17,4 % in the second year, shows that factors other than nutritional ones were probably responsible for the low herbage yields. However, no indication of what these factors were likely to be were given by the results of this experiment.

4.1.5 The influence of soil fumigation on herbage yields of grasses

Experimental results in 1967-68 showed that fumigating the soil with ethylene di-bromide to control plant parasitic soil nematodes increased yields of cotton growing on granite sand (Rodel, 1968a). The increase in yield of cotton due to fumigation was equivalent to the effect of applying 11,2 kg fertilizer borate per ha. But where boron was applied and the soil fumigated, the effects were not additive.

However, if fumigation increased cotton yields by controlling plant parasitic nematodes it was not unreasonable to suppose that it could do the same for grasses. Furthermore, it was known from the work of Daulton (1965) that certain grasses were resistant to the root-knot nematode, Meloidogyne javanica, and that Cynodon aethiopicus (cv. No. 2 Star) was a host. Examples of the former were Chloris gayana (cv. Katambora), Eragrostis curvula (cv. Ermelo), Panicum maximum var. trichoglume (cv. Sabi), Paspalum notatum (cv. Paraguay), P. plicatulum (cv. Beehive) and P. guenoarum (cv. Wintergreen) (Daulton, 1965).

Plant parasitic soil nematodes might therefore have affected the growth of Star No. 2 in the experiment described in Section 4.1.4. Whether or not nematodes were implicated might be determined by comparing herbage yields of grasses growing in a similar soil but with one site fumigated with a nematocide and one unfumigated. Complementary microscopic examinations of soil and grass roots would reveal the species and numbers of nematodes present in these media on the two sites.

If it were proved that plant parasitic soil nematodes affected the growth of some grasses and not others, then, clearly, grasses for grazed pastures would be selected from the former group because they would probably be more productive. However, soil fumigation is generally only a temporary measure because in most instances not all the nematodes are killed and survivors reproduce to build up the soil populations again. While this measure of control is suitable for crops of short duration, for example tobacco and vegetables, it would not be as effective for perennial pasture grasses because of its short term effect.

Experimental Objectives

The objectives of this study were to observe whether fumigating the soil with a nematocide would influence the herbage yields of certain grasses grown on granite sand soils. If it was found that soil fumigation did influence yields, then microscopic examination of soil and grass roots would be done to estimate numbers of plant parasitic nematodes present. From the numbers and species of nematodes present some indication would be obtained of whether nematodes did affect grass growth.

Materials and Methods

In January 1970 two adjacent experimental sites of equal area on a well drained granite sand were ploughed. The land had not been cultivated for the last 18 years and supported a sparse cover of indigenous grasses. After ploughing, one site of 16 x 24 m was fumigated with 1 kg methyl bromide per 20 m^2 introduced beneath a plastic sheet covering the soil. The plastic sheet was removed 48 hours after treatment. Following treatment, 90 kg P_2O_5 and 65 kg K_2O per ha were applied to both the fumigated area and an adjacent area of equal size that had not been fumigated.

Eight grass species were then planted on each site, with plants spaced 0,30 x 0,30 m apart in plots 2,74 x 2,74 m. Plots were separated by a clear strip 0,91 m wide. Plants were taken from a heavy clay soil where large herbage yields had been consistently obtained and so the plant material was assumed to be free of nematodes. On each site grasses were replicated three times in randomised blocks to form two separate, but adjacent, experiments. Treatments were not combined into one experiment because of difficulties in fumigating small plots, and to obviate contamination of fumigated plots from adjacent unfumigated plots.

Four of the grasses were believed to be resistant to the root knot nematode, *Meloidogyne javanica*, two were believed to be hosts and the resistance of the remaining two was unknown. The supposedly resistant grasses were *Eragrostis curvula* (cv. Ermelo), *Panicum maximum* var. *trichoglume* (cv. Sabi), *Paspalum notatum* (cv. Paraguay) and *Paspalum guenoarum* (cv. Wintergreen) (Daulton, 1963, 1965). The grasses believed to be hosts were *Cynodon aethiopicus* (cv. No. 2 Star) and *Chloris gayana* (cv. Giant Rhodes)(Daulton, 1950) and the grasses of unknown resistance were *Panicum repens* (cv. Victoria Falls) and *Panicum coloratum* (cv. Bushman Mine).

In October 1970 the grasses were cut to 5 cm, the herbage was removed and topdressings of 90 kg P_2O_5 and 65 kg K_2O per ha were applied to them all. During the 1970-71 growing season 450 kg N per ha was applied to all the grasses in four equal monthly dressings starting on 16 November 1970. In the same season the grasses were cut to 5 cm above ground level each time they reached early anthesis. When a given species was cut in the fumigated experiment it was also cut in the unfumigated experiment. The freshly cut herbage was weighed and the dry matter content determined from oven-dried samples.

During the 1971-72 growing season similar fertilizer treatments were imposed on the grasses in both experiments except that the first topdressings of nitrogen were given on 7 November 1971.

Herbage yields of the grasses in the two experiments were statistically compared by the χ^2 test for treatments x places interactions (Cochran and Cox, 1950) to determine whether soil fumigation affected yields.

Twenty soil samples were taken from each plot with a 2 cm internal diameter soil corer to a depth of 30 cm during February 1971 and again in May 1972. These were bulked for each grass within each experiment. After careful mixing a 200 g sub-sample was extracted using a modified Seinhorst two flask method (Goodey, 1963). The final nematode suspension collected from the Baermann sieves was made up to 100 ml, the number of nematodes in a 20 ml sub-sample counted and the plant parasitic forms identified to genus and the others to broader groups.

To determine root infestation by nematodes four plants were dug up from each plot, the roots were cut off and bulked. The roots were washed, cut into 1 cm lengths, mixed, and then a 2.5 g sample extracted for three days by Young's (1954) root incubation method. The endoparasitic forms were counted and identified to genus level (Shepherd, 1971, 1972).

Rainfall for 1970-71 and 1971-72 was similar both in distribution and amount recorded (Appendix 1).

Results

Herbage yields of the grasses from the fumigated and unfumigated experiments are compared in Table 11.

Table 11. Yields of dry herbage in kg per ha harvested in 1970-71 and 1971-72 from grasses grown in unfumigated soil and in soil fumigated with methyl bromide in 1970. (Analysis of variance tables Appendices 2.17 and 2.18).

Grass	Soil not fumigated		Soil fumigated		Response to soil fumigation	
	1970-71	1971-72	1970-71	1971-72	1970-71	1971-72
Ermelo Love	15 630	9 750	7 940	14 650	- 7 690	+ 4 920
Sabi Panicum	12 720	7 160	14 080	4 810	+ 1 360	- 2 350
Paraguay Paspalum	11 490	15 680	14 350	17 060	+ 2 860	+ 1 380
Wintergreen Paspalum	12 540	10 760	12 220	9 090	- 320	- 1 670
No. 2 Star	13 740	10 300	20 300	15 810	+ 6 560	+ 5 510
Giant Rhodes	18 270	5 330	15 920	3 720	- 2 350	- 1 610
Victoria Falls Panicum	11 120	6 590	18 130	16 760	+ 7 010	+10 150
Bushman Mine Panicum	10 750	10 670	22 570	13 130	+11 820	+ 2 460
Means	13 280	9 530	15 690	11 860	+ 2 410	+ 2 350
SE ±	940	1 270	930	830		
LSD P = 0,05	2 860	3 850	2 510	2 530		
P = 0,001	5 520	7 740	4 850	4 870		

Significant effects between unfumigated and fumigated sites

Yields unfumigated soil vs yields fumigated soil.
1970-71 $\chi^2 = 153$ with 4 d.f. ($P < 0,001$)
1971-72 $\chi^2 = 67$ with 4 d.f. ($P < 0,001$)

Yields of Paraguay Paspalum, No. 2 Star, Victoria Falls Panicum and Bushman Mine Panicum were greater in both years on the fumigated site than on the unfumigated site, though the increase was relatively small for Paraguay Paspalum and Bushman Mine Panicum in the second year. Although yields of Sabi Panicum from the fumigated site were greater in the first year than from the unfumigated site, they were 2 350 kg per ha lower in the second year. Yields from the fumigated site dropped from 14 080 kg in the first year to 4 810 kg per ha in the second year.

In both years yields of Wintergreen Paspalum from unfumigated soil were greater than from the fumigated soil, but the differences were not great. Although herbage yields of Giant Rhodes were greater on unfumigated soil in both years, yields on untreated and treated soil were considerably smaller in the second year.

Ten genera of plant parasitic nematodes were identified from the soil extractions (Table 12).

Soil fumigation markedly reduced the numbers of parasitic nematodes present in the soil. In 1971 the mean number of nematodes in soil from the fumigated plots was only 14 nematodes per 200 g of soil while there were 206 nematodes per 200 g of soil from unfumigated plots. In 1972 there were 169 and 384 nematodes per 200 g of soil from fumigated and unfumigated plots, respectively. By 1972 the numbers of Pratylenchus sp. had recovered in some grass plots on fumigated soil. Pratylenchus sp. also was the most numerous and widely distributed nematode, although only few were found in the unfumigated Paraguay Paspalum plots and it was not found in the fumigated plots of this grass. Between the 1971 and 1972 samplings there was a two-fold increase in the numbers of this nematode in the unfumigated soil and a sixteen-fold increase in the fumigated soil.

Only Pratylenchus sp. was found in the root samples inspected in 1971. Some other parasitic nematodes were found in 1972 but they were present in very small numbers and were probably of little consequence (Table 13).

Table 12. Estimated numbers and genera of plant parasitic nematodes in 200 g soil samples from unfumigated and fumigated grass plots.

Plant parasitic nematode genus	Year	GRASS CULTIVAR: Ermelo Love NF	F	Sabi Panicum NF	F	Paraguay Paspalum NF	F	Wintergreen Paspalum NF	F	Star NF	F	Giant Rhodes NF	F	Victoria Falls Panicum NF	F	Bushman Mine Panicum NF	F	Means all grasses NF	F
Tylenchorhynchus	1971	25				25	15			10		20		55		145	10	33	3
	1972	50		5			40	410			10		10	55		35		69	8
Meloidogyne	1971											45						6	0
	1972	25				5				25		100				55		26	0
Scutellonema	1971	65		85		35		15		55		85		80		40		48	0
	1972	85		45		5				65		135		80		55		59	0
Helicotylenchus	1971			5														1	0
	1972							180			5	5		25		10		28	1
Pratylenchus	1971	80	15	130	10	5		85	10	50		140	20	25	5	60	20	72	10
	1972	210	130	335	175	5		220	330	110	150	160	280	55	5	200	205	163	139
Rotylenchulus	1971					10				25		45	5					10	1
	1972	10		20		50	15	70				5		15				21	2
Criconemoides	1971	25				5				15		15		25		15		13	0
	1972	15		5						15				5				5	0
Longidorus	1971	5				20				5		20						6	0
	1972																		
Xiphinema	1971							5				20		5				4	0
	1972							15				25		30		5		9	0
Trichodorus	1971	5		15		10		15		25		10		5		20		13	0
	1972					5		25										4	0
Total number of parasitic nematodes	1971	205	15	175	10	110	15	120	10	165	0	400	25	195	5	280	30	206	14
	1972	395	130	410	175	70	55	920	330	215	165	430	290	275	5	360	205	384	160
Total number of plant parasitic and non-parasitic nematodes	1971	595	115	855	275	315	140	635	230	580	335	815	210	565	400	785	240	643	243
	1972	1200	445	1505	375	610	370	1640	640	720	500	850	535	430	120	850	850	976	479

Note : NF - Soil not fumigated
F - Soil fumigated with methyl bromide

Table 13. Numbers of Pratylenchus sp. found in 2,5 g of roots of grasses grown in unfumigated soil and in soil previously fumigated with methyl bromide.

Grass	Unfumigated soil		Fumigated soil		Response to fumigation	
	1971	1972	1971	1972	1971	1972
Ermelo Love	115	15	65	60	- 50	+ 45
Sabi Panicum	240	45	70	41	- 170	- 4
Paraguay Paspalum	15	5	0	0	- 15	- 5
Wintergreen Paspalum	115	35	0	230	- 115	+ 155
No. 2 Star	70	40	0	60	- 70	+ 20
Giant Rhodes	1 500	205	0	255	-1 500	+ 50
Victoria Falls Panicum	135	10	0	0	- 135	- 10
Bushman Mine Panicum	145	100	25	200	- 120	+ 100
Totals	2 335	455	180	846	-2 155	+ 391
Means	292	57	23	106	- 269	+ 49

In 1971 Pratylenchus sp. infested the roots of all eight grasses in unfumigated soil and of only three grasses in fumigated soil, and from these three grasses considerably fewer Pratylenchus nematodes were recovered than from the same grasses on the unfumigated site.

In 1972 fewer Pratylenchus sp. were extracted from the roots of grasses from the unfumigated site, than in 1971, especially from Giant Rhodes. In the fumigated site, over the two years, the roots of Paraguay Paspalum and Victoria Falls Panicum remained uninfested, the roots of Wintergreen Paspalum, No. 2 Star and Giant Rhodes became infested, and the roots of Ermelo Love, Sabi Panicum and Bushman Mine Panicum remained infested. The numbers in the roots of Bushman Mine Panicum had increased eight-fold.

Discussion

Eriksson (1972) reviewed the knowledge of effects of plant parasitic nematodes on pasture grasses and the economic losses that might be expected from infestations of different nematodes. He noted that various authors had reported grass herbage losses of 25 to 70 % due to nematode damage.

Boyd, Schroder and Perry (1972) found that Belonolaimus spp., Trichodorus spp., Pratylenchus spp., Meloidogyne spp., Criconemoides spp., Helicotylenchus spp., Hoplolaimus spp. and Tylenchorhynchus spp., are commonly associated with forage grasses in the United States. In greenhouse trials they found that damage to roots of grasses varied with temperature and the nematode present.

More recently Hoveland, Rodriguez-Kabana and Berry (1975) studied the effects of treating fine sand with methyl bromide and carbofuran on the growth of the grasses Festuca arundinacea and Phalaris aquatica. They reported that in the second year herbage yields of F. arundinacea were increased by 107 % on sand treated with methyl bromide and by 39 % on sand treated with carbofuran while yields of P. aquatica were increased by 348 and 172 %, respectively. However, populations of Trichodorus christiei Tylenchorhynchus claytonis and Hoplolaimus galeatus increased in the soil during the second year but thereafter numbers of these nematodes declined. The nematodes destroyed the grass roots below 10 cm and stand losses occurred during drought. The authors concluded that the susceptibility of the grasses to nematodes contributed significantly to the poor performance of the two grasses but that other soil pathogens may also have had a damaging effect.

In this experiment rainfall was similar in distribution and amount in both years and was adequate for grass growth (Appendix 1). Thus the differences in grass herbage yields in 1970-71 and 1971-72 are not likely to have been caused by rainfall. In addition, amounts of nitrogen, phosphorus and potash applied were also similar in both years, and results from previous experiments indicated that minor elements were present in sufficient quantities for grass growth (Section 4.1.4).

The results suggest that the increased grass herbage yields in 1971 from the fumigated site might have been due to a reduction in the size of the plant parasitic nematode population as a result of soil treatment (Tables 11 and 12). The mean number of plant parasitic nematodes in soil from fumigated plots was 14 nematodes per 200 g of soil (range 0 to 30) while in soil from unfumigated plots the mean number was 206 nematodes per 200 g of soil (range 110 to 400). The mean herbage yield of the grasses on fumigated plots was 18 % higher than that of grasses on unfumigated plots (Table 11). This was despite the fact that fumigation had an adverse effect on the yield of Ermelo Love grass which reduced the mean yield of the grasses on fumigated plots.

The mean herbage yield of all grasses on fumigated plots decreased from 15 690 kg per ha in 1971 to 11 880 kg per ha in 1972 (Table 11). During the same time plant parasitic nematodes increased from 14 to 168 nematodes per 200 g of soil (Table 12). On unfumigated plots herbage yields declined from 13 280 kg per ha in the first year to 9 530 kg per ha in the second and there was a corresponding increase in numbers of nematodes from 206 to 384 per 200 g of soil.

There were three apparent instances of the relationship between the mean herbage yields of the grasses and the mean number of parasitic nematodes present in the soil.

(i) On fumigated plots the mean herbage yields of grasses were greater and the nematode population lower than on unfumigated plots in both years.

(ii) On fumigated plots herbage yields of the grasses were smaller in the second year compared with the first, while the nematode populations had increased.

(iii) On unfumigated plots herbage yields of the grasses were also smaller in the second year as compared with the first, and the nematode population had also increased

The relationships between the changes in herbage yields of the grasses and the changes in soil nematode population between years are illustrated in Figure 12.

There were three exceptions to the association between the changes in herbage yields and nematode populations and in all three cases there are possible explanations.

Firstly, on fumigated soil Ermelo Love grass produced considerably more herbage in the second year compared with the first, despite an increase in nematode numbers. In the first year growth on this grass on fumigated plots was adversely affected by methyl bromide (Rodel and Shepherd, 1972). By the second year this effect had apparently disappeared and consequently the grass grew more vigorously and produced more herbage. Methyl bromide has been observed to have similar adverse effects on the growth of plants other than grasses (Laver, 1967 ; Richards, 1970).

Secondly, the herbage yield of Paraguay Paspalum increased on treated soil despite a small increase in numbers of nematodes. On untreated soil there was a small decrease in nematode numbers and a correspondingly greater increase in herbage yield. It is known that this grass is resistant to <u>Meloidogyne javanica</u> (Daulton, 1963). The fact that herbage yields increased on both treated and untreated soil in the second year indicates that Paraguay Paspalum might be resistant to other nematodes as well.

Thirdly, herbage yields of Victoria Falls Panicum on untreated soil decreased and there was a corresponding increase in nematode numbers. On treated soil, nematode numbers remained the same but there was a small decrease in herbage yield. While the numbers of nematodes in treated soil were the same in both years they might have been present in sufficient numbers to damage the grass roots and therefore cause lower herbage yields.

The numbers of <u>Pratylenchus</u> sp. found in the roots of the grasses in 1971 in both unfumigated and fumigated plots substantiates the arguments already outlined. However, in 1972 despite a decrease

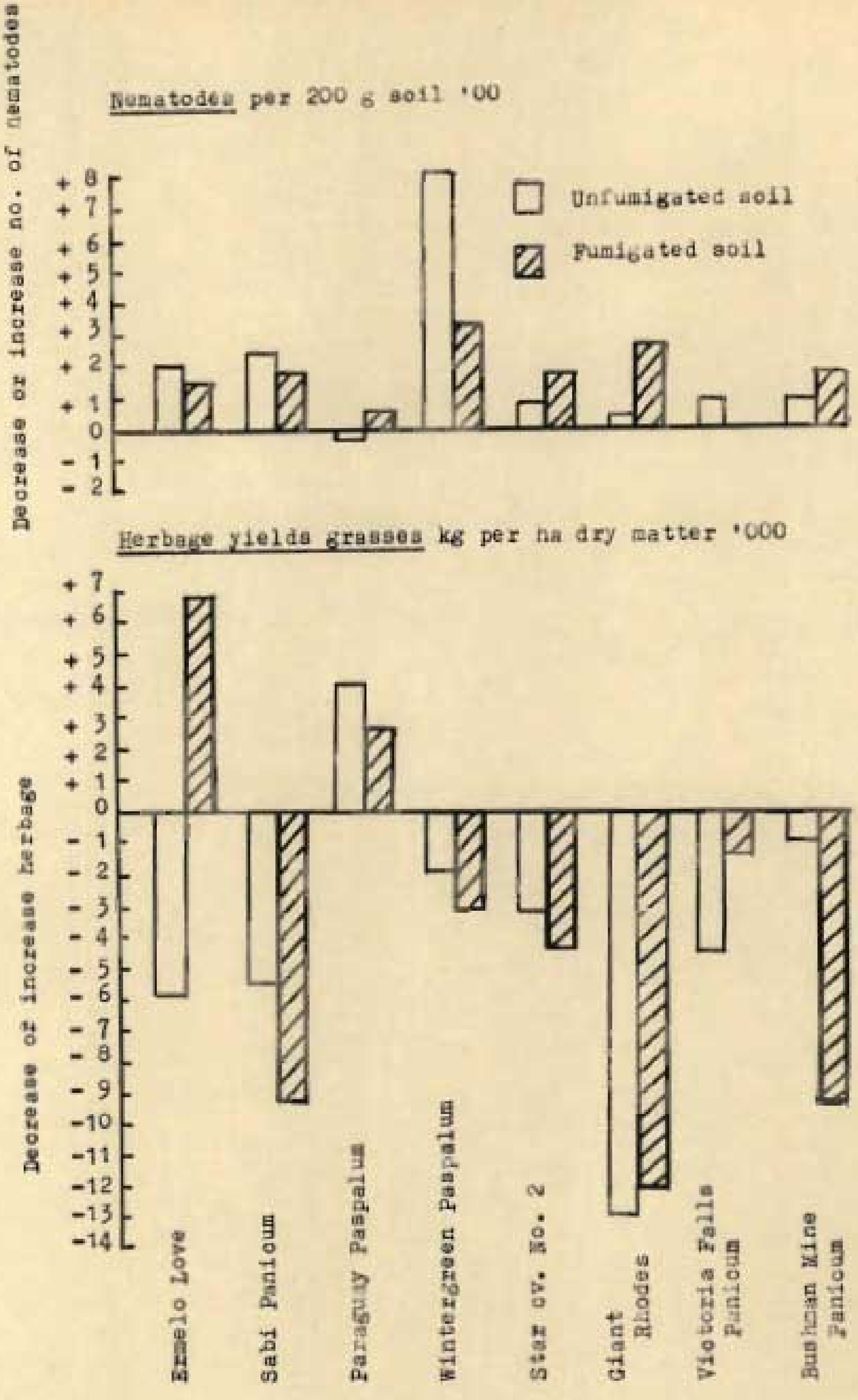


Figure 12. Differences in herbage yields of grasses and in numbers of plant parasitic nematodes in soil between 1971 and 1972.

in nematode numbers in the roots of grasses on unfumigated plots, herbage yields were lower than in the first year. On fumigated plots an increase in nematode numbers in the grass roots was again accompanied by a decrease in herbage yields. Pratylenchus sp. was the most numerous plant parasitic nematode found and because of its endoparasitic habit may cause severe root pruning. It is possible that the cumulative effect of this nematode over two years may have reduced the amount of roots and consequently the yield of grasses.

Hoveland, Rodriguez-Kabana and Berry (1975) found that the populations of plant parasitic nematodes increased in the soil up to the second season after treating soil with nematocides and thereafter declined. The results in the present experiment are in agreement with this observation in so far as the soil nematode population increased after fumigation up to the second season. The population in soil from unfumigated plots also increased up to the second season but as no further estimations were made it is not known whether numbers declined thereafter. These authors also observed that nematodes attacked grass roots and caused stand losses. At the end of the second season in the experiment being reported, Sabi Panicum, Giant Rhodes and Victoria Falls Panicum on the unfumigated plots had nearly died out while they persisted on treated plots.

The evidence presented here indicates that there was an association between soil fumigation, plant parasitic nematode population, and grass yields in that, on fumigated soil, nematode populations were smaller and grass yields larger, than on unfumigated soil. While it does not explain why herbage yields on the granite sand were lower than on the silty clay soil in the experiment described under Section 4.1.3, it does indicate a possible reason for the lower yields on the sand. However, further research would be necessary to confirm this.

4.2 Herbage Production, Shoot and Root Mass, Carbohydrates and Crude Protein in Three Grasses of Different Growth Habits

Included in the experiment described in Section 4.1.1 where the herbage yields of 30 grasses were compared, were grasses having either tufted, rhizomatous or stoloniferous growth habits. Upon examination of the results it was found that none of the highest yielding grasses had a tufted growth form. They were either stoloniferous or rhizomatous. The highest yielding tufted grass was Panicum maximum var. trichoglume (cv. Sabi). This grass produced 8 080 kg dry matter per ha compared with 17 890 kg per ha from Panicum coloratum (cv. Bushman Mine) the highest yielding stoloniferous grass, and 14 110 kg per ha from Paspalum notatum (cv. Paraguay) the highest yielding rhizomatous grass. The large differences in herbage yields between these three grasses indicated that an examination of some of the factors linking their growth habit with their yield might explain these large differences. Herbage yield of grasses is dependent upon stored energy and the size of the energy reservoir and this may vary with growth habit.

It is well known that changes take place in the crude protein, total available carbohydrates (TAC) and fibre contents in grasses in relation to growth or regrowth stage, season and treatment. Also it is known that vigour and, therefore, the early productivity of a grass after defoliation is related to the TAC content of the grass, particularly in the roots and stem bases (Weinmann, 1950, 1961; Barnes 1960 a,b, 1961 ; Barnes and Hava, 1963; Steinke and Booysen, 1968; Bartholomew and Booysen, 1969). Furthermore, an analysis of the principles of growth reveal that early productivity is related to subsequent yield. Therefore the apparent differences in herbage yielding ability between the tufted, stoloniferous and rhizomatous grasses might be related to differences in amounts of TAC stored in their roots and stem bases and to the rates at which those amounts are depleted and replenished with growth and with defoliation treatments. A knowledge of such changes during growth and development might explain the differences in the herbage yielding ability of the three grasses with different growth habits and also provide a basis for developing sound management principles for them. Accordingly an experiment was done on the three grasses with different growth habits.

Experimental Objectives

The primary objective of this work was to compare three grasses of different growth habits in terms of

(i) herbage production,
(ii) root and stem base mass,
(iii) crude protein content of herbage, roots and stem bases,
(iv) TAC contents of roots and stem bases, and
(v) the seasonal changes in the foregoing and the effects of various defoliation treatments on them.

Materials and Methods

Panicum maximum var. trichoglume (cv. Sabi) which has a tufted growth habit, Panicum coloratum (cv. Bushman Mine) which has a stoloniferous growth habit and Paspalum notatum (cv. Paraguay) which has a rhizomatous growth habit, were selected for the experiment. It is acknowledged that these grasses may not be the most productive examples of each of the three growth habit categories but they were the three highest yielding grasses in the experiment described in Section 4.1.1 representing each of the growth habits.

The grasses were established vegetatively during the 1970-71 growing season in plots measuring 23,8 x 5,5 m in three replications of a randomised blocks design. The plots were later sub-divided across their length to accommodate the various treatments and measurements. By the 1971-72 growing season the grasses were well established and received 450 kg N, 90 kg P_2O_5 and 55 kg K_2O in this season. The phosphate and potash were applied during October 1971 while the nitrogen was applied in four equal monthly dressings starting on 17 November 1971.

In all cases herbage yields were estimated by cutting 1 m^2 quadrats to 5 cm above ground level. The herbage was weighed and the dry matter content determined from oven-dried samples. After cutting quadrats all the herbage in the plot was cut to 5 cm and removed except where growth was allowed to accumulate unchecked. The crude protein content of the herbage was determined by the Kjeldahl method.

The roots and stem bases of the grasses were sampled by driving a metal cylinder 15,24 cm long with 15,88 cm internal diameter into the top-soil until the top of the cylinder was level with the soil surface. Before sampling, all free aerial stems were cut low so as to leave only their bases intact. Therefore the rhizomes of Paraguay Paspalum, which grow on the soil surface were included with the root and stembase component, whereas the stolons of Bushman Mine Panicum were excluded. The stolons of Bushman Mine Panicum generally die off during the dry season and plants regenerate themselves from previously rooted nodes. For this reason the stolons were excluded because they were unlikely to be important storage organs in this grass. In the case of Sabi Panicum the cylinder was sited so that a tuft, approximately half the diameter of the cylinder, was enclosed. For Bushman Mine Panicum and Paraguay Paspalum the cylinder was placed over an area uniformly covered by the grass mat. Two such cylindrical soil samples were taken within the 1 m^2 quadrats used to measure herbage production. The soil samples were taken at, or just above, soil level after stems had been cut off at their bases.

When removed from the cylinder the soil cores were immersed in water until the soil was saturated. The coarse roots and stem bases were then separated from the soil by washing over a 5,5 mm sieve held over an elutriator as described by Barnes (1966a).

The fine roots that passed through the sieve with the soil were recovered by flotation and washing in the elutriator.

Before being analysed for their TAC contents, the roots and stem bases were killed by autoclaving for five minutes at 34,5 kPa pressure, then dried at 45°C and weighed. The material was then ground and stored in air-tight bottles. The TAC contents of the roots and stem bases were later estimated by the method used by Weinmann (1947) except that clarase and not takadiastase was used in the digestion process (Weinmann, 1961; Smith, 1969). The crude protein contents of the roots and stem bases were determined by the Kjeldahl method.

Each large plot measuring 23,8 x 5,5 m was sub-divided into three plots measuring 7,4 x 4,4 m. These plots were allocated at random to one of three treatments.

(i) One plot was used to measure the undisturbed growth of the grasses by harvesting 1 m^2 quadrats serially at monthly intervals for a year starting on 13 November 1971. Immediately following the monthly harvests two cylindrical soil samples were taken within the quadrat area for determining root and stem base mass.

(ii) One plot was used to measure the herbage yields of the grasses when defoliated infrequently. This was achieved by cutting whenever the grass reached early anthesis. For determining root and stem base mass, two cylindrical soil samples were taken within the quadrat area immediately after the herbage was cut. Harvesting of the herbage was done between 13 November 1971 and mid-April 1972, by which time growth had become negligible.

(iii) One plot was used to measure the herbage yielding ability of the three grasses under severe defoliation. This was done by cutting them at three-weekly intervals throughout the growing season lasting from 13 November to mid-April 1972. For determining root and stem base mass, soil samples were taken as in (ii).

As already stated plots were replicated three times and statistical analyses were done where possible.

During the 1971-72 growing season 901 mm of rain fell which was well distributed (Appendix 1).

Results

(i) Changes in the undisturbed growth of three grasses

The changes in herbage mass and crude protein content of the three grasses over the year are shown in Figure 13.

At all times Bushman Mine Panicum accumulated more herbage than the other two grasses attaining a maximum in mid-April. For about six weeks after mid-April the amount of standing Bushman Mine Panicum herbage decreased after which it remained at approximately the same level until early October when it began to accumulate again.

Sabi Panicum and Paraguay Paspalum accumulated similar amounts of herbage which were at near maximum by the end of February. For nine weeks after this there was little change in the amount of herbage of both grasses when amounts decreased to the end of May. Thereafter amounts of standing herbage remained at approximately the same levels until late September when herbage began to accumulate again.

The crude protein content in the herbage of all three grasses decreased in the manner normally expected in undisturbed growth. That is, as the herbage became more mature as the season advanced so the crude protein content became less. Early in the growing season it was on average 19,4% of the dry matter of the three grasses, by the end of the growing season it was 14,0% and in mid-dry season in July it was 8,5%. From the beginning of February onwards the level of crude protein in Bushman Mine Panicum herbage was lower than that in the herbage of Sabi Panicum and Paraguay Paspalum.

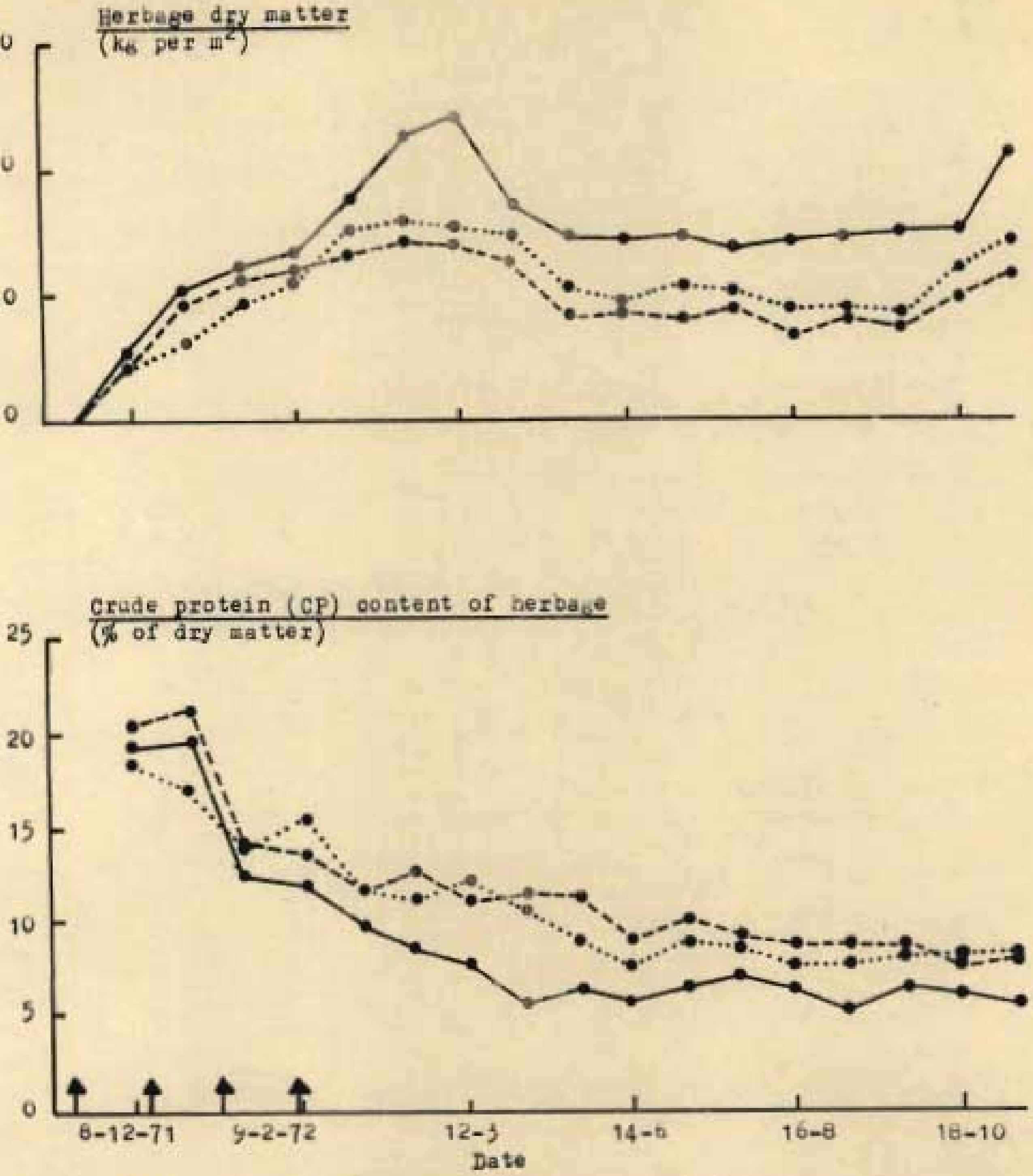


Figure 13. Amount of herbage in the undisturbed growth over one year of three grasses and the crude protein content of the herbage.

.... Paraguay Paspalum (rhizomatous)

------ Sabi Panicum (tufted)

——— Bushman Mine Panicum (stoloniferous)

↑ Dates when 112 kg N per ha applied

The seasonal changes in the mass of roots and stem bases and of the total available carbohydrates (TAC) and crude protein content of roots and stem bases from three grasses allowed to grow undisturbed for one year, are shown in Figure 14.

Although the mass of roots and stem bases per unit volume of top-soil fluctuated from one sampling to another in all three grasses, probably due to sampling error, the overall variation was relatively small. The mean masses of roots and stem bases per unit volume of top-soil were 55,2; 67,9 and 41,9 g for Paraguay Paspalum, Sabi Panicum and Bushman Mine Panicum, respectively.

Changes in the TAC contents in the roots and stem bases varied between grasses and as the season progressed. The TAC content of Paraguay Paspalum remained at a relatively high level throughout the year compared with those of the other two grasses, particularly Sabi Panicum, and had a mean value of 12,1%. However, there was a fall-off in TAC content in Paraguay Paspalum from the end of December to mid-February after which it increased again reaching a maximum of 16,2% in July.

In Sabi Panicum and Bushman Mine Panicum there were definite seasonal trends in TAC content of roots and stem bases. In both grasses the TAC content was at a low level during the growing season and ranged from 1,0 to 4,4% of the dry matter. From the end of the growing season in mid-April to the end of May, there was a very marked increase in the TAC content in the roots and stem bases of Bushman Mine Panicum. The content then remained at a relatively high level ranging from 7,4 to 10,4% of the dry matter for the remainder of the dry season, with an apparent slight fall-off during October with the approach of the new growing season. In Sabi Panicum the increase in TAC content did not occur until mid dry season in July and the increase was small, relative to the increase in Bushman Mine Panicum.

The crude protein contents in the roots and stem bases of all three grasses were similar and remained at similar levels

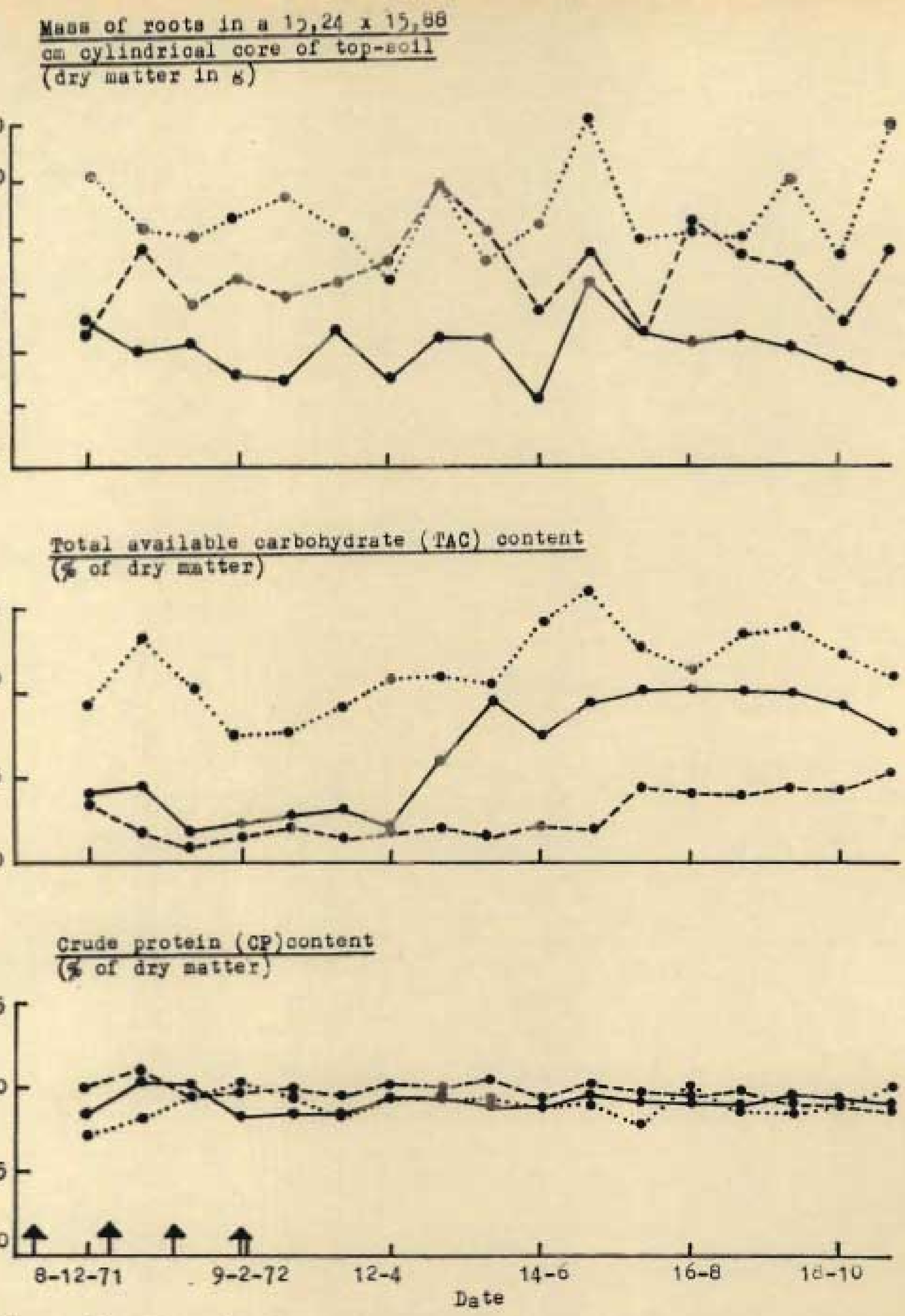


Figure 14. Mass of roots and stem bases in a cylindrical core of top-soil, and total available carbohydrates and crude protein content of roots and stem bases, from three grasses allowed to grow undisturbed for one year .

·········· Paraguay Paspalum (rhizomatous)

------ Sabi Panicum (tufted)

——— Bushman Mine Panicum (stoloniferous) throughout the year except for a slight increase soon after the start of the growing season. The mean crude protein contents in the roots and stem bases were 10,1; 9,4 and 9,8% of the dry matter for Sabi Panicum, Bushman Mine Panicum and Paraguay Paspalum, respectively.

(ii) Herbage yields and changes in the herbage, roots and stem bases of three grasses cut at early anthesis

The total herbage yields of the three grasses cut whenever they reached early anthesis, crude protein content of herbage, root and stem base mass, crude protein and TAC content of roots and stem bases, are shown in Figure 15.

All three grasses reached early anthesis on three occasions during the growing season when their herbage was harvested. Bushman Mine Panicum produced significantly more herbage ($P < 0,01$) than Sabi Panicum.

The mean crude protein contents in the herbage were 15,4; 15,7 and 16,2% in the dry matter of Bushman Mine Panicum, Paraguay Paspalum and Sabi Panicum, respectively. The variation in crude protein content in Bushman Mine Panicum herbage was greater than in the other two grasses.

The mass of roots and stem bases per unit volume of top-soil of the three grasses tended to increase from the first to the second harvests and then to decrease to the third harvest. This indicates that treatment affected the mass of roots and stem bases of the three grasses per unit volume of top-soil and that the effect was more marked in Bushman Mine Panicum and Paraguay Paspalum than in Sabi Panicum. Paraguay Paspalum had a greater ($P < 0,05$) mean mass of roots per unit volume of top-soil than either Bushman Mine Panicum or Sabi Panicum.

The crude protein contents in the roots and stem bases of the three grasses were similar throughout the growing season, the mean contents being 3,14; 3,14 and 3,28% of the dry matter for Paraguay Paspalum, Bushman Mine Panicum and Sabi Panicum,

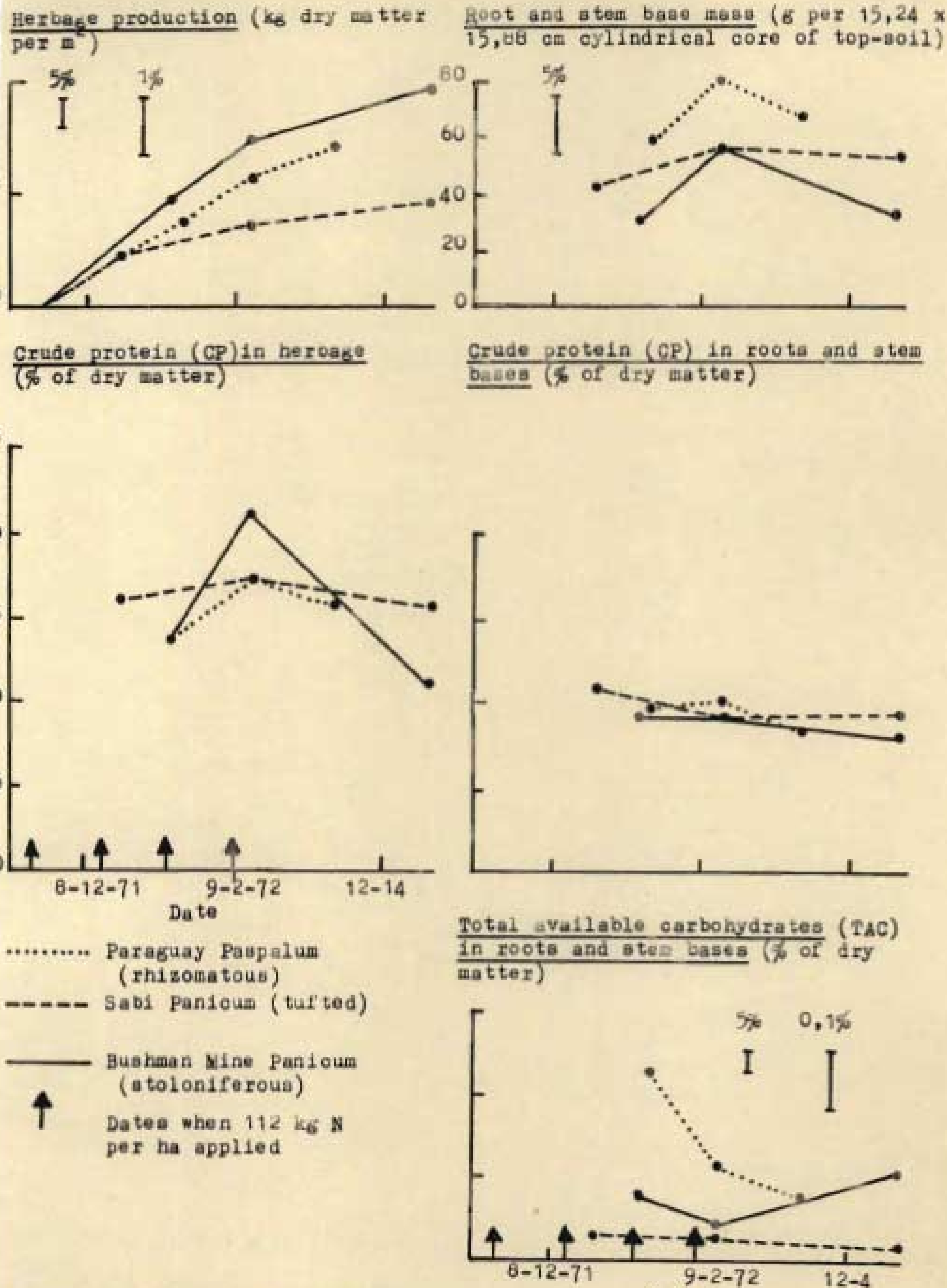


Figure 15. Effects of cutting three grasses at early anthesis on their herbage, stem base and root masses, crude protein contents of herbage, roots and stem bases, and total available carbohydrates in roots and stem bases, during the 1971-72 growing season. (Analysis of variance tables Appendices 2.19; 2.20; 2.21; 2.22; and 2.2[illegible]

The TAC content in the roots and stem bases followed different patterns between harvests and there were large differences in content at the first harvest. At first harvest the TAC content in the roots and stem bases was 11,4% in Paraguay Paspalum, 3,9% in Bushman Mine Panicum and 1,4% in Sabi Panicum. Thereafter the TAC content in Paraguay Paspalum decreased markedly between harvests, that in Bushman Mine Panicum decreased slightly between the first and second harvests and then increased again by the third harvest, while in Sabi Panicum it remained at a similar level throughout. There was a greater ($P < 0,001$) mean amount of TAC (7,1%) in Paraguay Paspalum roots and stem bases than in the other two grasses while Bushman Mine Panicum had more ($P < 0,01$; 3,9% TAC) than Sabi Panicum (1,2% TAC).

(iii) Herbage yields and changes in the herbage, roots and stem bases of three grasses cut at three-weekly intervals during the growing season

The effects of cutting the three grasses at three-weekly intervals during the growing season on herbage production, crude protein content of herbage, root and stem base mass, crude protein and TAC contents of roots and stem bases, are shown in Figure 16.

The grasses were all cut seven times between 17 November 1971 and 12 April 1972.

Paraguay Paspalum yielded 1,9 kg dry matter per m^2 over the growing season while Bushman Mine Panicum and Sabi Panicum both produced 1,4 kg per m^2. The differences were not significant. For the first two harvests Bushman Mine Panicum produced more herbage than Paraguay Paspalum but thereafter the reverse obtained.

The crude protein contents in the herbage of the grasses when cut at three-weekly intervals (Figure 16) were generally, but not unexpectedly, higher than where the grasses were cut at early anthesis (Figure 15). Sabi Panicum herbage contained a mean of

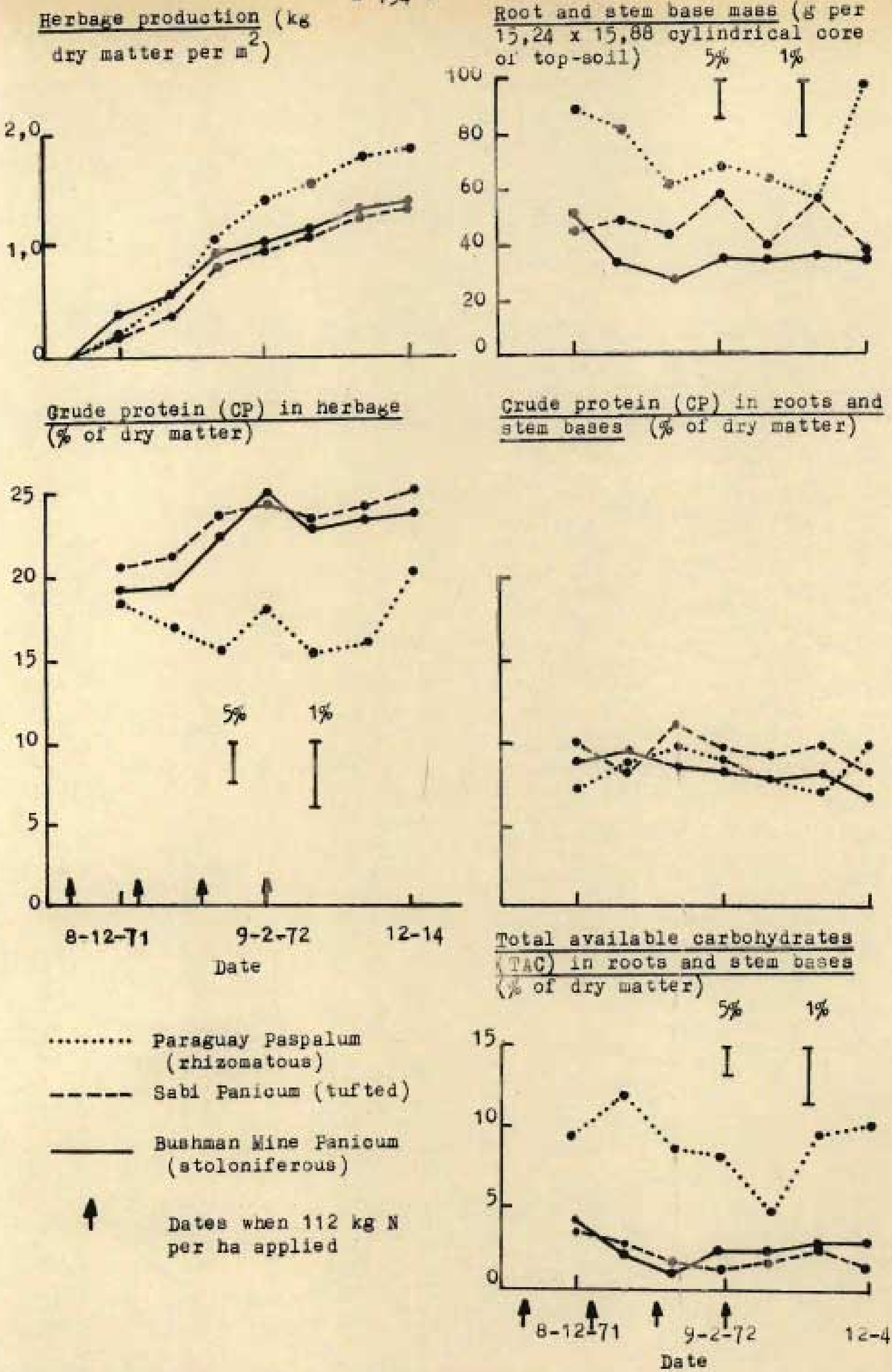


Figure 16. Effects of cutting three grasses at three-weekly intervals on their herbage, root and stem base masses, crude protein contents of herbage, roots and stem bases, and total available carbohydrates in roots and stem bases during 1971-72 growing season. (Analysis of variance tables

23,2% crude protein, Bushman Mine Panicum 22,7% and Paraguay Paspalum 17,3% of the dry matter. The former two grasses contained significantly more ($P < 0,01$) crude protein than the latter grass.

Paraguay Paspalum again had the greatest mean mass of roots and stem bases per unit volume of top-soil (76,6 g per unit volume) which was greater ($P < 0,01$) than the other two grasses. Sabi Panicum had a greater ($P < 0,05$) mean root and stem base mass (48,9 g per unit volume of top-soil) than Bushman Mine Panicum (35,8 g per unit volume of top-soil). The root and stem base mass per unit volume of top-soil of Paraguay Paspalum decreased over the first six, three-weekly samplings and then increased. There was some variation in the root and stem base masses per unit volume of top-soil of Sabi Panicum, the third and fifth samplings being higher than the others. The root and stem base mass per unit volume of top-soil decreased over the first three samplings and then increased slightly at which level it remained for the rest of the sampling period. The pattern of variation in the mass of roots and stem per unit volume of soil was however, very similar to the variations obtained over the same period (8 December 1971 to 12 April 1972) where the grasses were allowed to grow undisturbed (Figure 14). This indicates that the variations were true and were not due to sampling error.

The crude protein content of the roots and stem bases of the three grasses were very similar over the sampling period, and also very similar to those obtained over the same period where grasses were allowed to grow undisturbed (Figure 14). The mean crude protein levels in the roots and stem bases were 9,6; 8,5 and 8,1% of the dry matter for Sabi Panicum, Paraguay Paspalum and Bushman Mine Panicum, respectively.

The mean TAC contents in the dry roots and stem bases of Paraguay Paspalum, Sabi Panicum and Bushman Mine Panicum were 9,0; 2,3 and 2,5% respectively; the value for Paraguay Paspalum being significantly greater ($P < 0,001$) than the values for the other two grasses. The variations in TAC content in the roots and stem bases of Sabi Panicum and Bushman Mine Panicum over the sampling period were small but with Paraguay Paspalum large differences occurred. During the first three-week period the TAC content in this latter grass increased and then it decreased markedly until late February and thereafter increased again to the end of the harvesting period despite the intense defoliation treatment. A comparison of the TAC contents in the roots and stem bases of all three grasses where they were allowed to grow undisturbed (Figure 14) and where they were harvested at three-weekly intervals (Figure 16), shows that they were similar both in amount and in the patterns of increases and decreases in content over the period 6 December 1971 to 12 April 1972. This was despite the fact that in the first case grasses were allowed to grow naturally whereas in the latter they were subjected to a severe defoliation treatment.

Discussion

Sabi Panicum, Bushman Mine Panicum and Paraguay Paspalum were used in this study because of their different growth habits which may be related to their herbage yielding abilities as indicated by the results of the experiment reported in Section 4.1.1. It was possible that the relationship between their herbage yielding abilities and growth habit might be explained by the amounts of TAC in the roots and stem bases of the different growth forms and that the seasonal patterns of depletion and replenishment of these might be affected by different defoliation treatments.

The results show that there were marked differences between the grasses in amounts of TAC present in their roots and stem bases and in the seasonal trends of TAC. Although there were various increases and decreases in the TAC content of the rhizomatous grass Paraguay Paspalum when it was allowed to grow for a year, there was no definite trend and the content remained at a relatively high level throughout. Weinmann and Goldsmith (1948) found that there were also no definite trends with a rhizomatous cultivar of Cynodon dactylon, and Barnes (1960a) found no definite trends with the stoloniferous grass Cynodon aethiopicus (cv. No. 2 Star). However, in the experiment being reported there were definite seasonal trends with the stoloniferous grass Bushman Mine Panicum and with the tufted grass Sabi Panicum. Therefore grasses with the same growth habit, for example Bushman Mine Panicum and Cynodon aethiopicus (cv. No. 2 Star), do not necessarily have similar seasonal trends in reserves. The seasonal trends in TAC content in Sabi Panicum in this study was similar to that found by Barnes (1960 a) but the increase in content occurred in mid-dry season and not in the early-dry season.

Where the grasses were cut at early anthesis (Figure 15) the ranking in yield was the same as that observed in the experiment described in Section 4.1.1. (Bushman Mine Panicum again produced most herbage followed by Paraguay Paspalum and then Sabi Panicum). However, when the grasses were harvested at three-weekly intervals, Paraguay Paspalum produced most herbage with Sabi Panicum and Bushman Mine Panicum producing similar, but lower yields (Figure 16). This result indicates that Bushman Mine Panicum was affected adversely by the more frequent defoliation and its herbage yield was 26,3% less compared with its yield when cut at early anthesis. Furthermore, the TAC content in the roots and stem bases of Bushman Mine Panicum were at a slightly lower level at the end of the three-weekly harvesting period compared with the level where it was harvested at early anthesis (Figures 15 and 16).

In contrast Paraguay Paspalum appeared to be adversely affected by being harvested at early anthesis as its herbage yield was 24,2% less when cut at early anthesis (Figure 15), compared with the yield when harvested at three-weekly intervals (Figure 16). The TAC content in the roots and stem bases decreased sharply where Paraguay Paspalum was cut at early anthesis (Figure 15), but although the trend was similar where it was cut at three-weekly intervals, the fall-off was not as great and the content recovered again towards the end of the harvesting period (Figure 16). Ideally, a grass should have a high TAC content in the roots and stem bases at the beginning of the growing season so that it can draw on these for rapid growth and development.

When this occurs the TAC content would be expected to fall, which is acceptable provided the TAC content is restored to a high level by the end of the growing season. This definitely occurred in Bushman Mine Panicum and in Sabi Panicum. It apparently also occurred in Paraguay Paspalum as there was a rise in TAC content from mid-to-late growing season. However, this was not so obvious in this grass as it was in the other two grasses. Where the grasses were cut at early anthesis only Bushman Mine Panicum showed any increase in TAC content at the end of the season while only Paraguay Paspalum showed any increase where the grasses were cut at three-weekly intervals (Figures 15 and 16).

There were marked differences between grasses in the mass of roots and stem bases per unit volume of top-soil with the method of sampling used. The roots and stem bases were not separated. Therefore the relatively large mass of roots and stem bases for Paraguay Paspalum was probably due to a large proportion of rhizomes in the samples. For this reason and because only a small part of the root systems of the grasses were sampled these results must be treated with reserve.

While the experimental results show that there were marked differences between the three grasses with different growth habits they do not explain the differences in their herbage yielding abilities. Clearly any studies of this nature should include the whole plant, both below and above ground, and besides measuring herbage production, root and stem base mass and the TAC content of these, the efficiency of the photosynthetic tissue should also be studied.

4.3 The Effects of Grazing on Grasses

4.3.1 Preliminary observation trials

Before 1963 it had been found at Henderson Research Station that Chloris gayana (cv. Giant Rhodes) pastures fertilized with 100 kg N and 45 kg P_2O_5 per ha had a carrying capacity of 2,5 yearlings per ha during the growing season (Anonymous, 1961, 1962, 1963).

The herbage yields of up to 13 470 kg dry matter per ha obtained by Clatworthy (1967) from Chloris gayana (cv. Giant Rhodes) fertilized with 450 kg N per ha indicated that much heavier stocking than hitherto imposed on grass pastures might be possible. It was reasoned that if a yearling steer consumed approximately 7 kg of dry herbage daily, a herbage yield of 13 470 kg per ha per annum should provide for 1 210 steer grazing days per ha. Therefore 1 ha of pasture should provide the forage requirements for about 12 steers for 100 days during the growing season.

To test this hypothesis well-established pastures of three grasses Chloris gayana (cv. Giant Rhodes), Heckeropsis uniseta (cv. Natal) and Panicum repens (cv. Victoria Falls) were fertilized with 275 kg N and 90 kg P_2O_5 during the 1964-65 growing season. The nitrogen was applied in three equal monthly dressings. The pastures were grazed on a set-stocked basis with 12,50 yearling steers per ha between 16 December 1964 and 16 February 1965 after which growth of grass was negligible because little rain fell (Appendix 1). For this reason a fourth planned dressing of nitrogen was not applied. Despite the short growing season the steers were carried satisfactorily on the pastures (Table 14).

Table 14. Mean body mass gains in kg of yearling steers grazing three grasses fertilized with 275 kg N and 90 kg P_2O_5 per ha and stocked at the rate of 12,36 steers per ha during the 1964-65 growing season.

Grass	Body mass gain kg per steer	Body mass gain kg per ha	Body mass gain kg per steer per day
Giant Rhodes	28,3	350	0,46
Natal Beckeropsis	44,5	550	0,72
Victoria Falls Panicum	67,3	830	1,09

The body mass gain per ha on Victoria Falls Panicum was much greater than any gains recorded in Rhodesia previously. Observations indicated that the pastures withstood the heavy grazing pressure well and Victoria Falls Panicum in particular appeared to become more dense and more vigorous with such treatment.

Further observations were made during the 1965-66 growing season when Giant Rhodes, Victoria Falls Panicum and <u>Cynodon aethiopicus</u> (cv. No. 2 Star) pastures were fertilized with 350 kg N (applied in four equal monthly dressings) and 90 kg P_2O_5 per ha and were continuously grazed on a set-stocked basis by 7,41 and 12,36 yearling steers per ha. Grazing commenced on Victoria Falls Panicum and Star grass on 14 December and on Giant Rhodes on 21 December 1965. Grazing continued until 12 April on the latter grass and to 19 April 1966 on the former two grasses. The body mass gains of steers recorded on the grasses are shown in Table 15.

Table 15. Mean body mass gains in kg of yearling steers grazing at two stocking rates on three grasses fertilized with 350 kg N and 90 kg P_2O_5 per ha during the 1965-66 growing season.

Grass	Stocking rate steers per ha	Body mass gain kg per steer	Body mass gain kg per ha	Body mass gain kg per steer per day
Giant Rhodes	7,41 12,36	86,6 48,1	640 590	0,77 0,43
Star	7,41 12,36	55,6 52,6	410 650	0,44 0,42
Victoria Falls Panicum	7,41 12,36	85,7 78,5	640 970	0,68 0,62

On all three grasses a stocking rate of 7,41 steers per ha proved to be too light and much grass was wasted. A stocking rate of 12,36 steers per ha on Giant Rhodes was clearly too heavy because the gain per steer was much less than the gain per steer at a stocking rate of 7,41 steers per ha. On Star and Victoria Falls Panicum the body mass gain per steer at a stocking rate of 12,36 steers per ha was only marginally smaller than at the stocking rate of 7,41 steers per ha.

During the same growing season (1965-66) 350, 500 and 650 kg N per ha with a basic dressing of 90 kg P_2O_5 per ha, were applied to Giant Rhodes pastures grazed on a set-stocked basis, by 12,36 yearling steers per ha. The object was to observe effects of applying different levels of nitrogen to the pasture on body mass gains. Between 21 December 1965 and 12 April 1966 mean body mass gains on all pastures were similar (560 kg per ha ± 12 kg) regardless of nitrogen level.

The results obtained during 1964-65 and 1965-66 indicated that the application of heavy dressings of nitrogenous fertilizers might have immediate practical application to increase the carrying capacity of farms. Interest in beef cattle on maize farms about this time was increasing and it was clear that carrying capacity of these farms based on veld alone was limited. On many farms there were small areas of pastures of Chloris gayana (cv. Giant Rhodes), Panicum maximum var. trichoglume (cv. Sabi), Eragrostis curvula (cv. Ermelo Love) and Cynodon aethiopicus (cv. No. 2 Star). These grasses were being grown as leys within crop rotations or for hay or grazing purposes. By applying heavy dressings of fertilizers to the existing pastures an immediate impact on carrying capacity might result. Consequently, during 1966-67 and 1967-68 these four grasses and also Cynodon dactylon (cv. Henderson Couch) were heavily fertilized and intensively grazed to observe their suitability for such purposes.

In 1966-67 the grasses received 280 kg N per ha in four equal monthly dressings, and in 1967-68 210 kg N per ha in three equal monthly dressings. The fourth dressing of nitrogen was withheld in 1967-68 because of drought (Appendix 1). In both years 90 kg P_2O_5 per ha were also applied. Star grass was stocked each growing season at the rate of 12,36 yearling heifers per ha and the other grasses were stocked at the rate of 10,30 yearling heifers per ha. Grazing was on a set-stocked basis. The stocking rates were based to some extent on experience with these grasses and also on their herbage yields obtained from concurrent experiments (Section 4.1.1). Body mass gains obtained during the two years are presented in Table 16.

Table 16. Mean body mass gains in kg of yearling heifers grazing five grasses during the 1966-67 and 1967-68 growing seasons.

Grass	Stocking rate heifers per ha	No. of days grazing		Body mass gain kg per head		Body mass gain kg per ha	
		1966-67	1967-68	1966-67	1967-68	1966-67	1967-68
Sabi Panicum	10,30	140	54	67	17	690	180
Ermelo Love	10,30	162	62	80	27	820	280
Giant Rhodes	10,30	84	48	29	15	300	150
Henderson Couch	10,30	148	90	65	29	670	300
Star	12,36	162	97	74	60	910	740

Length of grazing period varied between grasses and between years. In the second year the grazing periods were considerably shorter than the first year because little rain fell (Appendix 1). Consequently, body mass gains in the second year were lower than in the first year.

It was clear from the results that the five grasses varied in their ability to withstand intensive grazing and drought. Star grass was outstanding while Sabi Panicum, Ermelo Love, Giant Rhodes and Henderson Couch had deteriorated considerably by the end of the second season. Point quadrat analyses done at the beginning and end of the 1967-68 season (1 000 points per grass on 0,4 ha, each time) indicated that the basal covers of Sabi Panicum, Ermelo Love, Giant Rhodes and Henderson Couch had decreased by 62,2; 46,5; 64,6 and 75,0 % respectively, during the season. By comparison the basal cover of Star grass had increased by 16,0 % during the same period. As swards deteriorated so weeds, principally Eleusine indica, increased. At the end of the 1967-68 season weeds comprised 15,2; 31,5; 44,8 and 47,4 % of the total basal covers on the Sabi Panicum, Ermelo Love, Giant Rhodes and Henderson Couch pastures, respectively. Only 3,4 % of the total basal cover on the Star grass pasture was weed.

Henderson Couch was badly infested with a smut, Ustilago cynodontis in both seasons. The disease appeared to affect the grass and this might have accounted for the poor results on this grass in comparison with Star.

Clearly, of the four grasses commonly grown by farmers at the time only Star grass was apparently suitable for heavy fertilization and intensive grazing. The results obtained on Star grass showed that it could be used in practice to carry large numbers of cattle on relatively small areas during the growing season. Thus overall carrying capacity of farms could be increased.

Conclusions from the preliminary observations trials

From the observational trials done between 1964 and 1968 the following points emerged.

(i) Grasses heavily fertilized with nitrogen (210 to 630 kg N per ha) could carry up to 12 yearling cattle per ha for periods ranging from 62 to 162 days per growing season, depending upon rainfall.

(ii) There were marked differences between grasses in their ability to withstand intensive grazing and therefore large differences in production from them in terms of body mass gains of the cattle grazing them. Of the grasses tried only Panicum repens (cv. Victoria Falls) and Cynodon aethiopicus (cv. No. 2 Star) had proved suitable for the purpose. Both grasses had a prostrate growth habit. The former is rhizomatous and the latter is stoloniferous, while the other grasses were mainly of a tufted and upright growth habit.

(iii) There were marked differences in the ability of grasses to withstand drought. In this respect *Cynodon aethiopicus* (cv. No. 2 Star) was outstanding.

(iv) Nitrogen levels between 210 to 650 kg N per ha had been applied to the grasses but it was not known what level was required for maximum production of herbage on pastures grazed for maximum body mass gains.

(v) Stocking rates of between 7,41 and 12,36 yearling steers or heifers per ha had been imposed on the grasses. The former stocking rate had proved to be too light on all the grasses while the latter had proved to be too heavy for some grasses and satisfactory for others, notably *Panicum repens* (cv. Victoria Falls) and *Cynodon aethiopicus* (cv. No. 2 Star). Clearly stocking rates would have to be more accurately determined on grasses selected as being possibly suitable for intensive grazing purposes.

(vi) In the preliminary trials the grasses had all been grazed on a set-stocked basis. Therefore little was known about the effects of rotational grazing on grasses, what the periods of stay or absence should be, and what the effect would be on production in terms of body mass gains of beef cattle.

(vii) The mean body mass gains achieved on *Panicum repens* (cv. Victoria Falls) and *Cynodon aethiopicus* (cv. No. 2 Star) grazed at the stocking rate of 12,36 yearling cattle per ha during the growing season, were 66,5 kg per head or 822 kg per ha. Earlier (Anonymous, 1957) it had been reported that yearling steers grazing on the *Hyparrhenia*/*Hyperthelia* veld on Henderson Research Station at a stocking rate of 1 steer per 1,62 ha in a four paddock one herd rotational grazing system, gained 72,0 kg per head in body mass during the growing season (December to April). This is equivalent to 44,4 kg body mass

> gain per ha. Therefore the gains achieved on pasture were only 7,6 % less per head but 10 times greater per ha at 19 times the stocking rate, compared with these results on veld. The tremendous impact that heavily fertilized intensively grazed pastures could have on increasing the carrying capacity of farms during the growing season was obvious.

The results of the preliminary observation trials indicated numerous fields for further detailed research. Consequently, from 1968 onwards research was planned to investigate, more deeply, the use of pastures for intensive grazing purposes by beef cattle.

4.3.2 The effects of grazing and applied nitrogen on the herbage production of Cynodon aethiopicus (cv. No. 2 Star)

Results of the experiments described under Section 4.1.3 showed that in the absence of grazing animals, the herbage yields of grasses on silty clay soils, increased with each increment of nitrogen applied up to 450 kg N per ha. It was not known what effects the grazing animal would have on the nitrogen requirements of a sward fertilized for maximum production of herbage. Although 210 to 650 kg N per ha had been applied to intensively grazed grasses (Section 4.3.1) no information had been obtained on levels of nitrogen required for maximum production of herbage. It was possible that with the heavy stocking rates imposed (12 yearling cattle per ha) animal excreta might have a marked effect on herbage produced because of the plant nutrients, particularly nitrogen, contained in the excreta. Furthermore, the experiment described in Section 4.1.2 indicated that if kraal manure was applied to Chloris gayana (cv. Giant Rhodes) in addition to 450 kg N per ha, a significant response in terms of herbage yield was obtained compared to yields with fertilizer nitrogen only.

On heavily fertilized, intensively grazed grass swards, there is likely to be an increase in soil fertility with time. Thus after a period of heavy fertilization and intensive grazing it might be possible to reduce the amount of fertilizer applied to a sward without reducing the level of productivity of that sward.

Experimental Objectives

The objective of this experiment was to determine the response, in terms of herbage yield, to applied nitrogen on grazed swards of Cynodon aethiopicus (cv. No. 2 Star).

Materials and Methods

A well-established Cynodon aethiopicus (cv. No. 2 Star) pasture on a silty clay soil was used for the experiment. This grass was selected because it had proved suitable for intensive grazing in preliminary observation trials (Section 4.3.1), and produced large herbage yields in experiments (Section 4.1.1) and was a commonly grown grass in Rhodesia. For the two growing seasons prior to the experiment the pasture had been grazed by 12,36 yearling heifers per ha and was fertilized with 280 kg N per ha in the first season and 210 kg N per ha in the second season. During both seasons 90 kg P_2O_5 per ha were also applied (Section 4.3.1).

In September 1968 the pasture was fenced into 12 paddocks, 52,24 x 7,74 m or 0,0404 ha in area. For the next five growing seasons different levels of nitrogen, 0, 170, 340 and 510 kg N per ha, were applied to the paddocks using a randomised block design. The nitrogen was applied in four equal monthly dressings in each growing season, starting with the first good rains of the season. On this basis the earliest date on which nitrogen was applied was on 15 November and the latest date was 3 December. In addition to nitrogen 90 kg P_2O_5 per ha was broadcast on the plots every season during October and in 1969 dolomitic limestone at the rate of 350 kg per ha was also applied to all plots. The pH of the soil was 5,5 (calcium chloride).

Each paddock was set-stocked by three young Blackhead Persian x Dorper sheep of mean body mass 25,5 kg (± 4,0 kg) giving an initial stocking rate of 74 sheep per ha, which previously had been observed to give satisfactory utilization of herbage (Rodel, 1968b). No excess herbage remained in paddocks which were not fertilized with nitrogen at the end of the 1968-69 season. In the paddocks fertilized with nitrogen excess herbage at the end of the season was made into hay and fed to the sheep in the paddocks during the dry season. At the beginning of the 1969-70 season the stocking rate was increased to 111 sheep per ha by making the paddocks smaller (0,0270 ha). Again the excess herbage from nitrogen-fertilized plots was conserved and fed to the sheep in the paddocks. In the 1970-71 season the plots were reduced to 0,0202 ha to give a stocking rate of 148 sheep per ha. At this stocking rate there was no excess herbage for conservation.

Although differential stocking rates were imposed after the first and second years and despite the fact that excess herbage in 1968-69 and 1969-70 was conserved as hay, all herbage produced in the paddocks fertilized with different amounts of nitrogen was consumed within the paddocks by the sheep. Therefore, the effects of altering stocking rates on the swards were minimal because all available herbage was consumed by the sheep and all their excreta returned to the paddocks each growing season.

The sheep were weighed weekly. The groups were removed from pastures in each treatment when they had lost body mass for two consecutive weeks. Anthelmintics were administered at monthly intervals to control internal parasites. Autumn-born lambs on Star grass pastures had previously been found to suffer from enlarged thyroid glands and skeletal deformities due to an iodine deficiency (Rodel, 1971, 1972; Herrington, Elliott and Brown, 1971; Rudert, 1976). Accordingly, a salt lick containing 0,03 % iodine was made available to the sheep at all times.

In each growing season the paddocks were not stocked until the mean amount of herbage in all treatments was 1 000 kg dry matter per ha. Herbage yields were determined by clipping two 1 m^2 quadrats within herbage crates in each paddock to 5 cm height when the grass in a particular treatment reached early anthesis. After every sampling the herbage crates were moved to a new site, the herbage on the new site being cut to 5 cm before placing the herbage crate on the new site. The dry matter content of the harvested herbage was estimated from sub-samples which were oven-dried.

Because the size of the paddocks was reduced in 1969-70 and further reduced in 1970-71, portions of each paddock were excluded from grazing. These excluded areas were fertilized at the original rates and herbage production was measured by harvesting two 1 m^2 quadrats to 5 cm whenever the sample sites in the corresponding grazed area were harvested. After each sampling, the whole of the excluded area was cut to 5 cm and the herbage removed. By changing paddock boundaries in 1971-72 and splitting paddocks in 1972-73 a sequence of differential treatments involving grazing and resting during the period 1968-69 and 1972-73 were applied. These are shown in Table 17.

Table 17. Schedule of comparisons between plots grazed (G) each growing season and those grazed for various periods and then rested (R) from grazing for various periods.

Year	Plots continuously grazed (G)	Plots continuously grazed (G) and then rested (R) for			
		4 years	3 years	2 years	1 year
1968-69	G	G	G	G	G
1969-70	G	R	G	G	G
1970-71	G	R	R	G	G
1971-72	G	R	R	R	G
1972-73	G	R	R	R	R

In the 1968-69 growing season all plots were grazed. In 1973 it was possible to compare herbage yields from plots that had been grazed each growing season from 1968-69 to 1972-73 with herbage yields from plots that had been grazed for one year and then rested for four years; plots that had been grazed for two years and then rested for three years; plots that had been grazed for three years and then rested for two years; and plots that had been grazed for four years and then rested for one year.

The amount and distribution of the rainfall and the amounts recorded varied considerably from year to year and in three years approached, or was more than, the 45-year mean of 875 mm. In 1972-73 only 568 mm were recorded while in 1969-70, when 707 mm fell, distribution was poor (Appendix 1).

Results

The effects of applied nitrogen on herbage produced by Star grass grazed on a set-stocked basis by steers each growing season are presented in Figure 17.

In all five years herbage yields were significantly increased by applied nitrogen. Detailed analysis showed that in three years (1969-70, 1971-72 and 1972-73) increments in yield diminished with each successive increase in nitrogen application and in two years (1968-69 and 1970-71) yields increased in proportion to nitrogen applied up to the 340 kg per ha level. The response to applied nitrogen in 1969-70, 1971-72 and 1972-73 was similar to the four-year mean response (1969-70 to 1972-73). In the first season (1968-69) herbage yields without applied nitrogen were considerably greater compared with those of succeeding years probably due to the residual effects of previous treatment (Section 4.3.1) and for this reason these results are excluded from the mean.

Herbage yields varied greatly between seasons but as might be expected there was a close relationship between yields and rainfall (Figure 17, Appendix 1).

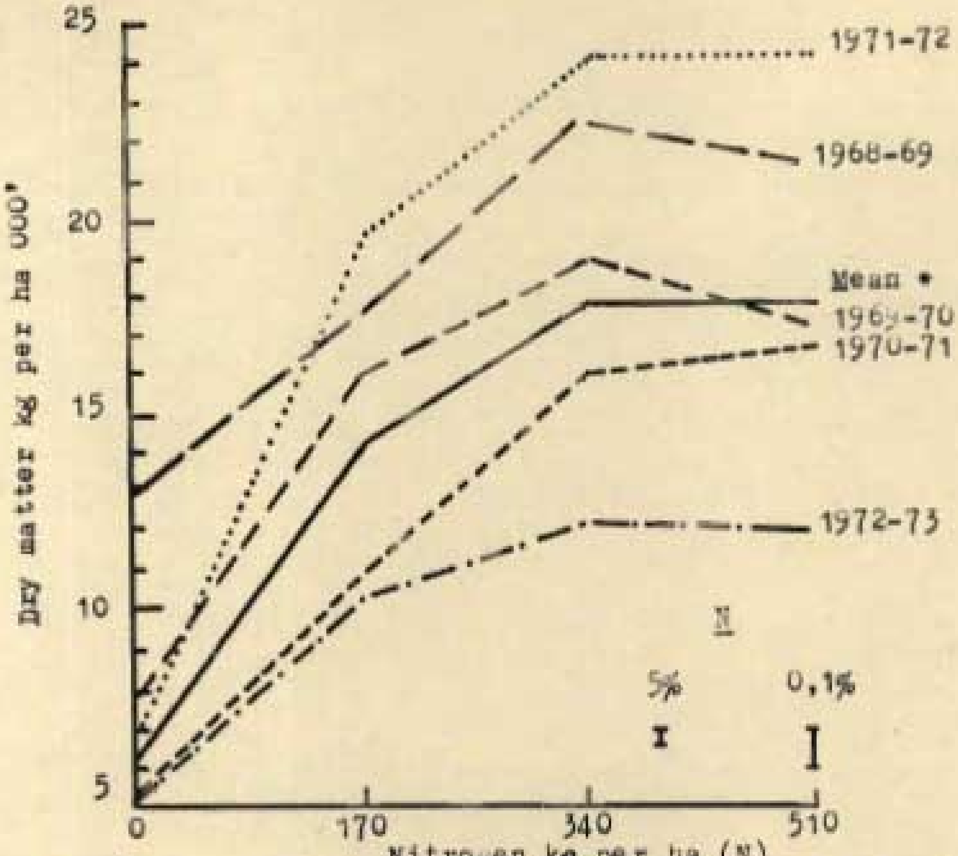


Figure 17. Mean effects of applied nitrogen (N) on the herbage yields in kg dry matter per ha of Star grass (cv.No. 2) grazed by sheep on a set-stocked basis each growing season. * Mean 1969-70 to 1972-73. Least significant differences for mean shown by vertical bars. (Analysis of variance table Appendix 2.29)

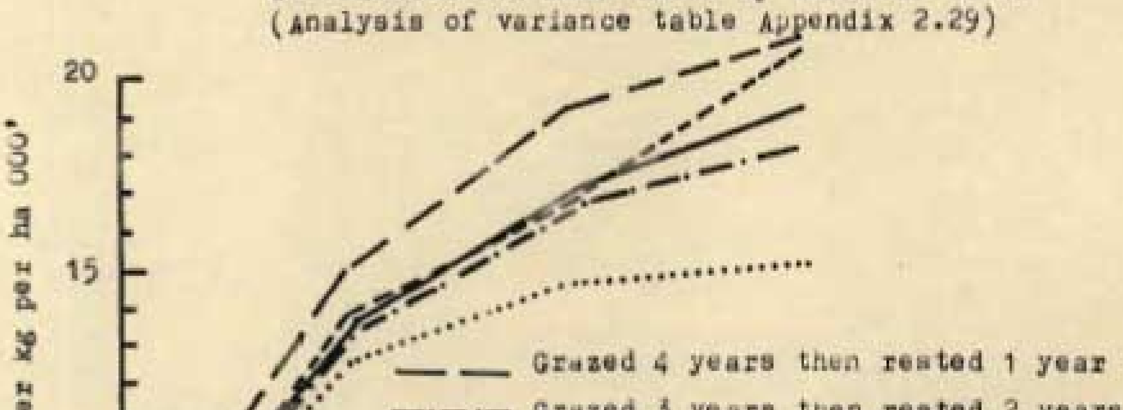


Figure 18. Mean effects of applied nitrogen (N) on herbage yields in kg dry matter per ha of Star grass (cv.No. 2) when rested from grazing for various periods. (Analysis of variance table Appendix 2.30).

The effects of resting after grazing on the response of Star grass to applied nitrogen are shown in Figure 18.

Where plots were grazed and then rested for one, two, three or four years, and with the mean effects of resting over all seasons, herbage yields increased as nitrogen applications increased but did so at a diminishing rate. There was a tendency for herbage yields to be greater in the first year of resting following grazing but there was little difference in herbage yields between the second and third years (Figure 18). This indicates that grazing had a residual effect on herbage yields the first year of resting after grazing probably due to the plant nutrients contained in the sheeps' excreta but this effect had disappeared by the second year of resting. In the fourth year herbage yields were generally lower probably because of the low rainfall in that year (Appendix 1).

In order to estimate the amounts of applied nitrogen required to produce maximum herbage yields where the Star grass was grazed each growing season and where it had been rested for various periods after grazing, the quadratic regression model was used to calculate theoretical herbage yields with applied nitrogen. For this purpose the mean herbage yields for 1969-70 to 1972-73 for the grazed plots (Figure 17) and the overall mean effect of resting after grazing on herbage yields for the rested plots (Figure 18), were used. The model is represented by the equation

$$Y = a + bx + cx^2$$

where Y is the yield, a, b and c are constants and x is the amount of nitrogen applied. The models used and the calculated responses to applied nitrogen with the actual mean data points, are shown in Figure 19.

From the models (Figure 19) the amounts of nitrogen required to produce maximum herbage yields were calculated by differentiation and by using the formula

$\frac{dy}{dx} = 0$ where d is a constant, y is the yield and x the amount of nitrogen.

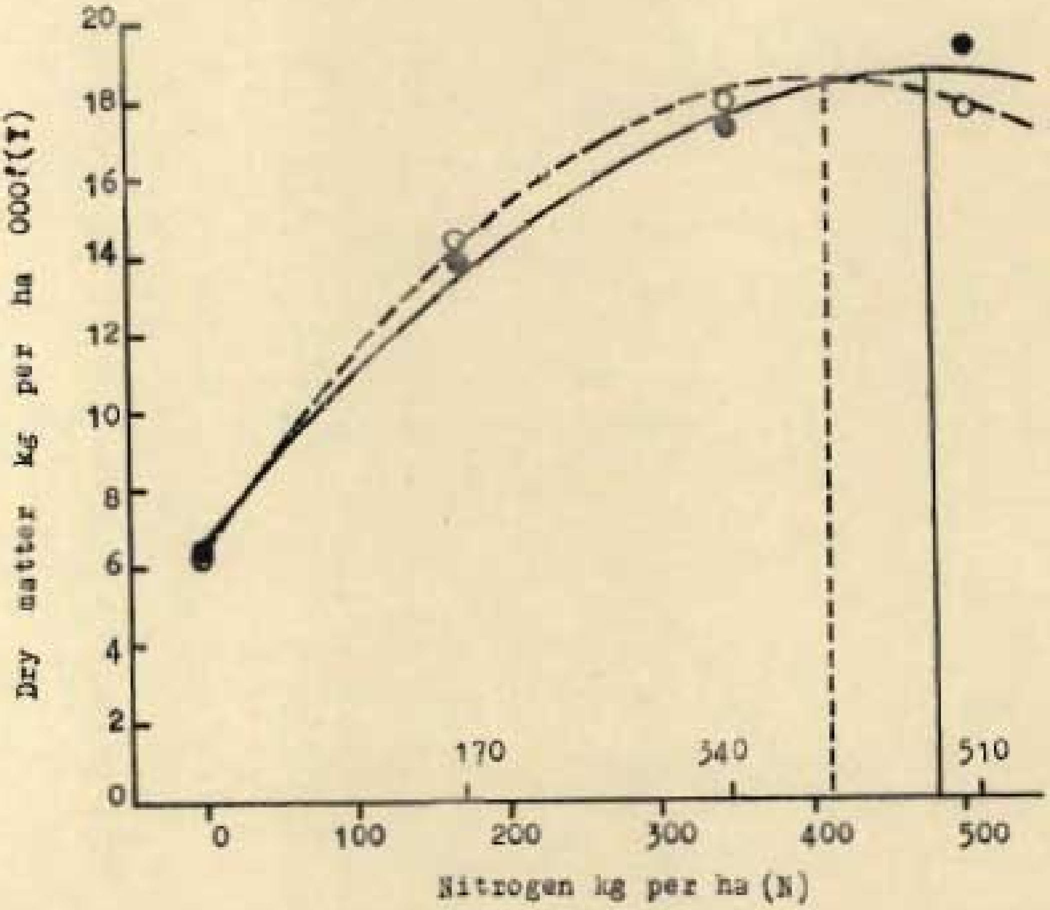


Figure 19. The calculated mean effects of applied nitrogen (N) on the herbage yields of Star grass (cv. No. 2) continuously grazed by sheep on a set-stocked basis each growing season compared with the effects of applied nitrogen (N) on the herbage yields of Star grass when rested from grazing for various periods. Actual data points indicated.

o - - o Star grass continuously grazed

$Y_2 = 6278{,}7 + 58{,}62\,x - 0{,}07083\,x^2$

$R^2 = 0{,}9692$

Maximum herbage yield 18 407 kg per ha with 414 kg N per ha.

●——● Star grass rested from grazing

$Y_2 = 6417{,}30 + 49{,}79\,x - 0{,}05098\,x^2$

$R^2 = 0{,}9793$

Maximum herbage yield 18 574 kg per ha with 488 kg N per ha.

For the grazed plots

$$58,62 - 0,14166\ x = 0$$

$$0,14166\ x = 58,62$$

$$x = \frac{58,62}{0,14166} = 414 \text{ kg N per ha}$$

For the plots rested after grazing

$$49,79 - 0,10196\ x = 0$$

$$0,10196\ x = 49,79$$

$$x = \frac{49,79}{0,10196} = 488 \text{ kg N per ha}$$

The calculated maximum herbage yields were 18 407 kg and 16 574 kg per ha for the grazed and rested plots, respectively, and, except at high rates of applied nitrogen (more than 450 kg N per ha), the responses were very similar.

Body mass gains per ha of the sheep grazing on the Star grass are presented in Table 18.

Table 18. Body mass gains in kg per ha of sheep that were set-stocked on Star grass fertilized with various amounts of nitrogen and mean number of days per season sheep grazed. (Analysis of variance table Appendix 2.31).

Year	Stocking rate sheep per ha	Nitrogen (N) kg per ha				SE	Significant effects
		0	170	340	510	±	
1968-69	74	333	326	470	544	126	N^{1} **
1969-70	111	116	364	503	529	231	N^{1} ***
1970-71	148	82	328	544	432	135	N^{1} *** N^{11} **
1971-72	148	185	1020	1233	1269	254	N^{1} ***
1972-73	148	77	176	305	359	170	N^{1} **
Three-year mean 1970-71 to 1972-73		115	508	694	687	118	N^{1} ***
Mean no. of days sheep grazed at stocking rate of 148 sheep per ha		96	107	119	125		

** = 1 %

In each of the five years, and with the three-year means (1970-73), body mass gains per ha increased, but did so at a diminishing rate in 1970-71.

In the first season (1968-69) body mass gains without applied nitrogen were similar to those where 170 kg N per ha were applied. In subsequent seasons body mass gains without applied nitrogen were much lower, particularly in 1970-71 and 1972-73.

The greatest body mass gains occurred in 1971-72, a year of good rainfall (Appendix 1) and high herbage yields (Figure 17). The lowest body mass gains were recorded in 1972-73 when drought occurred (Appendix 1) and little herbage was produced (Figure 17).

The mean number of days the pastures were grazed increased steadily from 96 days without applied nitrogen, to 125 days where 510 kg N per ha were applied.

Discussion

The effect of applying nitrogen to Star grass grazed by sheep was to increase herbage production with each increment of nitrogen up to 340 kg N per ha at which level of application herbage production was at, or nearly at, a maximum. The theoretical maximum amount of herbage (18 407 kg per ha) on grazed plots was produced with 414 kg N per ha (Figure 19). This yield was only 437 kg per ha greater than the actual yield with 340 kg N per ha (Figure 19). Therefore for practical purposes no more than about 340 kg N per ha should be applied because the response beyond this level of applied nitrogen is negligible. This result is in agreement with the findings of Mears and Humphreys (1974) who found that maximum amounts of herbage were produced with 336 kg N per ha on grazed _Pennisetum clandestinum_ pastures.

When the sheep were removed from pasture the response of Star grass to applied nitrogen changed in that positive responses were still obtained to the 510 kg level of nitrogen. This effect was apparent where plots had been rested for either one, two, three or four years from grazing (Figure 18).

The different effects of applied nitrogen on grass set-stocked with sheep each growing season and on ungrazed grass are shown in Table 19. The results obtained in 1968-69 on grazed Star grass (Figure 17) are excluded so that the means for the same four years (1969-70, 1970-71, 1971-72 and 1972-73) for both grazed and ungrazed grass are compared.

Table 19. Mean effect of applied nitrogen on herbage yields of Star grass grazed each growing season by sheep compared with herbage yields from ungrazed Star grass in kg dry matter per ha (1969-70 to 1972-73).

Star grass	Nitrogen (N) kg per ha per season			
	0	170	340	510
Grazed	6260	14250	17970	17770
Not grazed	6290	13790	17070	19010
Difference	- 30	+ 460	+ 900	- 1240

Although more herbage was produced on grazed as compared with ungrazed grass where 170 and 340 kg N per ha were applied, differences were insignificant. Where 510 kg N per ha were applied more herbage was produced on ungrazed grass than on grazed grass. Therefore the findings of Brockman, Rope and Stevens (1971) that the efficiency of applied fertilizer nitrogen is greater on grazed swards compared with ungrazed swards is not confirmed in this instance.

For the two years prior to this experiment the experimental area was uniformly fertilized with 280 and 210 kg N per ha for the first and second years, respectively, and was grazed on a set-stocked basis at a stocking rate of 12,36 heifers per ha in both years. This treatment, it was expected, would have caused some build-up in soil fertility due to the heavy chemical fertilization and also due to the nutrients returned to the pasture in the excreta of the cattle grazing them. However, from the experimental results it is clear that the previous basic treatment had little residual effect. Only in the first year of the experiment (1968-69) where no nitrogen was applied was there any indication of any residual effect on herbage production of treatment applied previously to the sward (Figure 17). However, there was some indication that treatment had a small residual effect on the production of herbage in the first year of resting following grazing (Figure 18). Herbage yields were greater in the first year of resting (mean of four seasons) compared with yields obtained in the second (mean of three seasons), third (mean of two seasons) and fourth years of resting. The effects of resting for four years was only measured in one year, 1972-73, a year of low rainfall (Appendix 1). This explains why lower yields were obtained in this year compared with other years of resting (Figure 18).

The body mass gains made by the sheep grazing on the Star grass fertilized with various amounts of nitrogen were greatest where 340 kg N per ha were applied. Greatest body mass gains were recorded where near maximum quantities of herbage were produced i.e. where 340 kg N per ha were applied (Figure 17, Table 18). The body mass gains generally were poor considering the very heavy stocking rate. However, the main object of using the sheep on the pasture was for them to provide the effects of the grazing animal on the sward and not to measure their body mass gains. The results do show that Star grass swards have a very high sheep carrying capacity during the growing season and that this fact could be explored in the development of production systems for sheep.

4.5.3 The effect of stocking rates on production from heavily fertilized dryland grass pastures

It was stated in Section 4.5.1 that there was a need to determine accurately the effect of stocking rates on heavily fertilized grasses. From 1964 to 1968 stocking rates of between 7,41 and 12,36 yearling cattle per ha were imposed on grasses that received from 210 to 630 kg N per ha each growing season. A stocking rate of 7,41 yearlings per ha had been found to be too light while 12,36 yearlings per ha was too heavy on some grasses, but satisfactory on others. It was not known what stocking rate(s) should be imposed to give maximum body mass gains per head or per unit area or maximum profitability.

In Section 4.1.1 the herbage yields of 30 heavily fertilized grasses were reported. During 1965-66 and 1966-67 results revealed a number of grasses that had the ability to produce in excess of 15 000 kg dry matter per ha, annually. The amount of herbage produced by these grasses indicated that they had a high potential carrying capacity but many of them had not been tested before for this purpose.

Furthermore the experiment reported in Section 4.5.2 indicated that approximately 340 kg N per ha were required on Cynodon aethiopicus (cv. No. 2 Star) grazed by sheep to produce near maximum amounts of herbage. Therefore if 350 kg N per ha were applied to selected grasses (producing in excess of 15 000 kg dry matter per ha) and a range of stocking rates imposed on them, more information would be gained on the effects of stocking rates on the body mass gains of cattle grazing them.

Experimental Objectives

There were two main objectives to this study and two separate experiments were done to achieve these objectives.

The objective of the first experiment was to compare Chloris gayana (cv. Giant Rhodes) with three newly selected grasses for grazing purposes. Giant Rhodes grass had previously been the most commonly used grass for this purpose.

In the second experiment the objective was to determine the effects of a range of stocking rates on the body mass gains of steers grazing three newly selected grasses that produced in excess of 15 000 kg dry matter per ha when heavily fertilized (Section 4.1.1).

Materials and Methods

(i) Grasses and stocking rates

The first experiment was done during the 1968-69, 1969-70 and 1970-71 growing seasons. Chloris gayana (cv. Giant Rhodes), Cynodon nlemfuensis var. nlemfuensis (cv. Muguga Star), Panicum coloratum (cv. Bushman Mine) and P. repens (cv. Victoria Falls) were all grazed at a stocking rate of 9,88 yearling steers per ha each growing season. The last three grasses were selected from those previously tested (Section 4.1.1) as being potentially suitable for pastures. Giant Rhodes grass was included because it would be a useful standard against which the productivity of the other three grasses could be assessed. Previously Giant Rhodes had been found to withstand a stocking rate of 7,41 steers per ha (3 steers per acre) but unable to withstand a stocking rate of 12,36 steers per ha (5 steers per acre) (Section 4.3.1). Therefore to compare Giant Rhodes with the three newly selected grasses a stocking rate of 9,88 steers per ha (4 steers per acre) was used.

Treatments were arranged in three completely randomised replicates of the four treatments i.e. 12 paddocks.

In the second experiment Cynodon nlemfuensis var. nlemfuensis (cv. Muguga Star), Panicum coloratum (cv. Bushman Mine and P. repens (cv. Victoria Falls) were each grazed at stocking rates of 9,88; 12,36; 14,83 and 17,30 yearling steers per ha during the 1968-69, 1969-70 and 1970-71 growing seasons. Paddocks of these grasses stocked with 9,88 steers per ha were common to both Experiment 1 and Experiment 2.

Treatments were arranged in three completely randomised replicates of a 4 x 3 factorial, comprising 36 paddocks in all.

In both experiments each paddock was grazed by four yearling Shorthorn x Africander steers. In order to vary stocking rate paddock size was adjusted as indicated in Table 20.

Table 20. Paddock size in ha for each of four stocking rates.

Stocking rate steers per ha	Paddock size ha
9,88	0,4046
12,36	0,3237
14,83	0,2698
17,30	0,2313

The two experiments covered 12 ha and were grazed by a total of 156 steers in each of the three growing seasons.

The establishment of grasses, experimental steers, grazing management and application of fertilizers were similar for both experiments and are described jointly under these headings.

(ii) Establishment of grasses

During January 1967 the grasses were planted into a well-prepared silty clay soil of pH 5,2 (calcium chloride). Giant Rhodes was sown at 11 kg seed for ha while Bushman Mine Panicum and Muguga Star were established vegetatively by planting rooted stolons 1 x 1 m apart. Victoria Falls Panicum was established from rhizomes planted at 0,5 x 0,5 m. Previous experience had shown that close planting of this grass was necessary because it was slow to form a sward. Soon after planting all grasses received 45 kg N per ha. Growth made during the remainder of the 1966-67 growing season was grazed during the ensueing dry season and residual herbage was mown off before the start of the following growing season. Drinking water was piped to every paddock.

During the 1967-68 growing season all paddocks received 100 kg N and 40 kg P_2O_5 per ha and were grazed by cows and calves to keep grass growth in check and encourage the formation of swards. Only 395 mm of rain were recorded in this season (Appendix 1), but the grasses were nevertheless well-established when it ended. All residual herbage was mown off at the beginning of the 1968-69 growing season before experimental treatments started.

(iii) Experimental steers

Each year, in June, Shorthorn x Africander weaner steers, with a mean body mass of approximately 210 kg each, were purchased. They were over-wintered on Hyparrhenia/Hyperthelia veld that had been rested all the previous growing season and were fed 700 g of cottonseed meal per head, daily. Each steer thus gained about 170 g a day in body mass and was about 240 kg in body mass on entering the experiments the following growing season.

Each season the steers were treated with anthelmintics before entering the experiments. Mineral lick in block form was made available to the steers on the pastures. They were dipped weekly and were weighed fortnightly until the latter part of the growing season when they were weighed weekly.

(iv) Grazing management

Each season every paddock was set-stocked with four steers. Before grazing started, the steers were weighed and sorted into groups of four steers with similar mean body mass (± 240 kg per steer). Grazing began on each grass, irrespective of stocking rate, when amounts of herbage clipped from quadrats showed that at least 1 000 kg of dry matter per ha was present. The pastures of each grass were destocked at the end of the season when the steers grazing them decreased in body mass for two consecutive, weekly weighings. On this basis the earliest date of starting grazing was 1 December and the latest date on which steers were removed from pasture was 29 April.

(v) Application of fertilizers

Each growing season 350 kg N per ha was applied to all paddocks in four equal dressings at monthly intervals starting with the first good rains of the season. In addition 90 kg P_2O_5 per ha was applied to all plots during October before the rains started. In October 1969, 250 kg per ha of dolomitic limestone was also applied.

(vi) Rainfall

In 1968-69, 1969-70 and 1970-71, 851, 707 and 941 mm of rain was recorded, respectively. Rainfall during the 1969-70 was poorly distributed, and dry spells occurred in the second half of the season (Appendix 1).

Results

Experiment 1

The body mass gains of the steers for each of the three growing seasons together with the means for the three seasons, are shown in Figure 20.

The three-year mean body mass gains both per steer and per ha of steers grazing Muguga Star, Bushman Mine Panicum and Victoria Falls Panicum were greater ($P < 0,05$) than those of steers

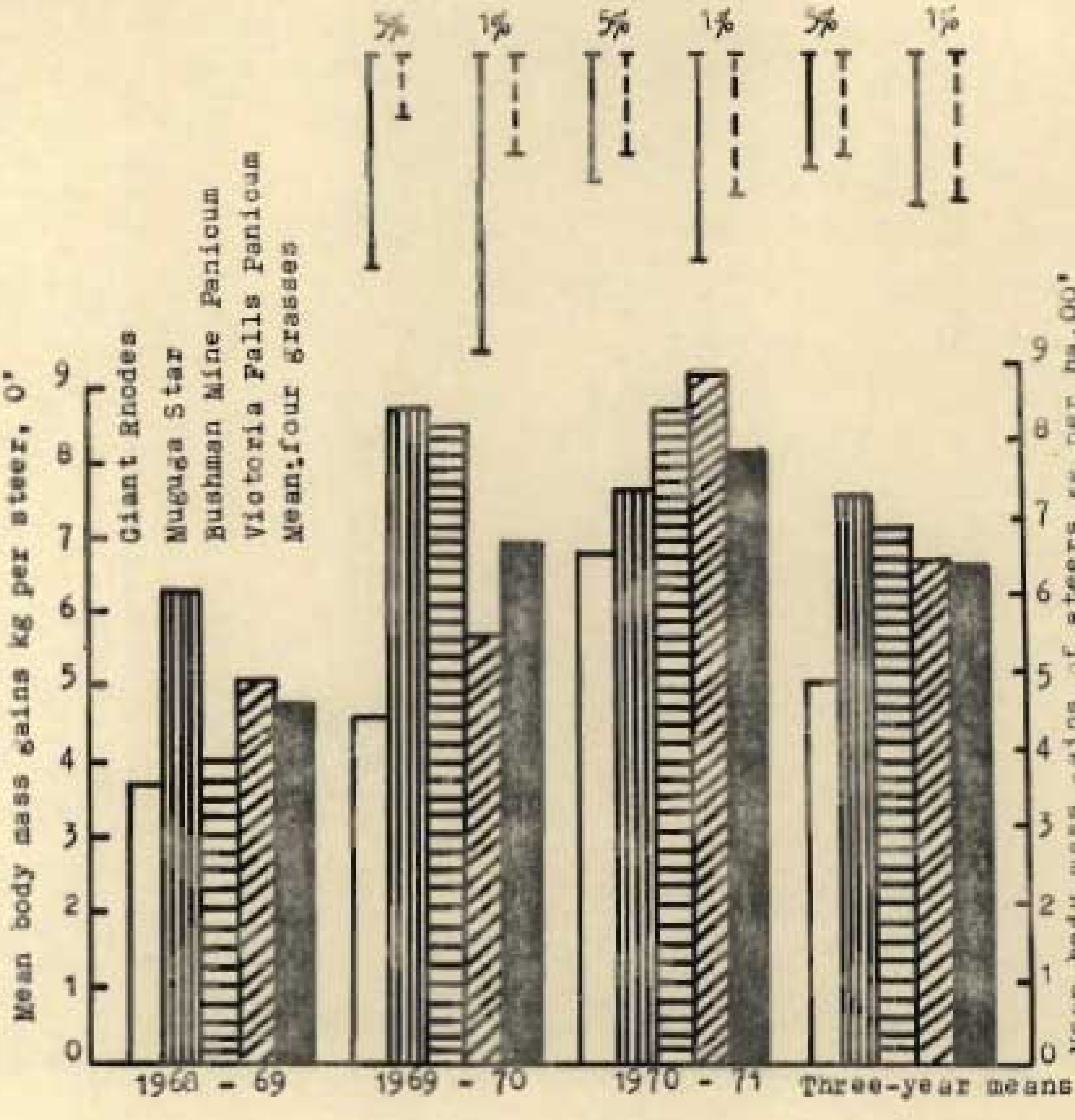


Figure 20. The mean body mass gains per steer and per ha in kg of steers grazing four grasses at a stocking rate of 9,88 steers per ha and fertilized with 350 kg N and 90 kg P_2O_5 per ha, annually. Least significant differences P = 0,05 and P = 0,01 indicated by solid vertical bar for body mass gains per steer and broken vertical lines for body mass gains per ha. (Analysis of variance tables (Appendices 2.32 and 2.33).

grazing Giant Rhodes grass. Muguga Star produced the greatest three-year mean body mass gain of 74,9 kg per steer or 740 kg per ha. The three-year mean body mass gain of all the grasses was 65,2 kg per steer or 644 kg per ha.

In 1968-69, the first year of the experiment, there were no significant differences in the body mass gains of the steers grazing on any of the four grasses. In 1969-70 Muguga Star and Bushman Mine Panicum produced greater body mass gains per head and per ha ($P < 0,05$) than Giant Rhodes. However, in 1970-71 Victoria Falls Panicum produced greater gains per steer and per ha ($P < 0,05$) than Muguga Star and Giant Rhodes while Bushman Mine Panicum produced greater gains per steer and per ha ($P < 0,05$) than Giant Rhodes.

The mean number of days the grasses were grazed each season, together with the number of steer grazing days per ha, are shown in Table 21.

Table 21. Mean number of days per growing season that steers grazed four grasses at a stocking rate of 9,88 steers per ha and number of steer grazing days per ha.

Grass	No. of days grasses grazed	No. of steer grazing days per ha
Giant Rhodes	85,7	847
Muguga Star	126,3	1248
Bushman Mine Panicum	104,0	1028
Victoria Falls Panicum	119,0	1176

Muguga Star was grazed for the longest mean period each year and therefore gave the greatest number of steer grazing days per ha. Giant Rhodes grass was grazed for the shortest period each year and therefore produced the lowest number of steer grazing days per ha.

Experiment 2

The body mass gains per steer and per ha on each of the grasses for the three growing seasons are shown in Figures 21 and 22.

The three-year mean results showed that body mass gains both per steer and per ha decreased linearly ($P < 0{,}001$) with increasing stocking rate.

In 1969-70, the second season, the rate of decrease in body mass gains per steer and per ha was more marked than in the other two seasons. The range in body mass gains from the lowest to the highest stocking rate was greatest in this season. In the first season the greatest gain was 614 kg per ha and the least gain 197 kg per ha while in the third season the corresponding gains were 955 kg and 463 kg per ha.

In 1970-71 the changes in body mass gains per ha with increasing stocking rate on Bushman Mine Panicum and Victoria Falls Panicum appeared to vary considerably from the general linear decreases found in other years. Statistical analyses showed that these variations were, in fact, not significant and no explanation can be offered for them.

At all stocking rates the mean body mass gains per steer and per ha changed from year to year (Table 22).

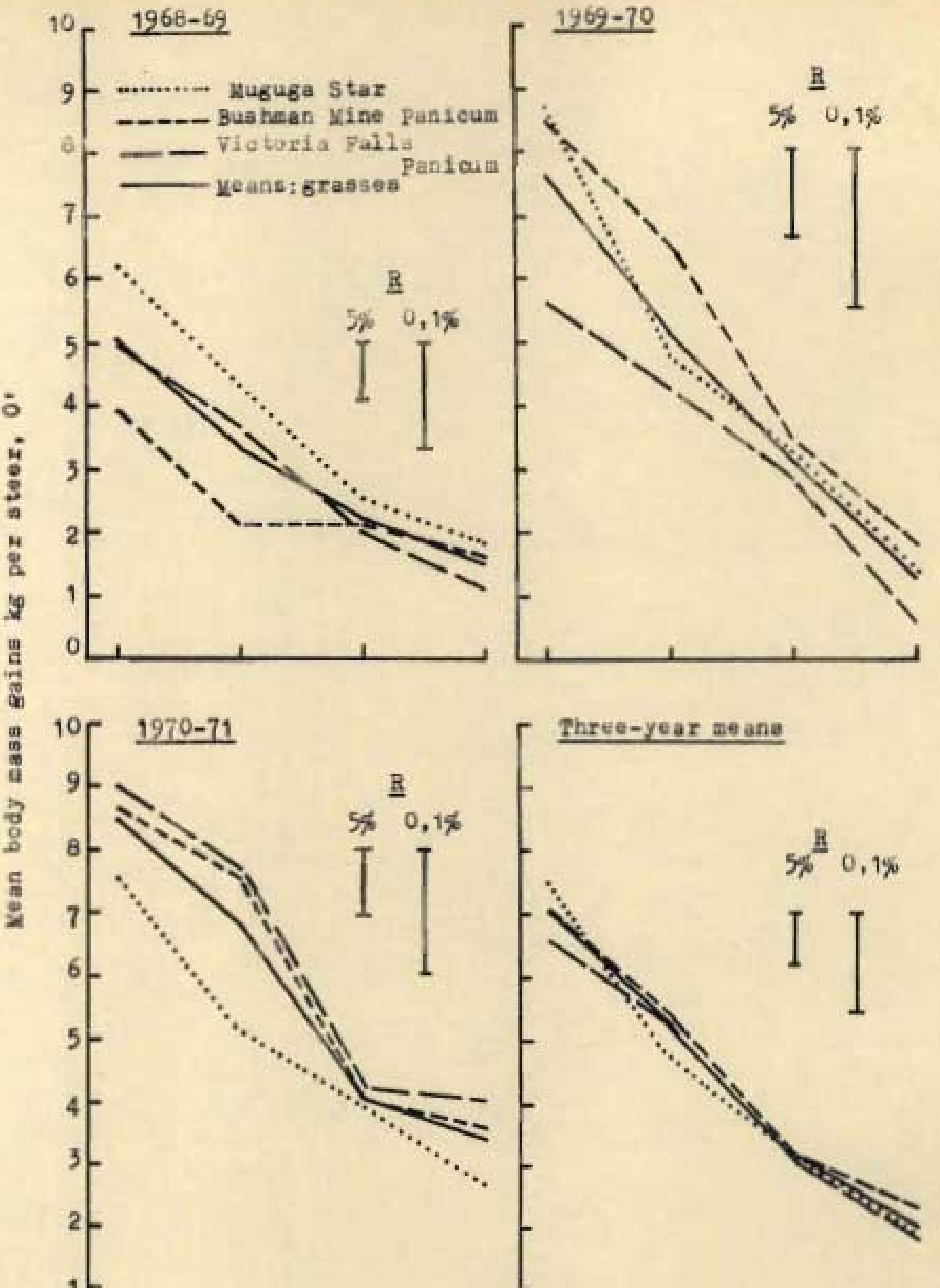


Figure 21. The effects of four stocking rates (R) on the mean body mass gains in kg per steer of steers grazing three grasses (G) fertilized with 350 kg N and 90 kg P_2O_5 per ha, annually. Least significant differences for P = 0,05 and P = 0,001 for stocking rates (R)(means three grasses) indicated by vertical bars. (Analysis of variance table Appendix 2.34).

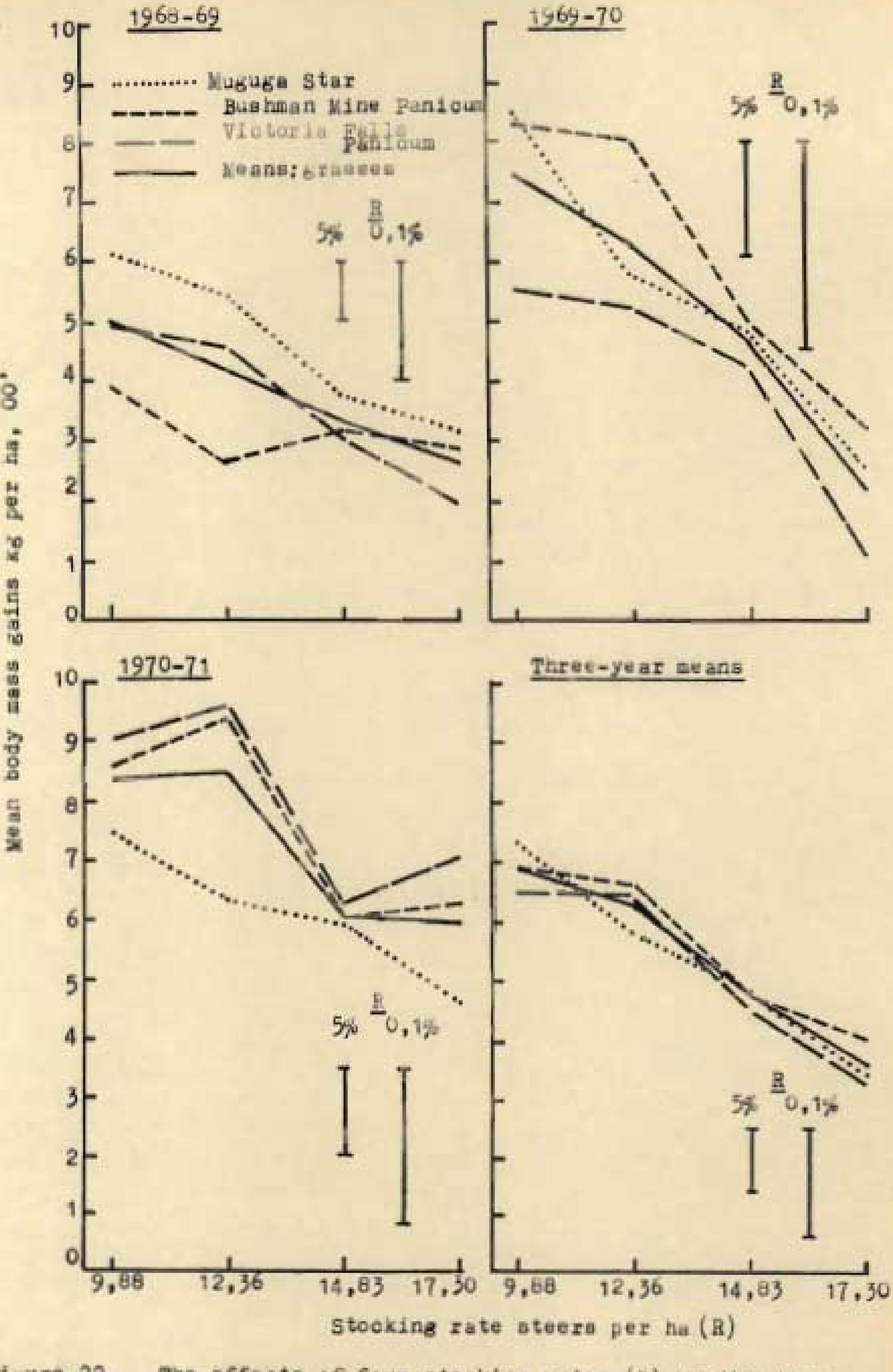


Figure 22. The effects of four stocking rates (R) on the mean body mass gains in kg per ha of steers grazing three grasses (G) fertilized with 350 kg N and 90 kg P_2O_5 per ha, annually. Least significant differences for P = 0,05 and P = 0,001 for stocking rates (R) (means three grasses) indicated by vertical bars. (Analysis of variance table Appendix 2.35).

Table 22. Mean body mass gains per steer and per ha in kg made on Muguga Star, Bushman Mine Panicum and Victoria Falls Panicum over all stocking rates. (Analysis of variance tables Appendices 2.34 and 2.35).

Year		Grasses		
		Muguga Star	Bushman Mine Panicum	Victoria Falls Panicum
1968-69	per steer	37,4 a	24,7 b	29,7 ab
	per ha	508 a	336 b	404 ab
1969-70	per steer	45,3 ab	50,6 a	33,6 b
	per ha	615 ab	688 a	457 b
1970-71	per steer	48,4 B	59,6 AB	62,9 A
	per ha	658 b	810 ab	855 a
Three - year means	per steer	43,7ab	45,0 a	42,1 b
	per ha	594 ab	612 a	572 b

	S E ± per steer	S E ± per ha
1968-69	3,0	35
1969-70	4,0	56
1970-71	3,0	43
Three-year means	2,5	30

Note : Small letters indicate significant effects at the 5% level of significance and capital letters significant effects at the 1% level significance. Grasses suffixed by the same letter are not significantly different at the level represented by the size of the lettering.

While the greatest body mass gains of steers in the first year were made on Muguga Star, this grass was the least productive in the third year. In all three years mean body mass gains per steer and per ha on the three grasses over all stocking rates were significantly different. No differences were observed with the three-year mean body mass gains per steer or per ha.

The period that the steers grazed on pasture each year varied with the season, the grass grazed and the stocking rate imposed. The three-year mean number of days for which each grass was grazed at the various stocking rates together with the total number of grazing days per ha are shown in Table 23.

Table 23. Mean number of days (D.) per growing season for which steers grazed three grasses at four stocking rates and number of steer grazing days (G.D.) per ha.

Grass	D. or G.D.	Stocking rates steers per ha				Means
		9,88	12,36	14,63	17,30	
Muguga Star	D.	126,3	110,0	77,3	72,7	96,6
	G.D.	1248	1360	1146	1258	1253
Bushman Mine Panicum	D.	104,0	97,0	80,0	70,0	87,8
	G.D.	1028	1199	1166	1211	1156
Victoria Falls Panicum	D.	119,0	102,7	81,7	53,3	89,2
	G.D.	1176	1269	1212	922	1145
Means	D.	116,4	103,2	79,7	65,3	91,2
	G.D.	1151	1276	1182	1130	1185

The number of days grasses were grazed decreased with increasing stocking rate. However, the greatest number of steer grazing days per ha was produced by a stocking rate of 12,36 steers per ha but differences between grasses over all stocking rates were relatively small.

Discussion

Numerous authors have reported body mass gains of cattle in excess of 1 000 kg per ha on tropical and sub-tropical grasses fertilized with large amounts of nitrogen (Evans, 1969, 1973; Bryan and Evans, 1971; Plucknett, 1970; Richards, 1970; Mears and Humphreys, 1974). In most instances 400 to 600 kg N per ha were applied and stocking rates were approximately 5 to 6 yearling to two-year-old animals per ha. In Rhodesia 970 kg body mass gain per ha was reported by Rodel and Boultwood (1967) on a Panicum repens (cv. Victoria Falls) pasture which received 350 kg N per ha and which was stocked at a rate of 12,36 yearling steers per ha (Section 4.3.1). In the experiments being reported the greatest body mass gain recorded in Experiment 1 was 900 kg per ha on Victoria Falls Panicum in 1970-71 at a stocking rate of 9,88 steers per ha and in Experiment 2 it was 955 kg per ha also on Victoria Falls Panicum in 1970-71 at a stocking rate of 12,36 steers per ha.

The grasses in the experiments, except for Giant Rhodes in Experiment 1, were selected on the basis of their herbage yielding ability when heavily fertilized and clipped periodically (Section 4.1.1) (Rodel and Boultwood, 1971a). All the grasses developed weaknesses when grazed. For example, the inflorescenses of Muguga Star become infested with a black, sooty smut Ustilago cynodontis after the first year. This appeared to affect the vigour of this grass. This might account for the fact that it was the most productive grass in the first year but the least productive of the newly selected grasses by the third year (Figures 20, 21 and 22). At this stage the black sooty smut covered the herbage and much remained ungrazed after the steers were removed from pasture.

Bushman Mine Panicum proved to be a very palatable grass but despite its stoloniferous growth habit it did not withstand intensive grazing as well as expected. Later studies (Section 4.2) indicated that Bushman Mine Panicum is affected adversely by frequent defoliation. Victoria Falls Panicum was also very palatable but it did not withstand drought well. This was particularly noticeable following the 1969-70 season when rainfall was poorly distributed (Appendix 1) and patches of grass died out. These patches were invaded in 1970-71 by the annuals Eluesine indica and Setaria pallide-fusca, and the perennials Sporobolus pyramidalis and Paspalum commersonii. Giant Rhodes grass which had only been grazed at the lightest stocking rate of 9,88 steers per ha had also been severely damaged by grazing by the time the experiments ended and large areas had also been invaded by Eluesine indica, Setaria pallide-fusca, Sporobolus pryamidalis and Paspalum commersonii.

The body mass gains made by the steers on the pastures in the first year of the experiments were not as great as those in the second and third years. This might be attributed to the fact that the grasses were not as well established in the first year as in the second and third years although on Giant Rhodes and Victoria Falls Panicum, annual grasses invaded these pastures in the third year.

Despite the weaknesses observed in Muguga Star, Bushman Mine Panicum and Victoria Falls Panicum they all proved to be superior to Giant Rhodes grass in Experiment 1. They all produced greater body mass gains per steer and per ha than Giant Rhodes and were grazed for much longer and gave more steer grazing days per ha than Giant Rhodes. The stocking rate of 9,88 steers per ha on Muguga Star, Bushman Mine Panicum and Victoria Falls Panicum was too light to control growth of these grasses. Much herbage accumulated during the first half of the growing season. This herbage lodged and smothered the grass underneath and in some instances caused it to die. As the pastures of Muguga Star, Bushman Mine Panicum and Victoria Falls Panicum stocked with 9,88 steers per ha were common to Experiment 1 and 2 the same observations applied at this stocking rate in Experiment 2.

In Experiment 2 some herbage did accumulate on all three grasses at a stocking rate of 12,36 steers per ha in early to mid-season. These pastures had an uneven appearance but no grass lodged. By the end of the season most herbage was eaten and good utilization was achieved. At stocking rates of 14,83 and 17,30 steers per ha no grass accumulated and it was clear that the grasses were overstocked at these stocking rates. This is supported by the mean length of time the grasses were grazed at the different stocking rates (Table 23). If the period steers grazed on pasture at a stocking rate of 9,88 steers per ha is taken as 100,0 %, steers at a stocking rate of 12,36 per ha grazed on pasture for 88,7 %, steers at a stocking rate of 14,83 per ha 68,5 % and steers at a stocking rate of 17,30 per ha only 56,1 % as long as those stocked at a rate of 9,88 steers per ha. However, the number of steer grazing days obtained with the different stocking rates shows that differences between grasses and stocking rates were small. (Table 23). Therefore in a practical situation this would have to be taken into consideration in determining the whole farm strategy and forage flow for livestock. It might be argued that the excess herbage that accumulated at a stocking rate of 9,88 steers per ha could be conserved for use later in the year or utilized by increasing the stocking rate for a period long enough to prevent the accumulation. Conserving grass herbage for later use during the dry season is not justified in present circumstances for economic reasons and because there is adequate roughage on most farms to carry the present livestock population for that period.

The results from Experiment 2 show that the stocking rate of 9,88 steers per ha produced the greatest body mass gains per steer and per ha. However, utilization of herbage by steers at this stocking rate was poor and much was wasted. Had the experiment continued it is likely that these pastures would have deteriorated through under-use. As already stated excess herbage could in practice be conserved or alternatively grazed off by increasing the stocking rate during periods of rapid grass growth. By comparison good utilization of herbage was achieved at a stocking rate of 12,36 steers per ha and this stocking rate gave the greatest number of grazing days per ha (Table 23) but body mass gains were 27,0 % less per steer and 8,7 % less per ha than gains at a stocking rate of 9,88 steers per ha. In practice this might be acceptable because in a system of production where steers are fattened in the feedlot after coming off pastures compensatory growth occurs in steers that are not quite as heavy or in quite as good a condition as they might be. Such steers convert concentrates into meat more efficiently than steers of the same age but in better condition and of greater body mass when going into the feedlot. Therefore any advantage gained on pastures by steers grazing at a stocking rate of 9,88 steers per ha over steers grazing at a stocking rate of 12,36 steers per ha might be lost in the feedlot.

The results did not show at what stocking rate maximum body mass gains per steer or per ha occurred nor where the economic optimum was, because the stocking rates used produced a linear decrease from the lightest to the heaviest stocking rate. Clearly the maximum body mass gains per steer would have occurred at a lighter stocking rate than 9,88 steers per ha. Because this lies outside the range of stocking rates used it is not appropriate to extrapolate to this point. However, by using the data in Figure 21 a linear model (Jones and Sandland, 1974) was used to calculate the theoretical body mass gains per steer (Ys) over a range of stocking rates (R). The equation used was

$$Ys = 135,5857 - 6,771\ R$$

The theoretical body mass gains per ha (Yh) were then calculated by multiplying the body mass gains per steer by stocking rate. The results are shown in Figure 23.

The stocking rate at which body mass gains per ha were at a maximum was calculated from the model

$$Yh = 135,5857\ R - 6,771\ R^2$$

Yh is at a maximum when $\frac{d\ Yh}{d\ R} = 0$

$$135,5857 - 13,542\ R = 0$$

$$13,542\ R = 135,5857$$

$$R = \frac{135,542}{13,542}\ R$$

$$R = 10,01 \text{ steers per ha}$$

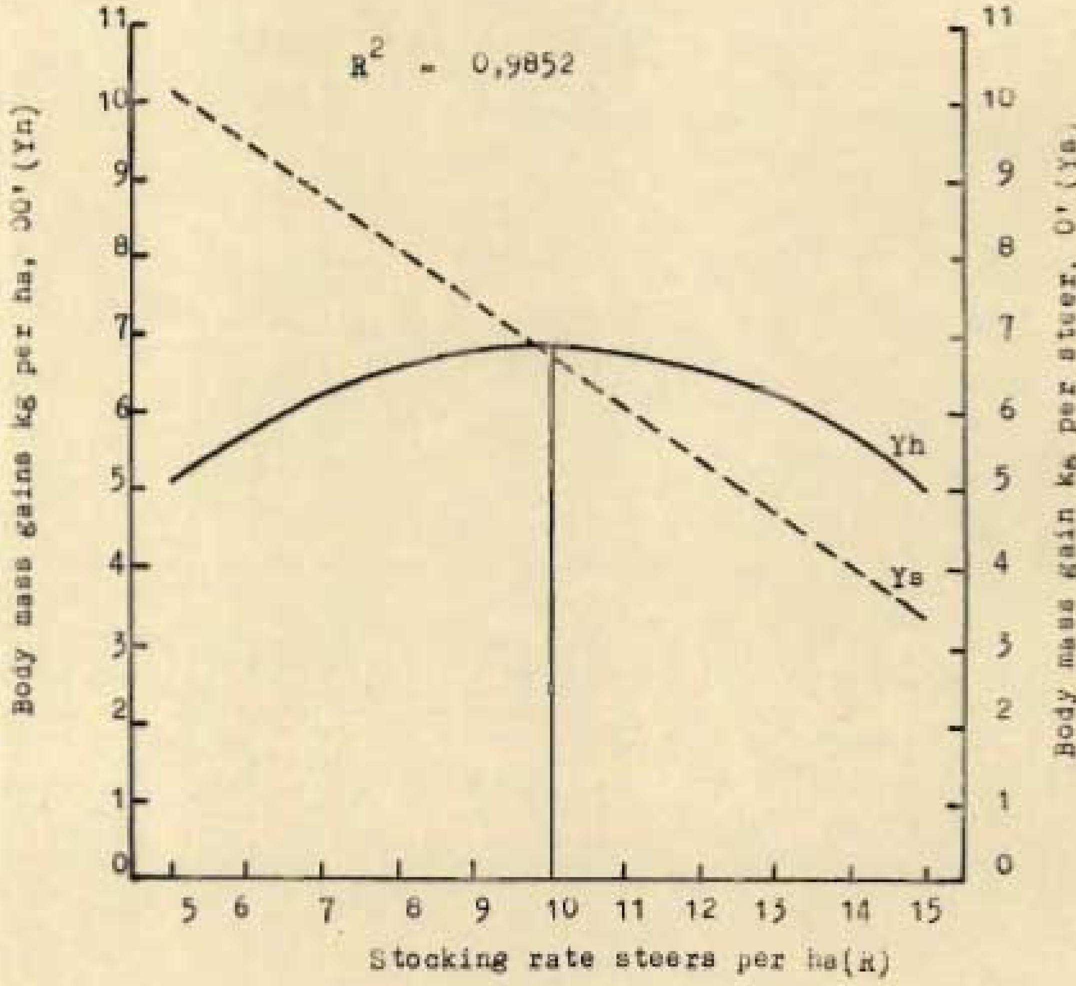


Figure 23. The theoretical relationship between stocking rate (R) and body mass gains per steer (Ys) and per ha (Yh) calculated from the equation Ys = 135,5857 - 6,771R (Jones and Sandland, 1974). Yh is at a maximum (679 kg) where R = 10,01 steers per ha.

The calculated body mass gain per steer at a stocking rate of 10,01 steers per ha was 67,8 kg and therefore the gain per ha was 678,8 kg (Figure 23).

The stocking rate that would have given the maximum profit per ha was calculated by the method used by Booysen (1975). For this calculation the equation used was derived from the Jones and Sandland (1974) model. The equation was

$$R = \frac{br - m}{2\ cr}$$

where b and c are constants in the equation used to calculate R at which body mass gains per ha were theoretically at a maximum, r is the price of the product (body mass gain) per kg in cents and m is the variable costs (interest on capital, veterinary and dipping costs, labour and other costs) in cents per day associated with holding a steer. Then

$$R = \frac{(135,5857 \times 33) - 7}{2 \times 6,771 \times 33}$$

$$R = \frac{4467,3281}{446,886}$$

$$R = 10,00 \text{ steers per ha}$$

Therefore the stocking rate that would have given the maximum profit per ha is very close to that which would have given the maximum body mass gains per ha.

The results of these experiments indicated what stocking rates should be imposed on the three grasses fertilized with 350 kg N and 90 kg P_2O_5 per ha annually to give maximum body mass gains per ha and maximum profit per ha. However, the grasses used all developed weaknesses during the experiment. Were the same amounts of fertilizers applied to a more suitable grass, even greater body mass gains and profit might be obtained.

4.3.4 The various effects of grazing on grasses

The experiments described in Section 4.3.3 provided an opportunity to study various effects that grazing might have on pastures other than those on herbage and livestock production. For example, basal cover of swards might be affected by defoliation and by trampling. Moreover, heavy trampling of the soil, particularly of a silty clay, might compact it, causing reduced infiltration and increased run-off of water ; both of which factors could affect productivity of the sward. Against this, compaction of any soil might be reduced or prevented if that soil has a grass sward of dense basal cover growing on it. Furthermore, if the soil were compacted by the trampling of the cattle grazing intensively on a grass, greater traction would be required to plough the soil compared to that required on a soil that was not compacted.

To assess the effects of intensive grazing on grass swards and on the soil under swards, differences in basal cover, soil density, rate of water infiltration and resistance to the passage of a plough through the soil after a period of intensive grazing, were measured on the pastures of the four grasses used for the experiments described in Section 4.3.3. These grasses were Chloris gayana (cv. Giant Rhodes), Cynodon nlemfuensis var. nlemfuensis (cv. Muguga), Panicum coloratum (cv. Bushman Mine) and P. repens (cv. Victoria Falls). Giant Rhodes was grazed only at a stocking rate of 9,88 yearling steers per ha while the other grasses were grazed at stocking rates of 9,88 ; 12,36; 14,83 and 17,30 yearling steers per ha in the 1968-69, 1969-70 and 1970-71 growing seasons. The grasses all received 350 kg N and 90 kg P_2O_5 per ha, annually.

Experimental Objectives

(i) Basal cover

To determine the effects of various stocking rates on changes in the basal covers of four grasses grazed during the growing season. Annual basal cover measurements of swards would indicate whether they were becoming denser or sparser with specific treatments. A vigorous sward is likely to have a dense basal cover while a deteriorating one is likely to have a more open cover.

(ii) Soil density

To determine to what degree stocking rate affects the density of the soil on which the grass is growing.

(iii) Water infiltration rate

To determine whether various stocking rates imposed on different grasses affect the rate at which water infiltrates the soil.

(iv) Specific soil resistance (S.S.R)

To determine whether the resistance of the soil to a plough used to plough a sward is affected by the grass grown and by the stocking rate at which it was grazed.

Materials and Methods

The designs of the two experiments have already been described in Section 4.3.3.

(i) Basal cover

Estimations of basal cover in both experiments were made by the point quadrat method using a frame containing 10 spikes spaced 5,08 cm apart.

Before the experiments started all grasses and all paddocks had been treated similarly (Section 4.3.3) and it was assumed that the basal covers of all paddocks of the same grass would be similar. Therefore in each replicate only one paddock of each grass in the experiments was used to estimate the initial basal cover of the grasses in the experiments. In subsequent basal cover estimates, point quadrating was done in every paddock in the two experiments.

The frame was placed in 100 positions (10 rows of 10 positions each) within each paddock giving a total of 1 000 points per paddock. The rows were spaced so that the surface of each paddock was evenly covered and the frame was placed at every eight paces taken by the operator within each line. A strike was only recorded if, at ground level, a spike touched a stem which was rooted at that point. Strikes on stems which were not rooted at the point of contact were not recorded.

The experimental stocking rates were imposed on the grasses in the 1968-69, 1969-70 and 1970-71 growing seasons. In the May to June periods of 1969, 1970 and 1971 the basal cover of all grasses and all paddocks in the two experiments was estimated in the manner already described.

(ii) Soil density

When grazing ceased in the two experiments in April 1971, soil density measurements were made on all pastures at 7,62 and 22,86 cm below ground level (Metelerkamp, 1971) to determine whether grazing had compacted the soil. Four core samples were taken diagonally across each paddock at both depths. The samples taken nearest to the corners of the plots were 9 m away from the corners while the remaining sample points were evenly spaced on the diagonal. At each sample point the soil was excavated to 7,62 cm below soil surface and the sample area and immediate surrounds saturated with water. This was done to facilitate the operation of the core sampler. After the core samples had been taken at the 7,62 cm depth the soil was excavated to 22,86 cm below soil surface, the soil was again saturated and the sample taken at this depth.

The core sampler consisted of two small cylinders each measuring 48 x 38 mm that were housed, adjacent to one another, in an external cylinder threaded at both ends. At one end of the external cylinder a cylindrical head with 48 mm internal diameter was screwed on. The head was tapered to facilitate entry of the sampler into the soil. At the other end of the external cylinder a round metal base plate with handle was screwed on. The base plate had holes drilled in it to allow air trapped within the cylinder to escape when the sampler was being pushed or hammered into the soil. The object of having two cylinders was for ease of removal of the sample of soil from the cylinders. When the soil was thoroughly wet the sampler was driven into the soil until the head was level with the soil excavated to 7,62 or 22,86 cm below soil surface level. The sampler was removed, the head unscrewed and the cylinders enclosing a core of soil taken out. The soil at each end of the internal cylinder was trimmed off flush with a knife. The core sample was then removed from the cylinders by sliding each cylinder off in opposite directions. This left a soil core sample 48 mm in diameter and 76 mm long. The samples were oven-dried and then weighed. By dividing the volume of each core sample (68,79 ml) by the mass of the core, soil density in g per ml was obtained.

In addition, four core samples were taken at each depth at each end of each replication of the experiment in adjacent veld, so that soil density under veld could be compared with that under intensively grazed pasture.

(iii) Water infiltration rate

The water infiltration measurements were done on the two experiments between the 18 and 22 May 1971. The soil at this time contained 12,7 % moisture. The technique used was to site a short section of a 10,16 cm internal diameter steel pipe on bare ground within the pasture. One edge of the pipe had been tapered to facilitate sealing the pipe with the ground in order to contain the water in the pipe. Sealing was achieved by pressing the pipe into the ground and simultaneously turning the pipe to the left and to the right, disturbing as little soil as possible. Once the pipe was sealed with the soil, 100 ml of water was poured into the pipe and the time taken for all the water to infiltrate the soil was noted by means of a stop watch. The measurements were made on bare soil because it was found that if a grass plant was contained within the pipe, water tended to seep rapidly into the soil via channels next to the root system. In each paddock four such measurements were taken on the diagonal opposite to that used for the soil density measurements but at corresponding positions. The four readings obtained for each paddock were meaned.

Similar measurements (16 sites) were made in adjacent veld and in maize plots (16 sites) within the same experimental area. In the maize, eight measurements were taken where the stover was ploughed under annually and eight where it was removed annually. These additional measurements were taken to compare the rate of infiltration of water on these sites with those under intensively grazed pasture.

(iv) Specific soil resistance (S.S.R)

Ploughing of the grass pastures used in the two experiments started on 10 May 1971 when the soil was dry (12,7 % moisture) and the measurements were completed three days later. The mechanical analysis of the soil is given under Section 2.2.

A caterpillar tractor and a trailing three-furrow disc plough fitted with standard 70 cm diameter discs were used to plough the grasses under. A mouldboard plough was tried but the soil was found too hard for this plough to do the operation satisfactorily.

The tractor was linked to the plough through a dynamometer which measured the draught required to pull the plough. Ploughing started in the centre of the paddocks along the length of each replication of the two experiments in both directions. When the opening furrows in both directions had been completed dynamometer readings were taken in each paddock as the plough moved from one plot to the other. Boundaries between paddocks were still clearly visible. With each pass of the plough, five dynamometer readings were taken per paddock by a recorder walking alongside the tractor and plough. A pressure gauge attached to the dynamometer with a flexible lead enabled the recorder to carry the gauge and make the readings. In each paddock 50 such readings were taken, 25 in each direction. These were meaned for each paddock.

With each pass of the plough the width and depth of the furrow was recorded along a line across the middle of each paddock. Thus in every plot 10 of each of these measurements were made which were meaned. The specific soil resistance (S.S.R) was used as the measuring unit in preference to plough draught as it was the soil property that was being measured and not the characteristics of a particular plough (Meikle, 1978). As the data was comparative in nature it was decided to include total plough draught in the calculation of S.S.R. This considerably simplified the equipment needed for measurement. The S.S.R. was calculated using the formula

$$\text{S.S.R.} = \frac{d}{x \times y}$$

where d is the total plough draught in newtons (N), x is the width of cut of the plough in cm, and y is the depth of plough furrow in cm. S.S.R. is expressed in kilopascals (kPa).

When all measurements on the pastures were complete an area of veld adjacent to the pastures was also ploughed. Similar measurements to those taken on the pastures were made and the S.S.R. for soil under veld calculated. Thus the S.S.R. of soil under cultivated pasture and under veld could be compared. The soil under veld contained 10,84 % moisture when ploughed. The plough settings were the same for both sites.

Results

(i) Basal Cover

The initial basal cover of the four grasses in November 1968 before the experimental stocking rates were imposed on the grasses in the two experiments are shown in Table 24.

Table 24. Mean basal cover of four grass pastures expressed as a percentage of total pasture area.

	Grass			
	Giant Rhodes	Muguga Star	Bushman Mine Panicum	Victoria Falls Panicum
Basal cover, %	1,80	3,70	2,20	2,53

Muguga Star had the highest initial basal cover and Giant Rhodes the lowest. Bushman Mine Panicum and Victoria Falls Panicum had similar, and intermediate, covers.

In Table 25 the basal covers of the four grasses grazed at a stocking rate of 9,88 steers per ha for three seasons in Experiment 1 (Section 4.3.3) are shown after each season's experimental grazing together with their three-year means. The basal covers of all weeds in the swards are also shown.

Table 25. The mean basal cover as a percentage of total pasture area of four grasses (G) and weeds (in parenthesis) grazed at a stocking rate of 9,88 steers per ha during three growing seasons and fertilized with 350 kg N and 90 kg P_2O_5 per ha, annually. (Analysis of variance table Appendix 2.36).

Year	Grasses				Means four grasses
	Giant Rhodes	Muguga Star	Bushman Mine Panicum	Victoria Falls Panicum	
1969	1,77(0,5)	5,27(0,0)	7,10(0,4)	4,50(0,4)	4,66(0,3)
1970	2,30(0,6)	7,60(0,0)	9,00(0,2)	5,60(1,1)	6,13(0,5)
1971	1,23(2,4)	7,03(0,4)	9,83(0,3)	4,63(3,0)	5,66(1,5)
Three-year means	1,77(1,2)	6,63(0,1)	8,64(0,3)	4,91(1,5)	5,46(0,8)

	SE ±	LSDs 5%	LSDs 1%	LSDs 0,1%
1969	1,72	3,43	5,20	6,36
1970	0,64	1,28	1,94	3,11
1971	1,96	3,92	5,95	9,56
Three-year means	1,30	2,72	4,12	4,62

The three-year mean basal covers of Bushman Mine Panicum and Muguga Star were greater ($P < 0,01$) than the cover of Giant Rhodes, and the mean basal cover of Bushman Mine Panicum was greater ($P < 0,05$) than that of Victoria Falls Panicum. Of all the swards Victoria Falls Panicum contained the greatest proportion of weeds.

At the end of the first season's grazing (1969) the basal covers of Muguga Star, Bushman Mine Panicum and Victoria Falls Panicum had increased considerably compared with their cover before grazing started, while the basal cover of Giant Rhodes had remained nearly the same (Tables 24 and 25). Between 1969 and 1970 basal cover of all the grasses had increased but between 1970 and 1971 only the cover of Bushman Mine Panicum had shown any further increase. The basal covers of Giant Rhodes and Victoria Falls Panicum were 46,5 % and 17,3 % lower in 1971, respectively, compared with their cover in 1970. The basal cover of Giant Rhodes in 1971 was lower than its initial cover before experimental grazing started (Tables 24 and 25). The basal cover of Muguga Star was only slightly lower in 1971 than in 1970.

Although 1 000 points taken with a point quadrat provided an acceptable degree of experimental accuracy (cv. range 6,6 to 28,3 %) for the basal cover of the grasses it did not provide an acceptable degree of accuracy for the total basal cover of weeds in the swards. For the weeds, cv.'s of 63,4 to 114,6 % were obtained and for this reason statistical criteria for them are not presented. However, the proportion of weeds in Giant Rhodes and Victoria Falls Panicum tended to increase with time but in Muguga Star and Bushman Mine Panicum swards the weed population was negligible. In 1971 weeds comprised 67,1 % of the total basal cover in Giant Rhodes swards, 39,3 % of Victoria Falls Panicum swards and only 5,4 % and 2,9 % in Muguga Star and Bushman Mine Panicum swards, respectively. The principal weeds were Eluesine indica, Setaria pallide-fusca, Sporobolus pyramidalis and Paspalum commersonii.

In Figure 24 the basal cover of three grasses grazed at stocking rates of 9,88; 12,36; 14,83 and 17,30 steers per ha for three seasons in Experiment 2 (Section 4.3.3) are shown after each seasons grazing with their three-year means. The total basal cover of all weeds in the swards is also shown.

The three-year mean basal cover of Bushman Mine Panicum over all stocking rates was greater than that of Muguga Star ($P < 0,05$) and of Victoria Falls Panicum ($P < 0,01$). Stocking rate had no effect on the three-year mean basal covers of the grasses . The mean basal cover of the weeds in Victoria Falls Panicum pastures was similar at all stocking rates. In Muguga Star and

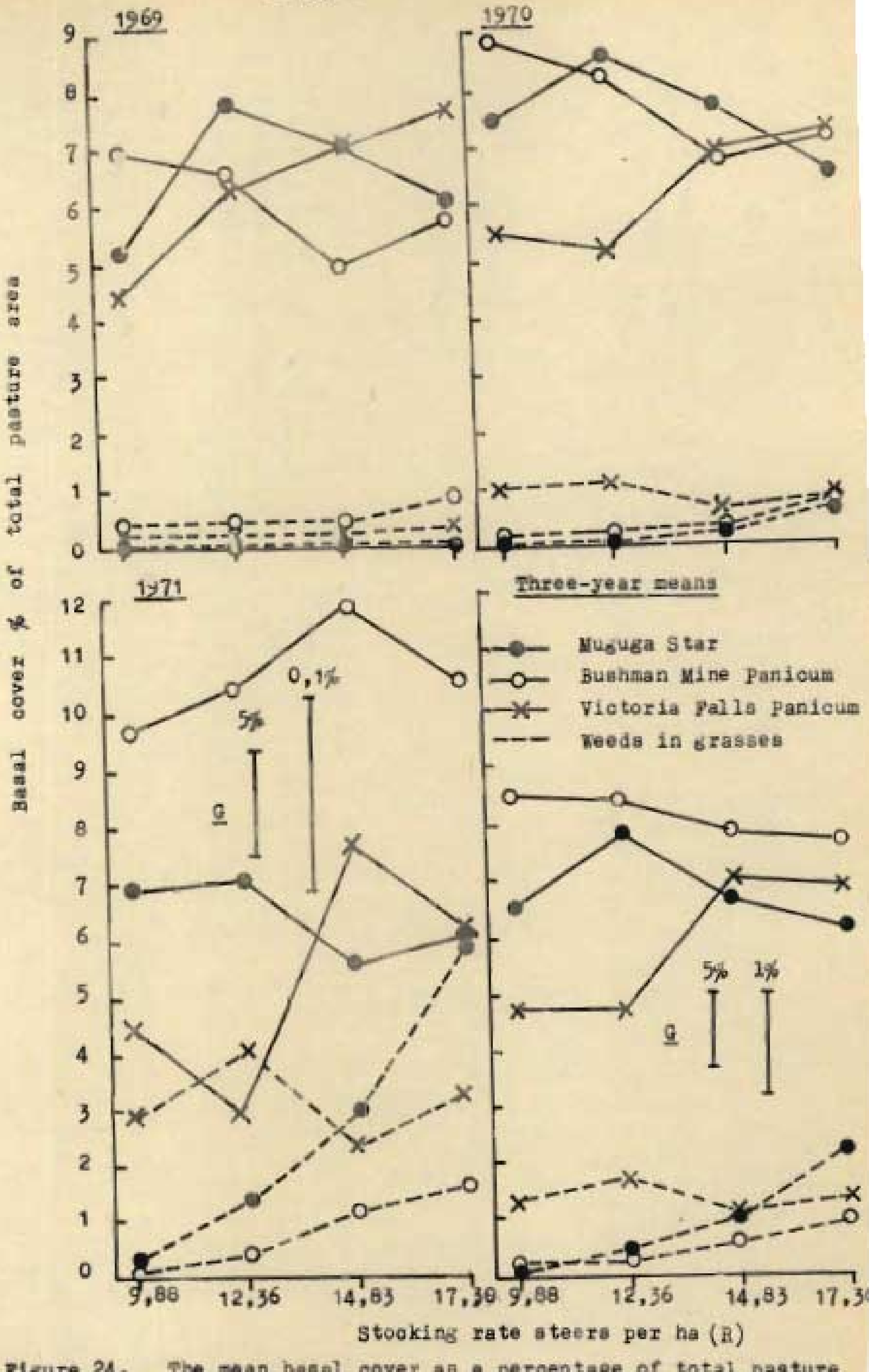


Figure 24. The mean basal cover as a percentage of total pasture area of three grasses (G) and weeds grazed at four stocking rates (R) during three growing seasons and fertilized with 350 kg N and 90 kg P_2O_5 per ha, annually (Analysis of variance table Appendix 2.37).

Bushman Mine Panicum pastures the amount of weed tended to increase with increasing stocking rate. No statistical criteria are presented for basal covers of weeds for reasons already given in regard to Experiment 1.

No differences in basal cover between grasses were found in 1969 and 1970 but in 1971 Bushman Mine Panicum had a denser cover ($P < 0{,}001$) than either Muguga Star or Victoria Falls Panicum. Only in 1969 did stocking rate have any influence on the basal cover of the grasses. With Muguga Star basal cover increased between the first and second stocking rates and thereafter decreased with increasing stocking rate but only between the first two stocking rates were differences significant ($P < 0{,}05$). The basal cover of Victoria Falls Panicum increased with increasing stocking rate but significant differences ($P < 0{,}05$) only occurred between the first and third and between the first and fourth stocking rates.

In the first two years the proportions of weeds in all three grasses were small but by the third year weeds had increased. In Victoria Falls Panicum there was no relationship between stocking rate and proportion of weeds but in Bushman Mine Panicum and particularly in Muguga Star pastures the proportion of weeds increased with increasing stocking rate. The weeds were the same as those found in Experiment 1.

(ii) Soil density

In Table 26 the density of the soil under four grasses grazed at a stocking rate of 9,88 steers per ha in Experiment 1 is shown.

Table 26. The density of oven-dried soil in g per ml at 7,62 and 22,86 cm below soil surface under four grasses (G) fertilized with 350 kg N and 90 kg P_2O_5 per ha, annually and grazed at a stocking rate of 9,88 steers per ha for three growing seasons. (Analysis of variance table Appendix 2.38).

Grass (G)	Soil Depth cm		G means
	7,62	22,86	
Giant Rhodes	1,42	1,32	1,37
Muguga Star	1,38	1,29	1,34
Bushman Mine Panicum	1,39	1,27	1,33
Victoria Falls Panicum	1,39	1,29	1,34
Depth means	1,40	1,29	1,35
S E ±	0,05	0,04	

There were no differences at both depths in the density of the soil under the four grasses. The density of the soil at the 22,86 cm depth was slightly lower than that at the 7,62 cm depth for all grasses.

In Table 27 the density of the soil under three grasses grazed at four stocking rates in Experiment 2 is shown.

Table 27. Density of oven-dried soil in g per ml at 7,62 and 22,86 cm below soil surface under three grasses (G) fertilized with 350 kg N and 90 kg P_2O_5 per ha, annually and grazed at four stocking rates (R) during three growing seasons. (Analysis of variance table Appendix 2.39).

Grass (G)	Depth cm	Stocking rate (R) steers per ha				G means
		9,88	12,36	14,83	17,30	
Muguga Star	7,62 22,86	1,38 1,29	1,42 1,33	1,42 1,36	1,42 1,30	1,41 1,32
Bushman Mine Panicum	7,62 22,86	1,39 1,27	1,38 1,28	1,38 1,32	1,42 1,32	1,39 1,30
Victoria Falls Panicum	7,62 22,86	1,39 1,29	1,36 1,28	1,39 1,29	1,41 1,31	1,39 1,29
R Means	7,62 22,86	1,39 1,28	1,39 1,30	1,40 1,32	1,42 1,31	1,40 1,31
Veld	7,62 22,86	1,29 1,30				1,29 1,30
S E ±		G		R		
	7,62 22,86	0,01 0,01		0,02 0,01		

Soil densities at 7,62 cm were similar under all grasses and so were the densities at 22,86 cm. Also, the various stocking rates imposed on the grasses had no effect on soil density. The soil density at the 7,62 cm depth was slightly more than that at the 22,86 cm depth. Soil density at 7,62 cm depth under veld was less than that under cultivated grass but at the 22,86 cm depth density of soil under veld and cultivated grass were similar.

(iii) Water infiltration rate

The rate at which water infiltrated the soil under four grasses grazed at a stocking rate of 9,88 steers per ha in Experiment 1 is shown in Table 28.

Table 28. Mean time in minutes for 100 ml water to infiltrate the soil under four grasses (G) fertilized with 350 kg N and 90 kg P_2O_5 per ha, annually and grazed at a stocking rate of 9,88 steers per ha for three growing seasons. (Analysis of variance table Appendix 2.40).

Grasses (G)	Giant Rhodes	Muguga Star	Bushman Mine Panicum	Victoria Falls Panicum	G means
Mean time minutes	58,2	44,1	49,0	74,3	56,4
S E ±		30,6			

The times taken for 100 ml of water to infiltrate the soil under the four grasses were not significantly different despite the fact that the range between the fastest (Muguga Star) and slowest (Victoria Falls Panicum) rates of infiltration was 30,2 minutes. There was a high degree of experimental error in these measurements (cv. 54.3%) which probably accounts for the lack of significant effects.

In Table 29 the rate at which water infiltrated the soil under three grasses grazed at four different stocking rates is shown.

Neither grasses nor the different stocking rates at which the grasses were grazed were significantly different from one another in terms of the rate at which water infiltrated the soil. On veld however, it took less than half the time for the same amount of water to infiltrate the soil.

Table 29. Mean time in minutes for 100 ml water to infiltrate the soil under three grasses (G) fertilized with 350 kg N and 90 kg P_2O_5 per ha, annually and grazed at four stocking rates (R) during three growing seasons compared with veld and with maize. (Analysis of variance table Appendix 2.41).

Grasses (G)	Stocking rate (R) steers per ha				G means
	9,88	12,36	14,83	17,30	
Muguga Star	44,1	37,8	78,8	49,9	52,7
Bushman Mine Panicum	49,0	59,9	69,2	53,3	57,9
Victoria Falls Panicum	74,3	41,5	29,7	37,8	45,8
R means	55,8	46,4	59,2	47,0	52,1
Veld					22,5
Maize stover removed					19,6
Stover retained					17,0
S E ±	G 8,4		R 9,7		

On land ploughed annually for a maize crop it took considerably less time, as expected, for the same amount of water to infiltrate the soil as it did on the pastures but only slightly less time than on veld. On the maize land where maize stover was returned to the soil each year, it took 13,3 % less time for the water to infiltrate the soil than it did where maize stover was removed annually.

(iv) Specific soil resistance (S.S.R)

In Table 30 the S.S.R to a disc plough used to plough under four grasses grazed at a stocking rate of 9,88 steers per ha in Experiment 1 is shown.

Table 30. Specific soil resistance (S.S.R) in k Pa to a disc plough used to plough under four grasses (G) grazed at a stocking rate of 9,88 steers per ha during three growing seasons. (Analysis of variance table Appendix 2.42).

Grasses (G)	Giant Rhodes	Muguga Star	Bushman Mine Panicum	Victoria Falls Panicum	G means
S.S.R. k Pa	90,95	97,03	112,55	93,65	98,55

SE ±	LSD 5%	LSD 1%
3,29	6,10	9,25

The S.S.R. on Bushman Mine Panicum was greater ($P < 0,01$) than on the other three grasses.

The S.S.R. to a disc plough used to plough under three grasses grazed at four different stocking rates is shown in Figure 25.

There were no differences between grasses or between stocking rates in S.S.R. However, the interaction between grasses and stocking rates was significant. With Bushman Mine Panicum the S.S.R. decreased between the first and third stocking rates and then increased again to the fourth stocking rate, this quadratic effect being significant ($P < 0,01$). The S.S.R. of Victoria Falls Panicum increased at an increasing rate between the first

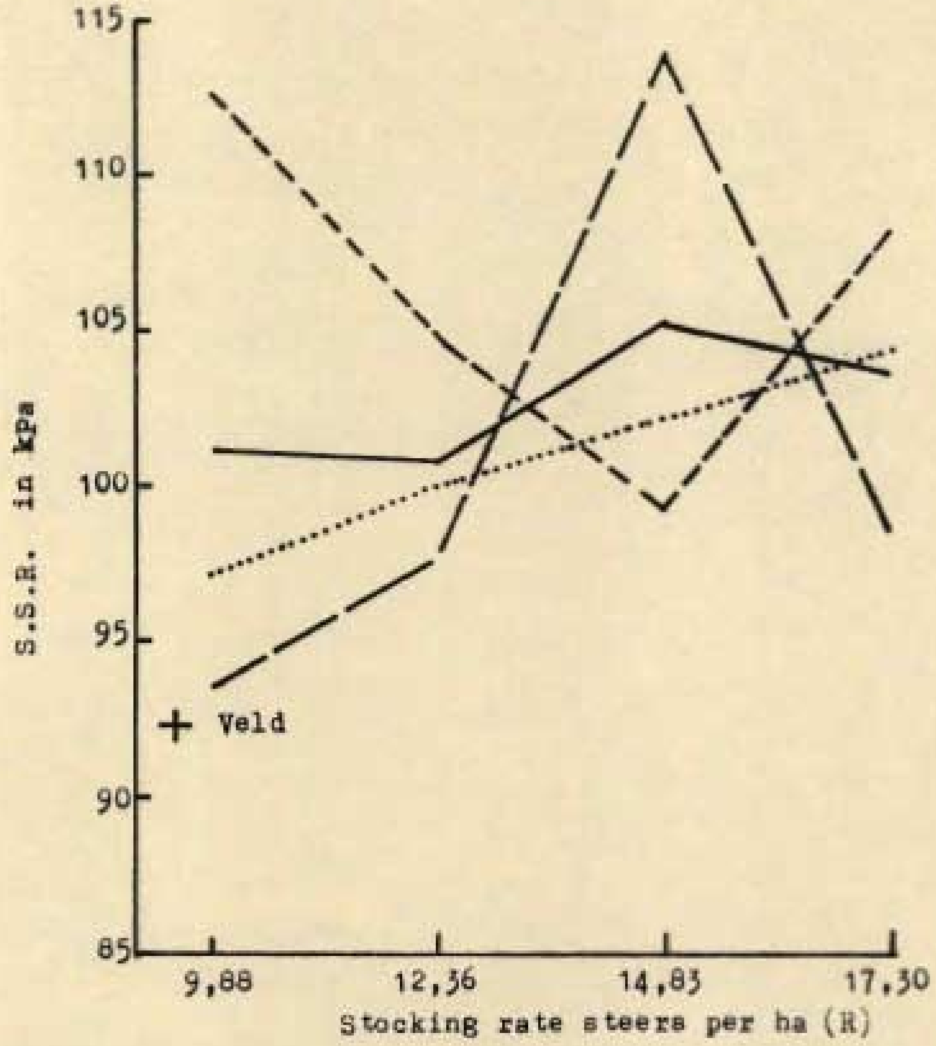


Figure 25. The specific soil resistance (S.S.R) in kPa to a disc plough used to plough under three grasses (G) grazed at four stocking rates (R) during three growing seasons compared with the S.S.R. of veld. (Analysis of variance table Appendix 2.43).

Grasses (G)

....	Muguga Star
– – – –	Bushman Mine Panicum
—— ——	Victoria Falls Panicum
————	Mean

and the second, and the second and the third stocking rates and then decreased to the fourth stocking rate and this cubic effect was also significant ($P < 0{,}05$). The S.S.R. of Muguga Star increased with increasing stocking rate but this response was not significant.

Discussion

Only in 1970 was the basal cover of Giant Rhodes greater than its initial cover in 1968 (Tables 24 and 25). By the third year Giant Rhodes pastures had deteriorated to the extent where only 33,9 % of the basal cover was Giant Rhodes and 66,1 % was weed. This is clearly a grass which is unable to withstand intensive grazing.

In 1970 Muguga Star became infested with a black smut, Ustilago cynodontis, on the flower and seed heads. This disease appeared to affect it's vigour, particularly during 1970-71 and this probably accounts for its slightly lower basal cover in 1971 compared with 1970 (Figure 24). The basal cover of weeds in Muguga Star pastures was small during the first two years but increased markedly with increasing stocking rate in the third year and at the highest stocking rate was equal to the grass cover (Figure 24). This also indicates that the smut reduced the vigour of the Muguga Star swards.

During the 1969-70 season, one of below average and poorly distributed rainfall (Appendix 1), it became apparent that Victoria Falls Panicum was not suited to dryland conditions. Patches of it died out and these areas were invaded by weeds in the 1970-71 season. At the end of 1970-71 season 39,3 % of the total basal cover of the sward over all stocking rates comprised weeds.

In all three seasons Bushman Mine Panicum had a consistently good basal cover and it was on this grass that the densest basal cover of 12,1 % was recorded in 1971 where the stocking rate was 14,83 steers per ha. The three-year mean basal cover of this grass was also the highest of all the grasses. Furthermore the weed component in Bushman Mine Panicum swards was the lowest and so it is deduced that of the four grasses, Bushman Mine Panicum withstood intensive grazing most satisfactorily.

Only in 1969 did stocking rate have differential effects on the basal covers of the grasses (Figure 24), though its effects were inconsistent. A reason for the small response to stocking rate over the duration of the experiment could be that the periods for which the grasses were grazed each year became shorter as stocking rate increased although the number of steer grazing days per ha for all stocking rates were similar (Table 23). In consequence, pastures stocked at the two heavier rates were destocked in time to allow them to recover somewhat before the end of the season. For this reason basal covers of the grasses at the two heaviest stocking rates were no better or no worse than the basal covers at the two lighter stocking rates.

Because the densities of the soil 7,62 cm below soil surface on the intensively grazed grasses were similar regardless of the grass or stocking rate, it is clear that these factors did not have any influence on soil density at that depth. However, if the density of the soil under veld is compared with that under pasture there is a difference. The soil density under intensively grazed cultivated grass was 0,11 g per ml greater than soil under lightly grazed veld. A possible explanation for this difference is that virgin soil usually has a higher organic matter content and a better crumb structure than ploughed soil and therefore is not as dense.

At the 22,86 cm depth below soil surface there were also no differences in soil density between grasses or stocking rates but the soil was 0,09 g per ml less dense than the soil at 7,62 cm. This indicates that there was slight compaction nearer the soil surface or that the ploughing process caused the changes. This supposition is strengthened when the density of the soil under veld is compared with that of pasture since the density under veld was similar at both depths.

Larger variations in soil density may have been obtained had

2,54 cm below the soil surface. The conclusion reached from the results was that there was some compaction of soil under the intensively grazed grasses when compared with that under virgin veld.

There were no differences in the rate of water infiltration into the soil between grasses or between stocking rates. However, there was a large difference in the rates at which water infiltrated the soil under veld compared with pasture. This indicates that there might have been differences possibly in the physical structure and organic matter content of the soil under veld and under pasture but the soil density measurements showed that at the 7,62 cm depth the soil under pasture was only 8,5 % more dense than that of the veld. At the 22,86 cm depth soil densities were similar under pasture and under veld. This indicates that if there were differences in the physical structure of the soil under veld and under pasture they must have occurred between the soil surface and the 7,62 cm depth of sampling.

When the four grasses Giant Rhodes, Muguga Star, Bushman Mine Panicum and Victoria Falls Panicum grazed at a stocking rate of 9,88 steers per ha (Experiment 1) were ploughed under, the S.S.R. of Bushman Mine Panicum was greater than the other three grasses. This difference could not have been due to soil density because the densities of the soils under the four grasses were similar (Table 26). Bushman Mine Panicum did have a greater basal cover than the other grasses (Table 25) and this might have been the reason for the greater resistance to the plough. However, in Experiment 2 there were no differences in S.S.R. between Bushman Mine Panicum, Muguga Star and Victoria Falls Panicum despite the fact that Bushman Mine Panicum had a much higher mean basal cover in 1971 (Figure 24) when the grasses were ploughed under. Therefore the supposition arrived at in Experiment 1 that basal cover might have been the reason for the greater S.S.R. on Bushman Mine Panicum, must be treated with reserve. Although there was a significant interaction between grasses and stocking rate in Experiment 2, the results are difficult to interpret despite a high degree of experimental accuracy (cv. 5,9%) and no explanation is offered.

The veld had a similar S.S.R. to Giant Rhodes grass. Although the basal density of the veld was not measured it is assumed that this was lower than the cultivated pastures and therefore the veld grasses would have presented less resistance to the passage of the plough. However, the soil density measurements indicated that soil under veld within the plough layer (7,62 cm below ground level) was less dense than the cultivated grasses and it may also have been for this reason that there was less resistance to the passage of the plough through the soil.

General conclusions on the various effects of grazing on grasses

The measurements made on the basal cover of grasses, the density of the soil under grasses, the rate of water infiltration into the soil and the resistance to the passage of a plough through the soil after a period of grazing, showed that the grass used and the stocking rate at which the pastures were grazed influenced some of the measurements. However, the differences between the grasses grazed at the various stocking rates were not as great as were anticipated considering that grasses with different growth habits were used and the intensities at which they were grazed. Interpretation of some of the results was difficult despite a high degree of experimental accuracy. Furthermore no literature could be found on the subject and therefore the results of similar research could not be compared. Clearly this is a field of research which does not appear to have been investigated.

Generally the results show that the basal covers of the grasses used in the experiment varied from year to year and that the stocking rates at which they were grazed had little influence on this. Weeds tended to invade grasses that had been affected by disease or by poor rainfall at a faster rate than grasses that remained healthy and that were not affected by poor rainfall.

Heavy trampling by cattle of the soil under the grasses did not affect the density of the soil because this was similar under all grasses at all stocking rates. However, it was observed that the soil under veld at 7,62 cm depth of sampling was of lower density than soil under pasture, indicating either that there had been some soil compaction on pastures or that the ploughing of the soil for establishment of pastures caused this difference.

There were no differences in the rate at which water infiltrated the soil under the grasses and nor did stocking rate affect this. However, observations showed that it took the same volume of water (100 ml) 2,4 times as long to infiltrate the soil under pasture compared with soil under veld. This indicates that there might have been differences in the physical structure and organic matter content of the soil under veld and under pasture. Soil under pasture was slightly more dense than under veld at 7,62 cm depth but similar at 22,86 cm depth. Therefore any differences in the physical structure would have occurred between the 7,62 cm and the soil surface which was not sampled.

Differences to the resistance to the passage of a plough through the soil under four grasses grazed at a stocking rate of 9,88 steers per ha for three growing seasons were found. The differences appeared to be related to the basal cover of the grasses at the time of ploughing. However, this result must be treated with reserve because where three grasses were grazed at four stocking rates there were no differences between grasses to the passage of a plough despite differences between grasses in basal cover. The rate of stocking pastures with cattle also affected the resistance to a plough through the soil but interpretation of these results was not possible. It was observed that the resistance to a plough through the soil under intensively grazed grasses was greater than that in soil under natural veld grasses. There were four possible reasons for this. Firstly the soil under veld was observed to be less dense than under pasture, secondly that the basal density of the veld grasses was lower than on pasture although this was not measured, thirdly the veld and pastures were of different structures in that veld was mainly tufted and pastures mainly sod, and fourthly that ploughed soil has a different physical structure to that of virgin soil.

4.4 The Characterisation of the Growth of Cynodon aethiopicus (cv. No. 2 Star)

In early experiments in which the herbage yields of grasses were compared (Section 4.1.1) it was found that Panicum coloratum (cv. Bushman Mine) and Cynodon nlemfuensis var. nlemfuensis (cv. Muguga Star) yielded more herbage (2100 and 1960 kg dry matter per ha, respectively) than C. aethiopicus (cv. No. 2 Star), henceforth referred to as Star grass. However, in grazing experiments where the effects of stocking rates on grasses were determined (Section 4.3.3), both Bushman Mine Panicum and Muguga Star developed weaknesses and proved to be unsuitable for grazing on dryland. In contrast, Star grass, both in preliminary grazing trials (Section 4.3.1) and in other experiments (Section 4.3.2) had shown that it had the ability to withstand intensive grazing and drought and was disease free. Also it has been grown in Rhodesia for many years with success and has a wide range of adaptation. Furthermore, Harlan (1970), Harlan, de Wet, Huffine and Deakin (1970) and Harlan, de Wet and Rawal (1970) described C. aethiopicus Clayton et Harlan as being the most widely distributed species in East Africa with a distribution from Ethiopia to the Transvaal, from coastal lowlands to highlands. For these reasons emphasis was given to Star grass in the pasture research programme between 1971 and 1975 and the remainder of this report deals principally with this grass.

In devising suitable systems of grazing management for a grass it is important to know what changes take place in the amount and quality of the herbage components during growth and development; that is, to characterise growth. Such a characterisation study was carried out during the 1974-75 growing season.

Experimental Objectives

To determine the changes in the amount and quality of the herbage components of Star grass during growth and development and to observe its regrowth potential after being harvested at different stages of growth. Such information might be used in devising systems of management that would maintain quality and production of herbage for grazing by beef cattle.

Materials and Methods

The study was carried out on a six-year-old pasture of Star grass that had been fertilized annually and grazed frequently during its life and was in a productive condition. Four replications of 24 plots each measuring 1,5 x 1,5 m were used. Before the rains started on 19 November 1974 (Appendix 1) all plots received 90 kg P_2O_5 per ha. In addition 500 kg N per ha was applied in four equal dressings at approximately monthly intervals starting on 20 November 1974 (see Figures 26 and 27). Three aspects of growth and development were studied and in all cases herbage was cut to 5 cm above ground level and net plots of 1 m^2 were harvested.

(i) Undisturbed growth

This was measured by harvesting plots serially at weekly intervals from the time growth started on 20 November 1974 until light interception in the sward was apparently at a maximum. Using this criterion two growth periods were studied. The first growth period lasted for 10 weeks from 20 November 1974 to 28 January 1975, that is, from early to mid growing season. On 28 January light interception in the sward was at a maximum and all plots not previously used were cut. These plots were then used to measure the undisturbed growth during the second period from mid-to-late growing season that lasted for 13 weeks from 28 January to 29 April 1975. At this time light interception in the sward was again at a maximum. The study was then terminated.

Light interception was measured at weekly intervals at solar noon on the day prior to harvesting plots. For this purpose a wooden probe fitted with photo-electric cells that were connected to a micro-ammeter was used. The probe was 33 cm long and 3 cm wide, and the 10 cells, which were made of selenium, were coupled in series and spaced 3 cm apart along the length of the probe. The cells were coupled to the micro-ammeter by means of an insulated flex 60 cm long. To measure light interception the probe was inserted into the sward at ground level and the reading taken.

Immediately thereafter another reading was taken above the canopy in full daylight, the difference between the two readings giving the amount of light intercepted by the sward.

At each harvest the yield of herbage and the proportions of green leaf, excluding sheaths, dead and dying leaf (hereafter termed dead leaf) and stem were determined by separating samples and oven-drying them. The dry mass, in vitro digestible dry matter and crude protein contents of each component were determined. The in vitro digestible dry matter was determined by digesting 0,25 g samples at 40°C for 48 hours in a mixture of four parts buffer solution to one part rumen liquor taken from fistulated sheep. After 'digestion' the samples were centrifuged, the liquor removed and the samples 'digested' again at 40°C for 48 hours in acid pepsin. The samples were again centrifuged, the liquor removed and the samples oven-dried. In vitro digestibility was then calculated by difference. The crude protein content of the various components of herbage were determined by the Kjeldahl method.

(ii) Initial regrowth

All plots harvested serially to determine uninterrupted growth were harvested again one week later and the herbage yield termed initial regrowth. The object of this was to determine the regrowth potential of Star grass after being cut at different stages of growth and development. The herbage was not separated into leaf and stem in this case but samples were taken to determine dry matter.

(iii) Residual regrowth

Following the initial regrowth harvests all plots in both the first and second growth periods were allowed to grow until light interception in the undisturbed growth was at a maximum when all were cut and the herbage yield termed residual regrowth. This herbage was not separated into its different components but dry matter was determined from oven-dried samples.

(iv) Total regrowth

This was obtained by summing initial regrowth and residual regrowth for both the first and second periods of growth.

(v) Total production

This was the sum of undisturbed growth, initial regrowth and residual regrowth, for both the first and second growth periods.

Results

Regression models were fitted to all the data in both the first and second growth periods. In each case the model which fitted the data most accurately was adopted. In both periods of undisturbed growth the cubic regression model

$$y = a + bD + cD^2 + dD^3$$

where y is the dry matter yield, a, b, c and d are constants and D is the number of days from when growth started, was used.

The daily growth rate for the undisturbed growth was calculated from the model

$$y = a + bD + cD^2$$

where y is the dry matter yield and a, b and c are constants and D is the number of days from when growth started. Then growth rate was at a maximum when

$$\frac{dy}{dD} = 0$$

The observed and derived values and the regression models for : undisturbed growth, growth rate of undisturbed growth, light interception in undisturbed growth, residual regrowth, total regrowth and total production, are shown in Figures 26 and 27.

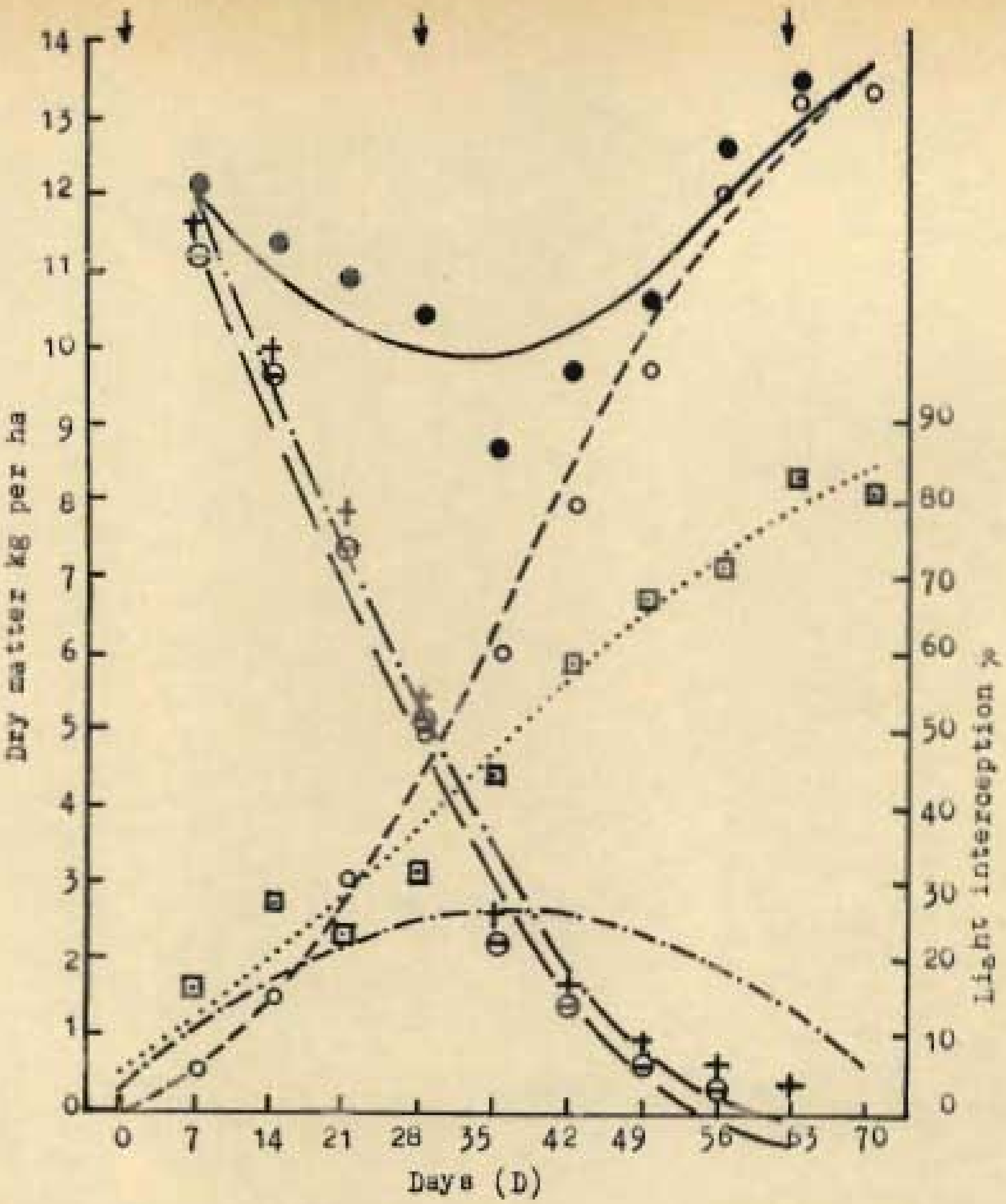


Figure 26. Growth curves of Star grass between 19 November 1974 and 26 January 1975 and the percentage light intercepted by a sward allowed to grow undisturbed. Arrows indicate when nitrogen was applied.

Undisturbed growth (UG) in 000'
$UG = 61,29 + 21,75\ D + 6,59\ D^2 - 0,06D^3$
$R^2 = 0,9981$

Residual regrowth (RR) in 000'
$RR = 13844,1 - 331,04D - 0,52D^2 + 0,035\ D^3$
$R^2 = 0,9950$

Total regrowth (TR) in 000'
$TR = 13844,1 - 331,04D - 0,52\ D^2 - 0,035\ D^3$
$R^2 = 0,9950$

Total production (TP) in 000'
$TP = UG + TR$

Daily growth rate of UG(DUG) in 00'
$DUG = 21,75 + 13,18\ D - 0,16\ D^2$
DUG at maximum when $\frac{dy}{dD} = 0$
when $13,18 - 0,36\ D = 0$
Maximum at 36,6 days

Light interception (LI) in %
$LI = 4,76 + 0,85\ D + 0,016\ D^2 - 0,00016\ D^3$
$R^2 = 0,9900$

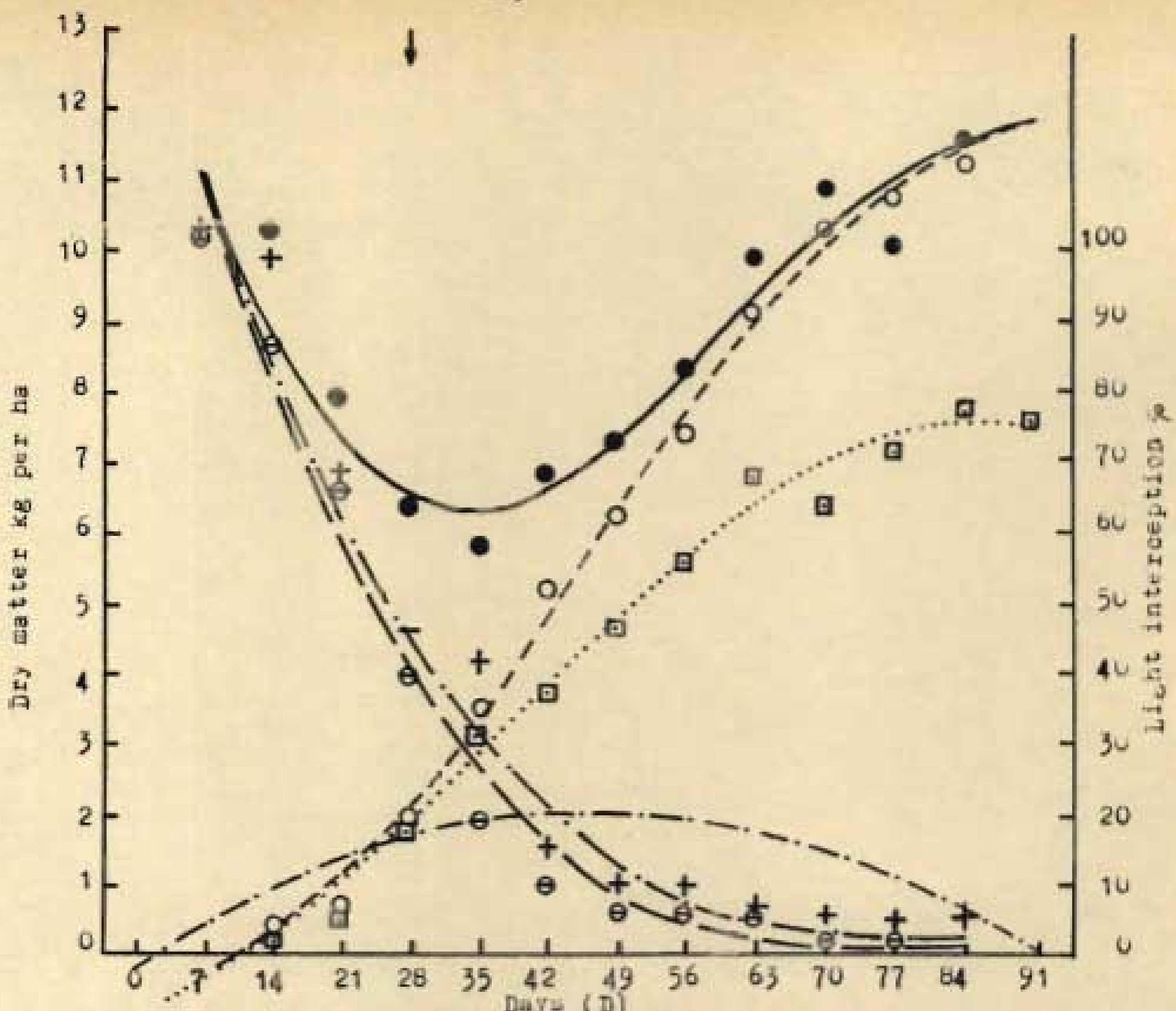


Figure 27. Growth curves of Star grass between 26 January and 29 April 1975 and the percentage light intercepted by a sward allowed to grow undisturbed. Arrow indicates when nitrogen was applied.

Undisturbed growth (UG) in 000'
$UG = -295,51 - 11,99\ D + 4,57\ D^2 - 0,032\ D^3$
$R^2 = 0,9926$

Residual regrowth (RR) in 000'
$RR = 14695,932 - 544,698\ D + 6,725\ D^2 - 0,027\ D^2$
$R^2 = 0,9703$

Total regrowth (TR) in 000'
$TR = 14546,65 - 508,64\ D + 5,98\ D^2 - 0,02\ D^3$
$R^2 = 0,9717$

Total production (TP) in 000'
$TP = UG + TR$

Daily growth rate of UG (DUG) in 00'
$DUG = -11,99 + 9,14\ D - 0,096\ D^2$
DUG at maximum when $\frac{dy}{dD} = 0$

when $9,14 - 0,192\ D = 0$
Maximum at 47,6 days

Light interception (LI) in %
$LI = -6,28 + 0,31\ D + 0,026\ D^2 - 0,0002\ D^3$
$R^2 = 0,9872$

The undisturbed growth in both the first and second periods of growth showed the typical sigmoidal growth curve. Growth started slowly for the first two to three weeks, increased rapidly for five to seven weeks, and then slowed down until light interception was at a maximum in the sward and the herbage was cut. Growth during the first period was more rapid than during the second. It reached a maximum of 13 550 kg dry matter per ha in 10 weeks in the first period (mean 194 kg per ha per day) and a maximum of 11 750 kg dry matter per ha in 13 weeks in the second period (mean 129 kg per ha per day). In both periods early flowering occurred in the fourth week of growth and by the fifth week the Star grass was in full flower. The calculated maximum daily growth rate occurred at 36,6 days (263 kg per ha per day) in the first period when light interception was 48,0%, and at 47,6 days (218 kg per ha per day) in the second period when light interception was 48,5%. At nine weeks in the first growth period light interception in the sward was at a maximum of 84,6% and in the second growth period it was at a maximum of 76,0 % at 12 weeks.

Initial regrowth was more uniform during the first growth period (mean 56 kg dry matter per ha per day, range 45 to 81 kg) than during the second period (mean 43 kg dry matter per ha per day, range 26 to 80 kg) (Figure 28). The data was too variable for regression models to be fitted, so only the actual data are presented. Most rapid initial regrowth in the first period occurred on plots harvested for undisturbed growth three weeks after growth started, whereas in the second period it occurred on plots harvested for undisturbed growth four weeks after growth started. The daily initial growth rates at these times were 81 and 80 kg dry matter per ha for the first and second growth periods, respectively.

Residual regrowth during both periods of growth (Figures 26 and 27) increased as time after the initial regrowth cuts increased. In the first period residual regrowth accumulated for eight weeks and in the second period it accumulated for 11 weeks when 11 510 and 11 200 kg dry matter per ha had accumulted, respectively.

In both growth periods greatest total regrowth was obtained on the first plots harvested for undisturbed growth followed by the first

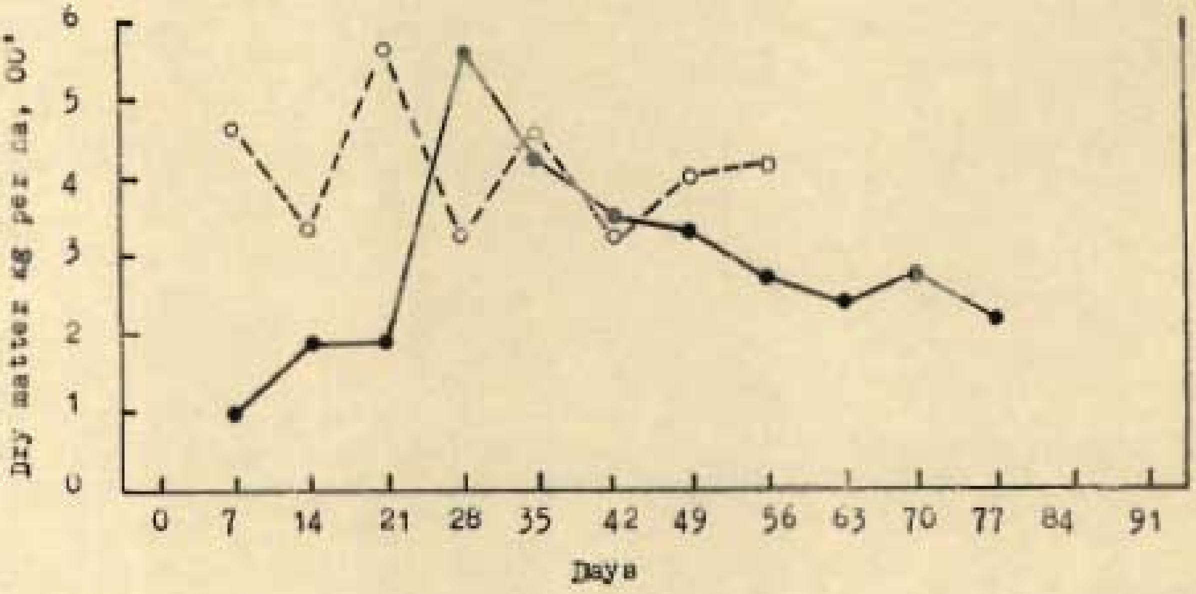


Figure 28. Initial regrowth of Star grass for the first (20 November 1974 to 28 January 1975) and second (28 January to 29 April 1975) growth periods, in kg dry matter per ha.

-o---o- First growth period

—•—•— Second growth period

harvests for initial regrowth. Total regrowth amounted to 11 990 and 11 270 kg dry matter per ha for the first, and second periods, respectively.

In both growth periods total production (Figures 26 and 27) was greatest at the beginning and at the end of the periods. Where plots were harvested seven days after growth started to determine uninterrupted growth followed by the initial regrowth cut and then the residual regrowth cut, total production was 12 510 kg and 11 100 kg dry matter per ha for the first and second periods, respectively. Total production at the end of the periods was 12 820 kg and 12 200 kg dry matter per ha for the first and second periods, respectively. Total production at the end of the periods comprised a single cut taken at 10 weeks in the first period and at 13 weeks in the second period. The smallest total production occurred at five weeks after growth started in both periods and amounted to 9 320 kg and 6 380 kg dry matter per ha for the first and second periods, respectively.

The most rapid rates of growth in the uninterrupted growth occurred between three and six weeks in the first growth period and between four and seven weeks in the second growth period (Figures 26 and 27). Light interception by the swards during these times was from 30 to 60% in the first period and from 26 to 60% in the second period. The results clearly show that harvesting Star grass during the period of most rapid growth (three to seven weeks after growth or regrowth starts) reduces the total production of herbage.

The amounts of green leaf, dead leaf and stem in the undisturbed growth of Star grass for the first and second periods of growth are shown in Figures 29 and 30. In Figure 29 the cubic regression model was used for all the data except for dead leaf where the quadratic model

$$Y = a + bD + cD^2$$ was used, where

y is the yield, a, b and c are constants and D is the number of days from when growth started. In Figure 30 the cubic model was used for undisturbed growth, stem and dead leaf but the quartic model was used for green leaf. This model is represented by the

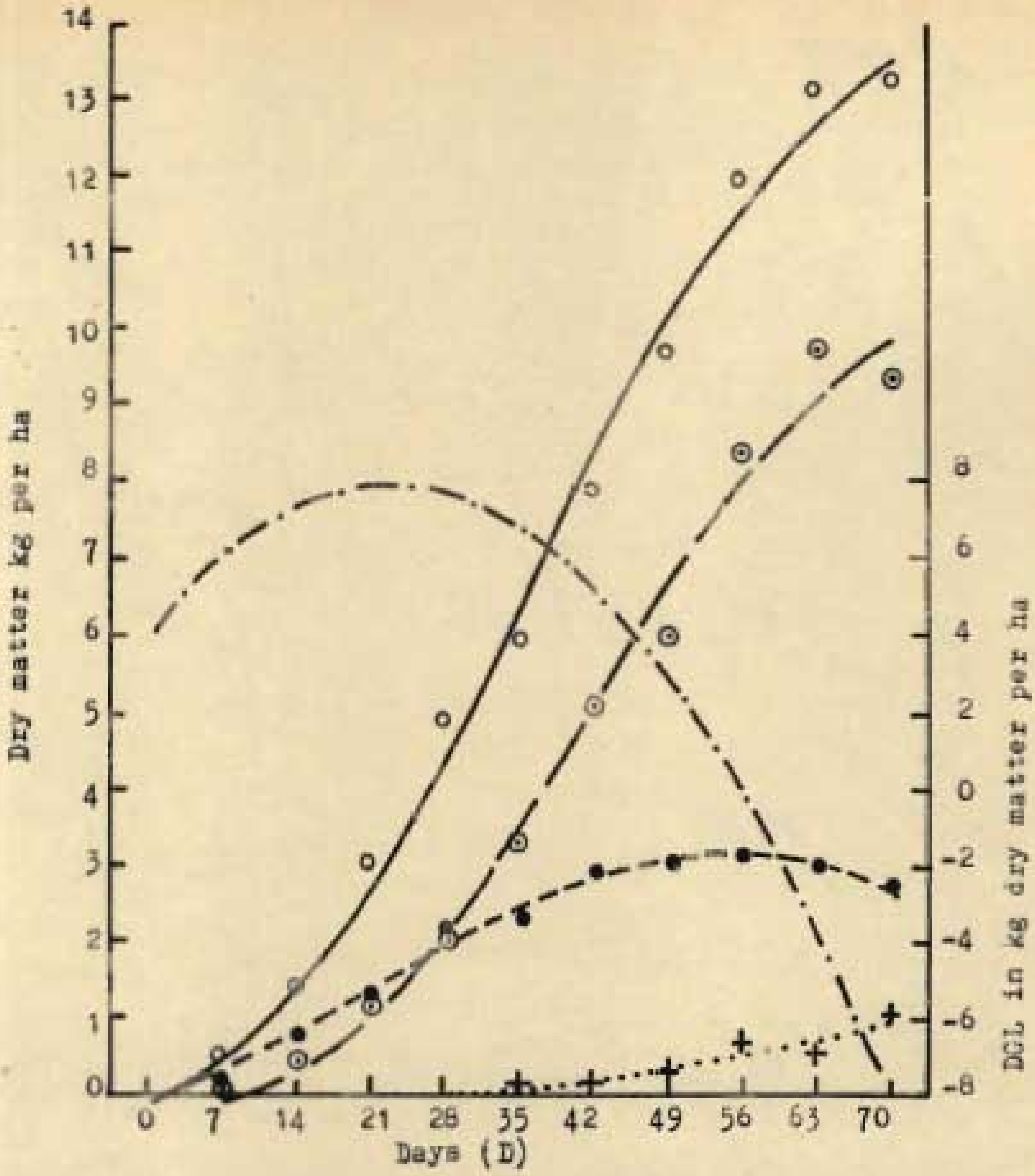


Figure 29. Amounts of green leaf, dead leaf and stem in the undisturbed growth of Star grass all in kg dry matter per ha, between 19 November 1974 and 28 January 1975.

Undisturbed growth (UG) in 000'
$UG = 61,29 + 21,75\ D + 6,59\ D^2 - 0,06\ D^3$
$R^2 = 0,9981$

Stem (S) in 000'
$S = 264,0037 - 92,00137\ D + 7,409378\ D^2 - 0,059158 D^3$
$R^2 = 0,9948$

Green leaf (GL) in 000'
$GL = -45,54185 + 44,24337\ D + 1,547857\ D^2 - 0,2321092 D$
$R^2 = 0,9983$

Daily growth rate of GL (DGL) in 0'
$DGL = 44,24 + 3,096\ D - 0,0696\ D^2$
DGL at maximum when $\frac{dy}{dD} = 0$
when $3,096 - 0,1392\ D = 0$
Maximum at 22,2 days

Dead leaf (DL) in 000'
$DL = 100842 - 6860\ D + 147\ D^2$
$R^2 = 0,4998$

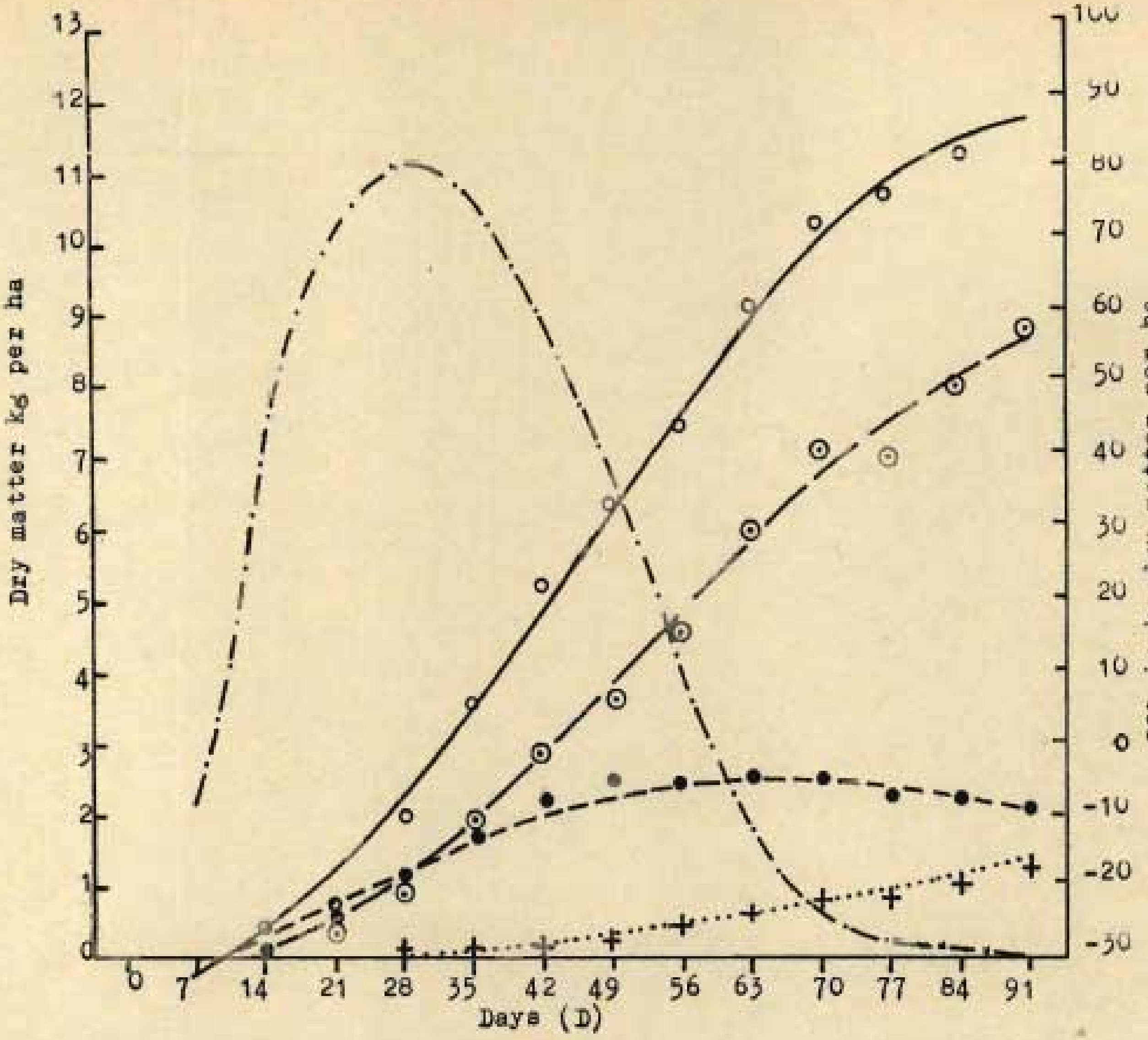


Figure 30. Amounts of green leaf, dead leaf and stem in the undisturbed growth of Star grass all in kg day matter per ha, between 28 January and 29 April 1975.

Undisturbed growth (UG) in 000'
$UG = -295,51 - 11,99\ D + 4,57\ D^2 - 0,0328\ D^3$
$R^2 = 0,9926$

Stem (S) in 000'
$S = 264,97 - 62,62\ D + 3,91\ D^2 - 0,0244\ D^3$
$R^2 = 0,9941$

Green leaf (GL) in 000'
$GL = 468,063 - 109,141\ D + 7,60296 D^2 - 0,12225 D^3 + 0,00059 D^4$
$R^2 = 0,9919$

Daily growth rate of GL (DGL) in 0'
DGL at maximum at 28,8 days
(for calculations see text)

Dead leaf (DL) in 000'
$DL = 388,93 - 35,30\ D + 0,889\ D^2 - 0,0043\ D^3$
$R^2 = 0,9960$

equation

$$y = a + bD + cD^2 + dD^3 + eD^4$$

where y is the yield, a,b,c,d and e are constants and D is the number of days after growth started.

In Figure 29 the daily growth rate of green leaves and the time when leaf growth was at a maximum were calculated in a similar manner as for undisturbed growth in Figures 26 and 27. But in Figure 30 the daily rate of growth for green leaves was calculated from the quartic model and the day (D) when growth was at a maximum from the same equation by differentiation represented by

$$D = b + 2 \times cD + 3 \times dD^2 + 4 \times eD^3$$

$$= -109{,}141 + 15{,}20592\ D - 0{,}36675\ D^2 + 0{,}00237824\ D^3$$

The daily rate of growth of green leaves was at a maximum (or minimum) when

$$15{,}20592 - 0{,}7335\ D + 0{,}0071347\ D^2 = 0$$

$$D = \frac{0{,}7335 \pm \sqrt{(-0{,}7335)^2 - 4(15{,}20592)(0{,}0071347)}}{2 \times 0{,}0071347}$$

$$= \frac{0{,}7335 \pm 0{,}32259}{0{,}0142694}$$

$$= 28{,}80 \text{ days (maximum) or } 74{,}01 \text{ days (minimum)}$$

In both periods green leaf in the undisturbed growth accumulated at a steady rate for seven weeks and thereafter the amount decreased. Initially, stem accumulated at a slower rate than green leaf but three weeks after growth started stem began accumulating rapidly and continued to do so for the remainder of each growth period. Approximately 25 days after growth started in the first period and approximately 31 days after growth started in the second period, proportions of green leaf, and stem, in the undisturbed growth, were equal. After this the proportion of stem increased markedly and by the time light interception was at a maximum in the undisturbed sward, stem actually comprised 71 and 72% and green leaf 21 and 17% of the herbage for the first and second growth periods, respectively. Dead leaf appeared in the undisturbed growth four weeks after growth started in both periods. Dead leaf during both periods accumulated slowly until there was 8 and 11% for the first and second periods, respectively, when light interception was at a maximum in the undisturbed swards. As the amounts of dead leaf increased so amounts of green leaf decreased. Maximum daily growth rates of green leaf occurred at 22,2 days after growth started in the first growth period and after 28,8 days in the second period. The daily growth rates at these times were 79 and 81 kg dry matter of green leaves for the first and second periods, respectively.

The in vitro digestibility for green leaves, dead leaves and stem in the uninterrupted growth of Star grass for the first and second growth periods are shown in Figures 31 and 32. In all cases, except for dead leaves in the first period, the cubic regression model fitted the data most accurately. The quadratic regression model was used for dead leaf in the first period because there were too few data points for the cubic model (Figure 31).

The levels and patterns of change in digestible dry matter contents of green leaf and stem were very similar for both growth periods and, in general, the digestibility of the stem component was slightly higher than that of green leaf. For the first three weeks of growth in the second growth period stem had relatively low values of digestibility. This was probably due to the fact that old stem in the stubble was elevated above 5 cm by intercalary growth following the cutting and removal of mature herbage before the second growth period started. The digestibility of dead leaf was, in general, some 18 units lower than that of green leaf. The rate of decrease in digestibility with time was similar for all three components.

In Figures 33 and 34 the crude protein content of green leaves, dead leaves and stem in the uninterrupted growth of Star grass for the first and second growth periods, are shown. The cubic regression

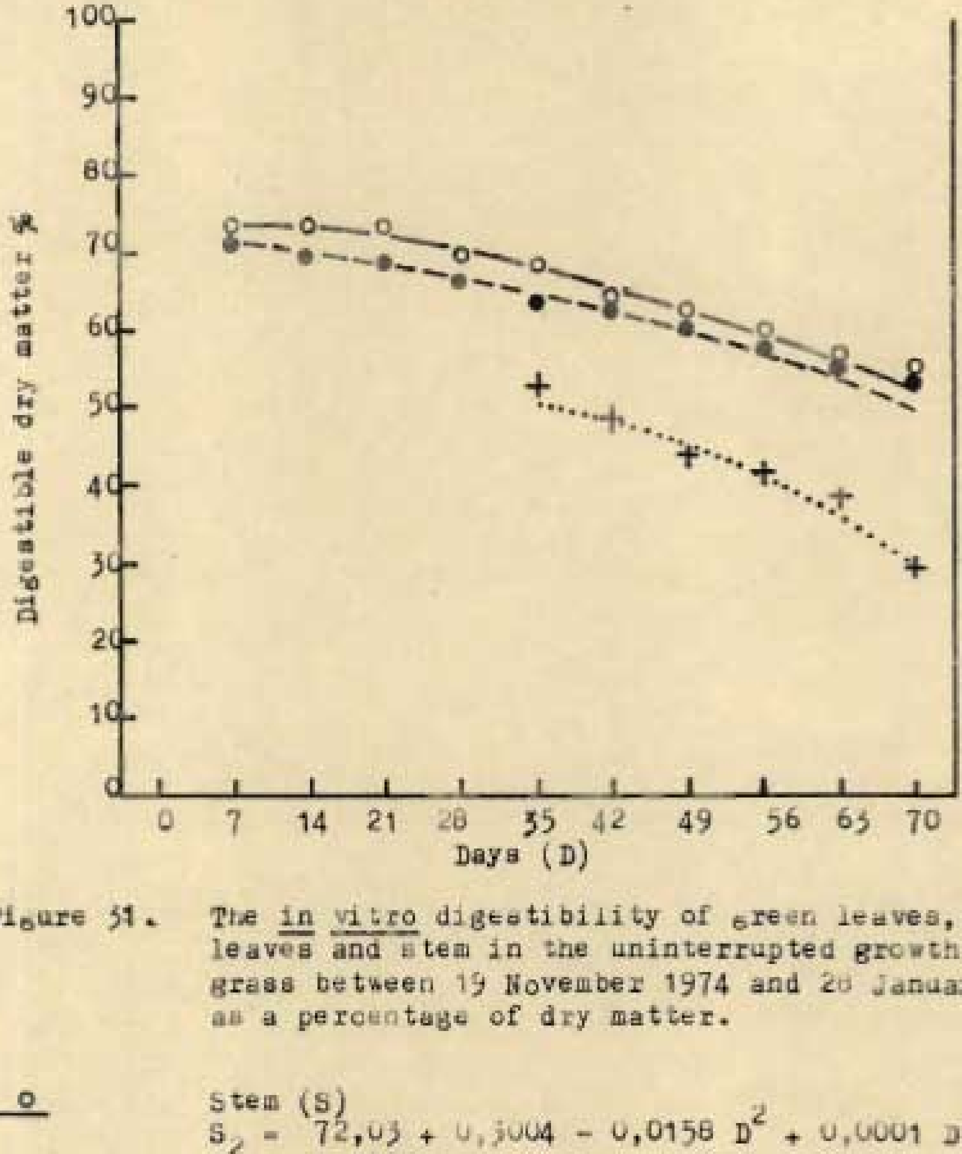


Figure 31. The *in vitro* digestibility of green leaves, dead leaves and stem in the uninterrupted growth of Star grass between 19 November 1974 and 28 January 1975, as a percentage of dry matter.

Stem (S)

$S_2 = 72,03 + 0,3004 - 0,0158\ D^2 + 0,0001\ D^3$

$R^2 = 0,9893$

Green leaf (GL)

$GL_2 = 72,154 - 0,1808 - 0,00068\ D^2 - 0,00002\ D^3$

$R^2 = 0,9821$

Dead leaf (DL)

$DL_2 = 29,73 + 1,074\ D - 0,015\ D^2$

$R^2 = 0,9719$

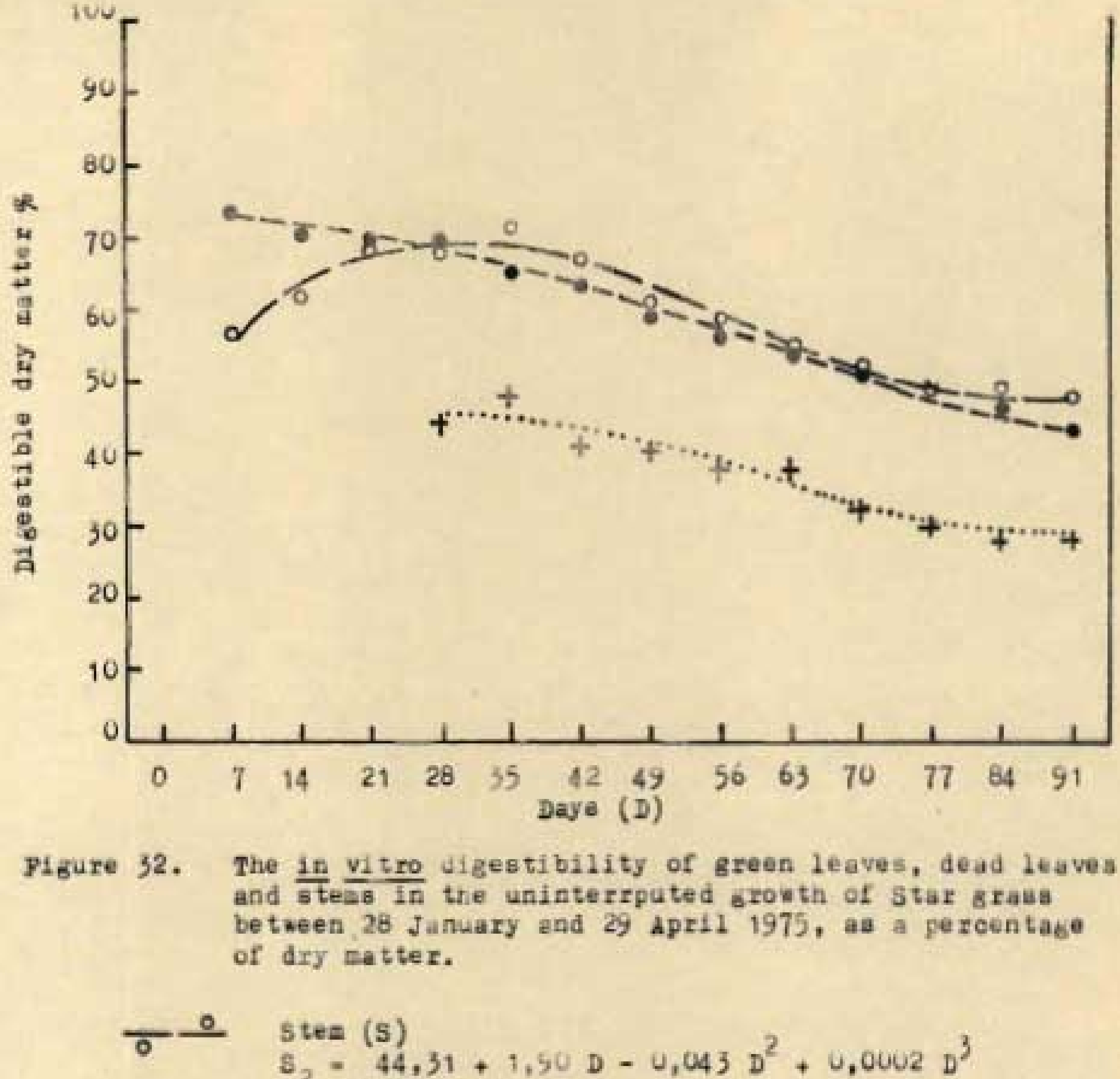


Figure 32. The in vitro digestibility of green leaves, dead leaves and stems in the uninterrupted growth of Star grass between 28 January and 29 April 1975, as a percentage of dry matter.

Stem (S)
$S_2 = 44,31 + 1,50\ D - 0,043\ D^2 + 0,0002\ D^3$
$R^2 = 0,9718$

Green leaves (GL)
$GL = 72,76 - 0,0033\ D - 0,0071\ D^2 + 0,0004\ D^3$
$R^2 = 0,9947$

Dead leaves (DL)
$DL = 27,28 + 1,31\ D - 0,028\ D^2 + 0,0016\ D^3$
$R^2 = 0,9509$

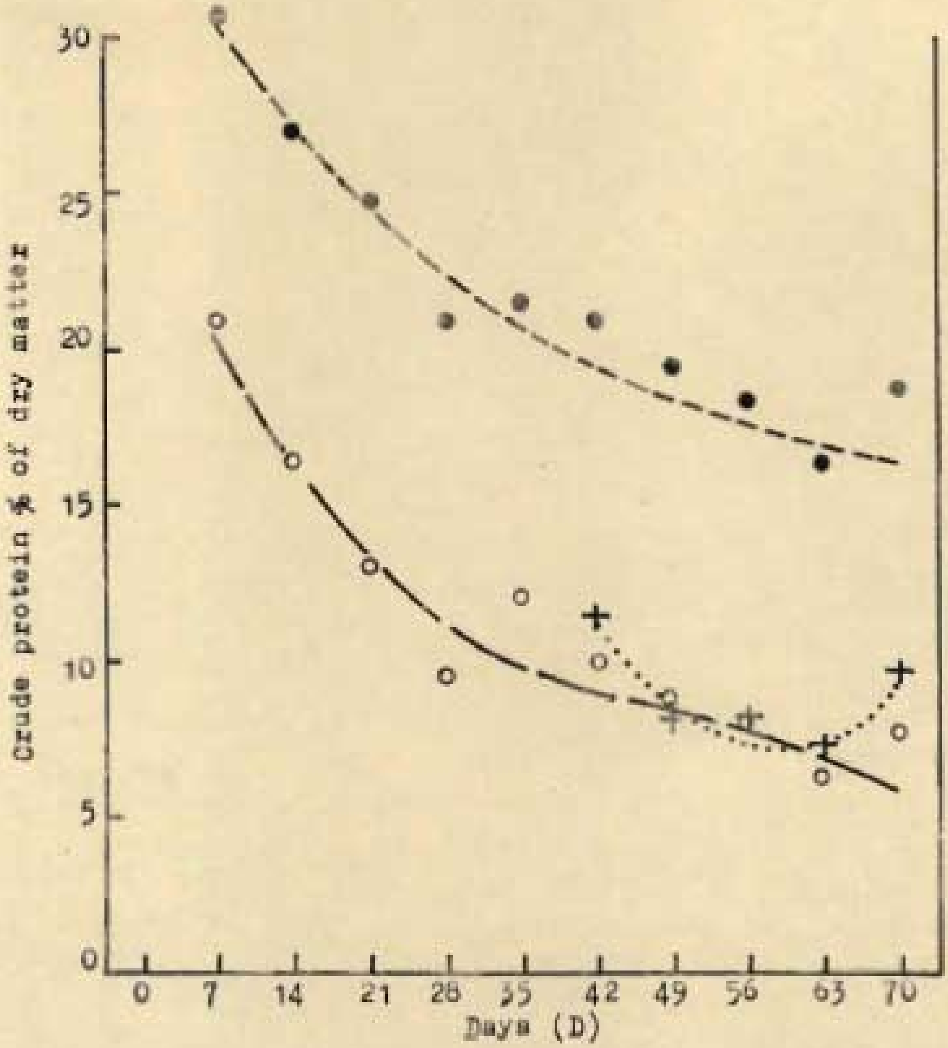


Figure 33. The crude protein content of green leaves, dead leaves and stem in the uninterrupted growth of Star grass between 19 November 1974 and 28 January 1975, as a precentage of dry matter.

Stem (S)
$S_2 = 26{,}16 - 0{,}912\ D + 0{,}016\ D^2 - 0{,}00011\ D^3$
$R^2 = 0{,}9348$

Green leaves (GL)
$GL = 34{,}70 - 0{,}659\ D + 0{,}009\ D^2 - 0{,}00005\ D^3$
$R^2 = 0{,}9574$

Dead leaves (DL)
$DL = 58{,}29 - 1{,}74\ D + 0{,}015\ D^2$
$R^2 = 0{,}9055$

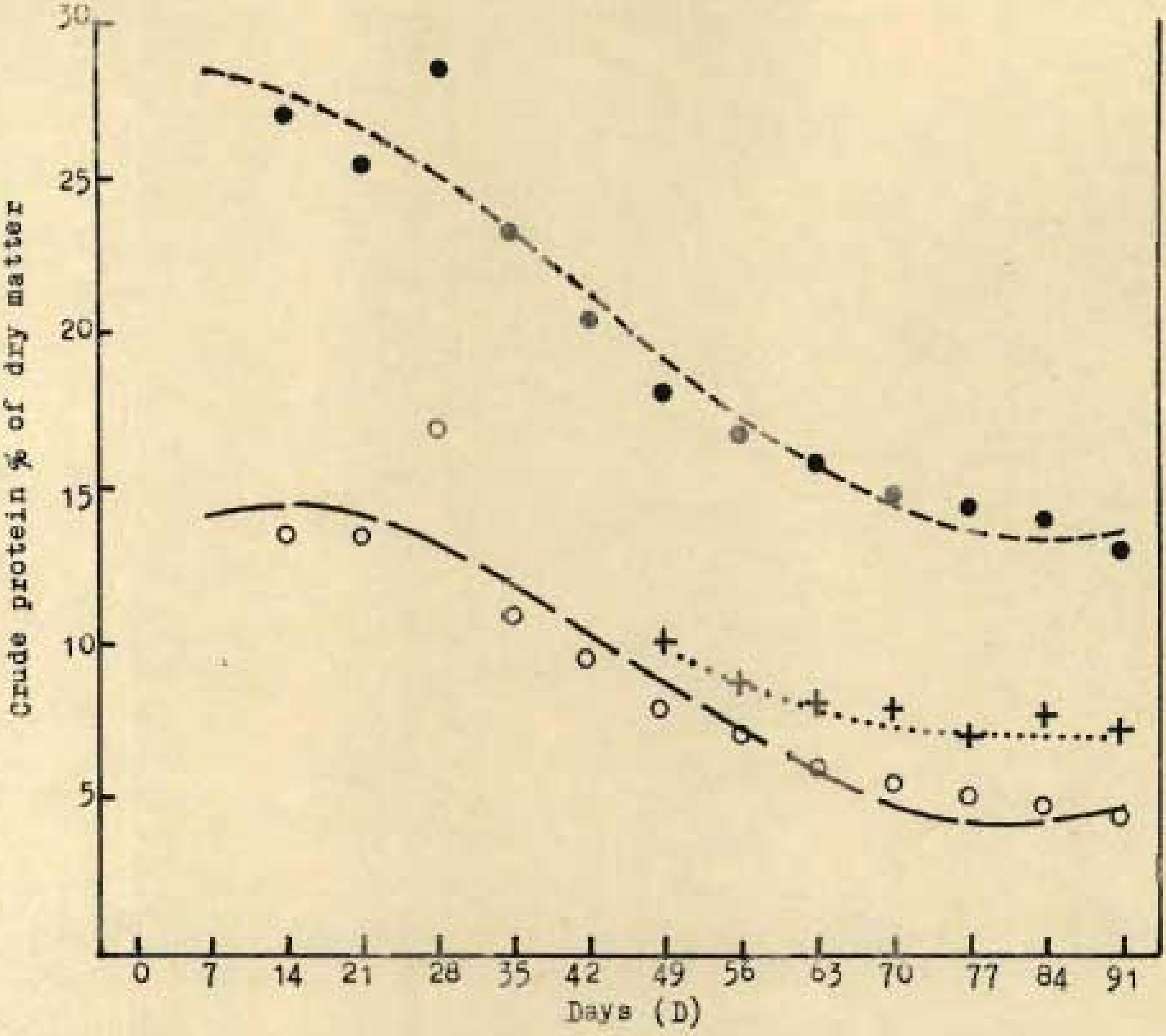


Figure 34. The crude protein content of green leaves, dead leaves and stems in the uninterrupted growth of Star grass between 28 January and 29 April 1975, as a percentage of dry matter.

—o—o— Stem (S)
$S = 264,9752 - 62,6273\ D + 3,9157\ D^2 - 0,0244\ D^3$
$R^2 = 0,9941$

-•--•- Green leaves (GL)
$GL = 28,2974 + 0,06051\ D - 0,0081\ D^2 + 0,0000625\ D^3$
$R^2 = 0,9421$

·+·····+· Dead leaves (DL)
$DL = 46,0648 - 1,4206\ D + 0,01754\ D^2 - 0,00007277\ D^3$
$R^2 = 0,9433$

model was used for all the data except for dead leaf in the first period when the quadratic model was used (Figure 33).

The crude protein content of stem was appreciably lower than that of green leaf and comparable to that of dead leaf. The pattern of change, however, was similar for all three components. The application of nitrogen resulted in temporary increases in the crude protein content. This effect can be seen between the fourth and fifth and between the ninth and tenth weeks in the first growth period (Figure 33) and between the third and fourth weeks in the second growth period (Figure 34).

Discussion

The results show that the herbage in the undisturbed growth of Star grass accumulated for 10 weeks in the first growth period and for 13 weeks in the second growth period. At this stage of growth light intercepted by the swards was at an apparent maximum of about 80% and herbage was about 1 m tall and lodging. Light interception did not exceed 80% probably because light was allowed to enter the sward wherever lodging occurred. In the first period dry matter accumulated at a mean rate of 194 kg per ha per day and in the second period at a mean rate of 129 kg per ha per day. Daily maximum growth rates were reached at 36,6 and 47,6 days for the first and second periods, respectively. Light interception at these times was 48,0% for the first period and 48,5% for the second period. The maximum daily growth rate of green leaves in the undisturbed growth was reached at 22,2 and 28,8 days in the first and second periods, respectively. Light interception at these times for both periods was 30,0%. The slower growth rates in the second period can probably be attributed to seasonal effects, in that growth rates generally decline from mid-to-late growing season.

Clearly Star grass is sensitive to defoliation when light interception in the undisturbed sward is between 40 and 50%. Maximum growth rates of herbage were obtained when light interception in the undisturbed growth was within the range and defoliation at this time reduced total production, particularly during the second growth period

(Figures 26 and 27). Total production was greatest where light interception was less than 30% or greater than 70%. These results lead to the conclusion that management of Star grass swards should aim at defoliating it only when light interception in the sward is within the range 0 to 30% or greater than 70%. But where light interception in the sward is greater than 70% the herbage will be at least seven weeks old and will be of relatively low quality because it will comprise mainly stem (Figures 29 and 30). Where light interception in swards is 30% or less, herbage will be less than five weeks old, the proportions of green leaf and stem will be more or less equal and the herbage will be of high quality.

In order to provide nutritious forage for beef cattle Star grass should be grazed within four weeks from the time growth starts. Up to this time the proportion of green leaf in the herbage is greater than, or equal to, the proportion of stem present, although the stem is of slightly higher digestibility than the leaf. After this time the proportion of stem becomes rapidly greater than that of leaf. While green leaf provides both protein and energy, stem mainly provides energy. For the growth of cattle a balance between protein and energy in the herbage is necessary and therefore green leaf is more desirable than stem. Furthermore, cattle require about 13% crude protein in their diet for the efficient digestion of food ingested. At four weeks after growth started in the first growth period and after five weeks in the second period, crude protein in the stem was about 13% but thereafter the amount decreased with time. Dead leaf made its appearance in the sward from four weeks after growth started. It had a lower <u>in vitro</u> digestibility than both green leaves and stem and a crude protein content similar to stem. Clearly it is undesirable to allow dead leaf to appear in a sward before grazing it. Laredo and Minson (1973) found that sheep voluntarily consumed more leaf than stem of five tropical grasses despite the fact that the leaf was less digestible (52,6%) than the stem (55,8%). This indicates that management should aim at maintaining as great a proportion of leaf in the sward as possible. However, it is known that preference of sheep and cattle for grasses are not the same (Mills, 1976) and therefore the same might not apply to cattle.

The changes in the leaf and stem components in Star grass are similar to those in other grasses. For example Barnes (1966) found that if Panicum maximum var. trichoglume (cv. Sabi) was allowed to grow unchecked throughout the growing season, stem comprised 65% of the total herbage at the end of the season. Similarly Taerum (1970) found that the proportion of stem in Cenchrus ciliaris var. biloela, Chloris gayana and Panicum maximum increased with advancing maturity of herbage from one month to nine months after planting.

The levels of digestibility and of crude protein in the herbage components of Star grass and the rate of decline in digestibility and crude protein with advancing maturity of herbage are similar to the findings of Gomide, Noller, Mott, Conrad and Hill (1969), Minson (1972, 1973), Hacker and Minson (1972), Ford and Williams (1973) and Reid, Post, Olsen and Mugerwa (1973), with other tropical grasses.

The results for initial regrowth show considerable variation from week to week due probably to rainfall. Temperature throughout the study was adequate for growth. However, despite these variations initial regrowth was greatest during the third week in the first growth period and during the fourth week in the second growth period. After this there was a tendency, particularly during the second period, for initial regrowth to decline with time. This can be explained by the fact that as herbage in the undisturbed growth became more mature so less green material capable of photosynthesis was left in the stubble for initial regrowth after the mature herbage was cut and removed to determine undisturbed growth.

Total regrowth in the first growth period was greater than in the second. This indicates that the sward in the late growing season is more sensitive to defoliation than in the first half of the growing season.

Total production was lowest at four weeks in the first growth period and lowest at about five weeks in the second period. Thereafter amounts of herbage harvested increased considerably.

Total production in the second half of each period consisted largely of undisturbed growth and therefore does not indicate any sensitivity of the sward to defoliation. However, during the first four weeks in the first period and during the first five weeks during the second period, results indicate that Star grass became increasingly sensitive to defoliation.

The results of the characterisation study on Star grass clearly showed that research into suitable systems of management for this grass for grazing by beef cattle should be aimed at maintaining the sward herbage components, their digestibility and crude protein contents, in a similar state to that found during the first four weeks of undisturbed growth. It is also during this time that Star grass swards appear to be least sensitive to defoliation and the regrowth potential is greatest. It was to this end that further studies into the management of Star grass were directed.

4.5 Management of Star Grass Pastures

4.5.1 Preliminary observations on management

Clearly, in devising systems of management suitable for Star grass pastures it is necessary to examine a number of harvesting procedures to find one which produces the maximum sustained amount of herbage of a quality suitable for animal utilization and production. Booysen (1966) indicates that this involves the repetitive harvesting of new growth so that the largest possible amount of herbage must be removed at each harvest and the interval between successive harvests is as short as possible. Thus after each defoliation there must be a rapid recommencement of new growth and a rapid regrowth rate must be maintained until the next defoliation.

The study in which the changes in the amount and quality of the herbage components of Star grass (Cynodon aethiopicus cv. No. 2) during growth and development were observed (Section 4.4) indicated that this grass should be grazed within the first four weeks of growth or regrowth. During this time quality of herbage was optimal and growth and regrowth rates had reached a maximum (Figures 29 and 30). However, before this study was made other investigations were carried out to try to find a management system that would maximise production from Star grass pastures.

Experimental Objectives

To determine the level of applied nitrogen required, and the height that Star grass should be allowed to attain before being grazed, to produce maximum amounts of herbage.

Materials and Methods

Star grass that had been established during January 1969 and that had been fertilized uniformly (200 kg N and 40 kg P_2O_5 per ha) and grazed by 3 cows and calves per ha during the 1969-70 growing season, was used for the experiment.

During the 1970-71 and 1971-72 growing seasons 170, 340 and 510 kg N per ha were applied to the Star grass annually, with a basic dressing of 90 kg P_2O_5 per ha. The nitrogen was applied in four equal monthly dressings starting on 17 November in both seasons. The phosphate was applied during October each season. In addition the Star grass was grazed whenever growth or regrowth reached a mean height of 10, 20 or 30 cm above ground level with each amount of applied nitrogen, giving nine treatment combinations on unreplicated plots of 0,4 ha. The mean height of grass growth within a plot was estimated from measurements taken at 20 random sites with a ruler. Whenever this mean corresponded to the allotted experiment height the plot was grazed by 296 cow and calf units per ha for up to 24 hours, so that nearly all the herbage was removed quickly.

Three groups of cows were used to graze the experimental plots, one for each level of applied nitrogen. When the cows were not grazing experimental plots they were held in adjacent paddocks of Star grass fertilized at the same rates of nitrogen as those applied to the experimental plots. Each group of cows grazed Star grass fertilized at the same rate of applied nitrogen in both experimental and non-experimental pastures. This was done to reduce transference of plant nutrients through the animal from high nitrogen to low nitrogen plots. Immediately before grazing three 1 m^2 quadrats were cut to 5 cm at random in every plot and the dry matter content of the herbage determined from oven-dried samples. Following grazing, plots were mown to 5 cm with a rotary mower and any residues left _in situ_. The sampling, grazing and mowing procedures were carried out as many times as possible in both seasons.

When the experimental treatments ceased at the end of both growing seasons, the basal cover of Star grass and weeds in each treatment was determined by the point quadrat method. In every 0,4 ha plot 100 frames of 10 points each were systematically distributed over the plot. Hits were recorded only when a point at ground level touched a stem rooted at that point. The object of determining basal cover was to establish whether pastures were improving or deteriorating with treatment. An increase in basal cover would indicate improvement whereas a decrease would indicate deterioration.

Rainfall in both seasons was similar in amount and distribution, 941 mm falling in 1970-71 and 901 mm in 1971-72 (Appendix 1).

Results

As treatments were unreplicated, the results were analysed by comparing the mean squares for nitrogen and for heights against the mean square for the nitrogen x heights interaction. The F test in all cases was therefore conservative because the interaction term used was larger than the normal error term. Herbage yields obtained during the 1970-71 and 1971-72 growing seasons are shown in Figure 35.

In both growing seasons the amount of herbage reaped decreased significantly ($P < 0{,}01$) as the height of herbage at which grazing commenced increased. The effect of nitrogen on herbage yields was not significant. However, in 1971-72 nitrogen had a marked effect on the amount of herbage reaped at the 10 cm grazing height when yields increased proportionately with increasing nitrogen application. At all other grazing heights in both seasons, including the 10 cm height in 1970-71, herbage yields were at a maximum where 340 kg N per ha were applied.

By dividing the amount of herbage reaped at every grazing for each treatment by the number of days between grazings, the mean daily growth rate of herbage for each rest period was calculated. The daily growth rates of herbage for all treatments for the 1970-71 and 1971-72 growing seasons are shown in Figures 36 and 37. Also shown are the amounts and distribution of rainfall.

In both seasons daily growth rates of herbage decreased as the height of herbage at which grazing commenced increased. In 1970-71 the daily growth rate at 20 cm grazing height was 66,0% and that at 30 cm 59,7% of the daily growth rate at 10 cm (97 kg

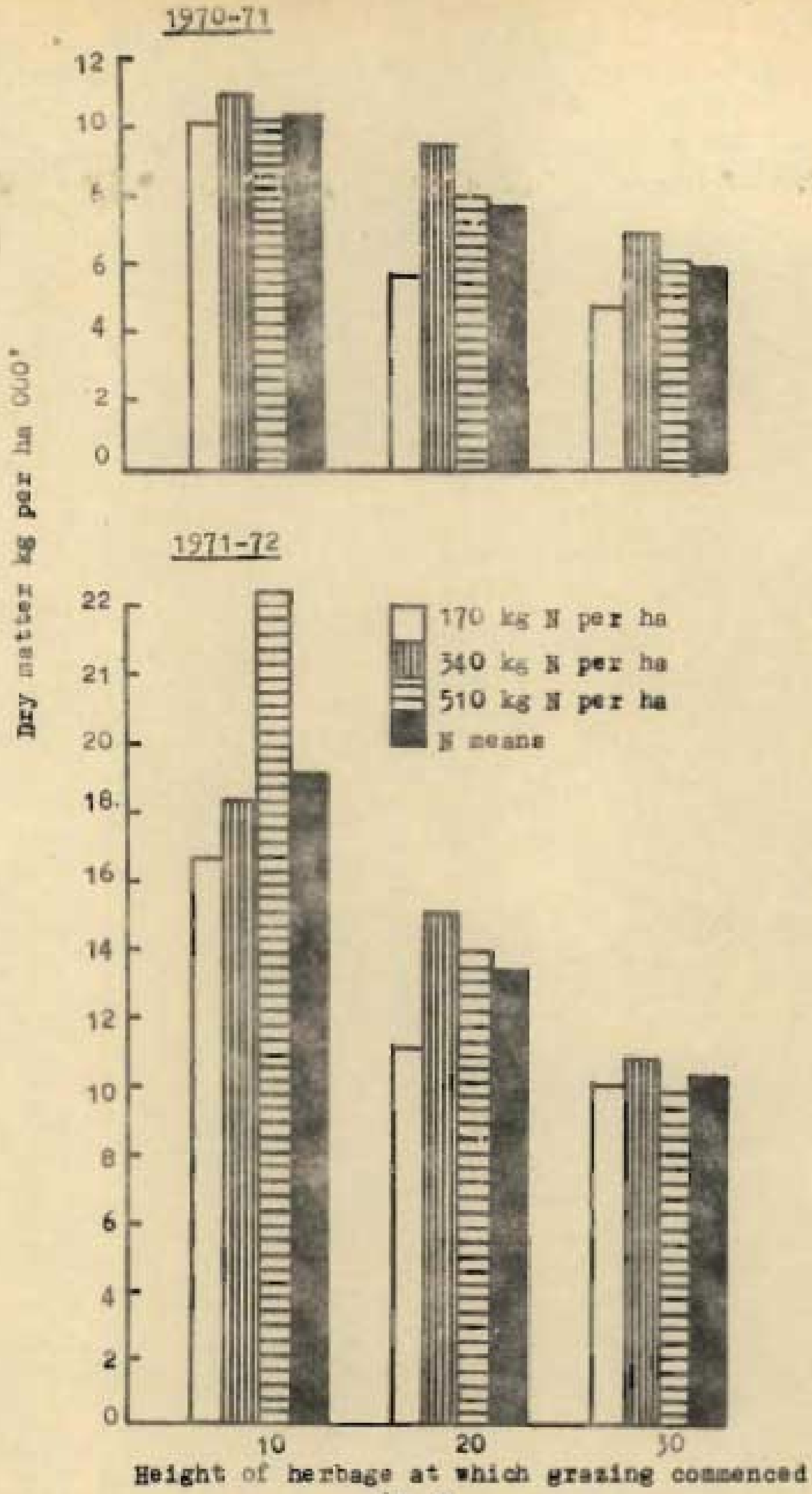


Figure 55. The effects of applied nitrogen (N) and the height at which grazing of Star grass was commenced (GH) on herbage yields in kg dry matter per ha during the 1970-71 and 1971-72 growing seasons. (Analysis of variance tables Appendix 2.44).

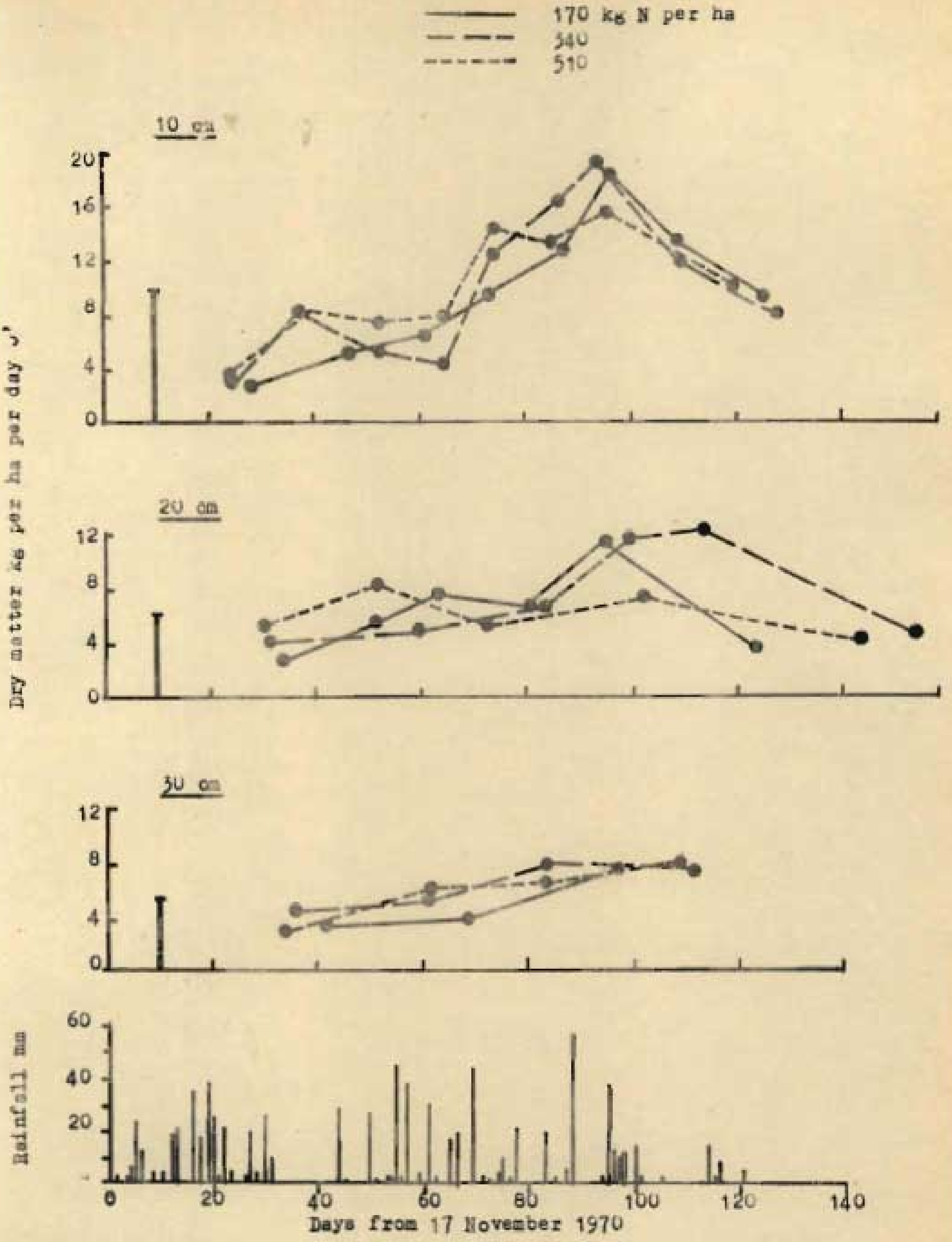


Figure 36. The effects of applied nitrogen and the height at which grazing of Star grass was commenced on the mean daily herbage growth rates in kg dry matter per ha during 1970-71. (Mean seasonal daily growth rates of herbage over all nitrogen applications for each grazing height shown by vertical bars).

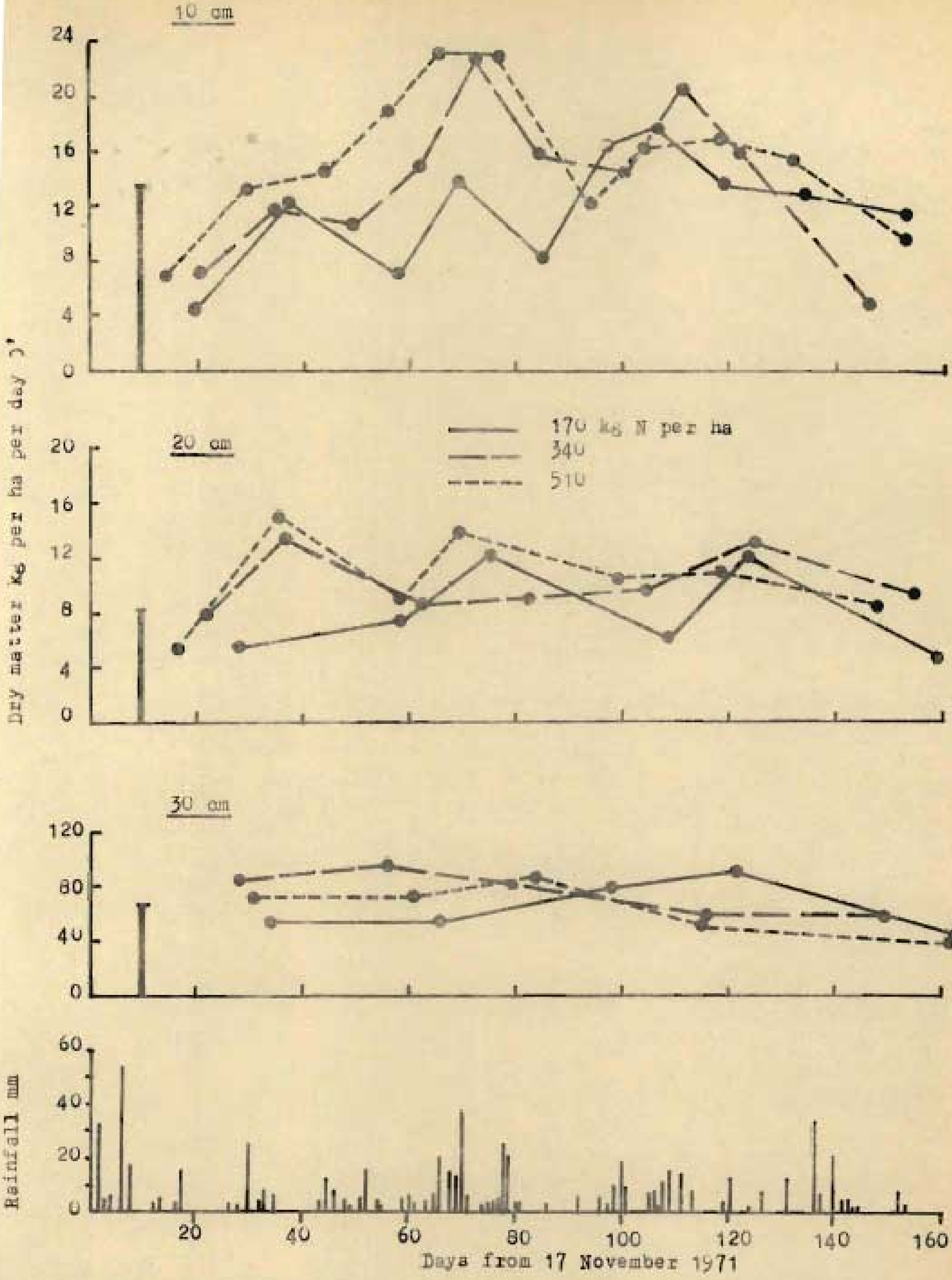


Figure 37. The effects of applied nitrogen and the height at which grazing of Star grass was commenced on the mean daily herbage growth rates in kg dry matter per ha during 1971-72. (Mean seasonal daily growth rates of herbage over all nitrogen application for each grazing height shown by vertical bars).

per ha per day). In 1971-72 the daily growth rates at the 20 and 30 cm grazing heights were 68,5 and 50,0%, respectively of that at the 10 cm height (138 kg per ha per day).

In 1970-71 daily growth rates at all grazing heights were greatest where 340 kg N per ha was applied. In 1971-72 the greatest daily growth rates were achieved with an application of 510 kg N per ha and where herbage was grazed when reaching 10 cm in height but at the 20 and 30 cm heights it was again achieved with 340 kg N per ha. In general the effect of applied nitrogen on daily growth rates was not as great as the height of herbage at which grazing commenced.

Greatest variations during the two seasons in daily growth rates occurred where grazing commenced when herbage was 10 cm tall, but variations became progressively less with increasing height of herbage at which grazing commenced. There was a tendency for growth rates to increase as the season progressed up to 100 to 120 days in 1970-71, regardless of applied nitrogen and height of herbage at which grazing commenced. In 1971-72 this was not apparent but where grazing started when herbage was 10 cm tall rainfall apparently affected daily growth rates 60 to 80 days and 100 to 110 days, after the season started.

The mean intervals between grazings with the various amounts of applied nitrogen and the height of herbage at which grazing commenced are shown in Table 31.

Table 31. The effects of applied nitrogen and the height of herbage at which grazing commenced on Star grass on the mean intervals in days between grazings for the 1970-71 and 1971-72 growing seasons.

Height of herbage when grazing commenced cm	Nitrogen kg per ha per season			Means
	170	340	510	
10	15,5	14,5	14,0	14,7
20	24,5	22,0	23,0	23,2
30	30,5	28,0	28,5	29,0
Means	23,5	21,5	21,8	22,3

The number of days for herbage growth or regrowth to reach 10, 20 or 30 cm height between grazings became progressively more with increasing height at which grazing commenced. Only 14,7 days were required between grazings for growth or regrowth to reach 10 cm height.

The effects of treatments on the changes in the basal covers of the pastures are shown in Table 32.

Table 32. The effects on Star grass pasture of applied nitrogen and the height of herbage when grazing was commenced on the basal cover of Star grass and weeds expressed as a percentage of total pasture area during the 1970-71 and 1971-72 growing seasons. Means of 1 000 points.

Nitrogen kg per ha	Component of basal cover	Height of herbage when grazing commenced on						
		10		20		30		
		1970-71	1971-72	1970-71	1971-72	1970-71	1971-72	Means
170	Star grass	4,4	4,8	4,0	3,4	3,2	4,3	4,0
	Weeds	5,2	5,0	5,5	5,3	5,8	4,2	5,2
	Total	9,6	9,8	9,5	8,7	9,0	8,5	9,2
340	Star grass	6,2	7,0	4,9	6,4	5,4	5,0	5,8
	Weeds	4,0	1,3	6,4	3,7	3,8	4,1	3,9
	Total	10,2	8,3	11,3	10,1	9,2	9,1	9,7
510	Star grass	6,7	7,4	7,2	8,3	5,8	7,4	7,1
	Weeds	1,2	0,6	1,0	0,2	1,1	0,2	0,7
	Total	7,9	8,0	8,2	8,5	6,9	7,6	7,8
Means	Star grass	6,1		5,7		5,2		5,6
	Weeds	2,9		3,7		3,2		3,3
	Total	9,0		9,4		8,4		8,9

The basal cover of Star grass increased and that of weeds decreased as the amount of applied nitrogen increased. Basal cover of Star grass tended to decrease as the height at which herbage was grazed increased. The principal weed was Sporobolus pyramidalis.

Discussion

Generally, in experiments where the effects of applied fertilizers and various clipping frequencies on the production of grass herbage are measured, clipping frequencies are nearly always fixed subjectively. Examples of such experiments are those reported by Burton, Jackson and Hart (1963), Oakes and Skov (1964), Hallock, Brown and Blaser (1965), Ahmad, Tullock-Reid and Davis (1969), 't Mannetjie and Shaw (1972), Jung, Balasko, Alt and Stevens, (1974), Olsen (1974) and Whitney (1974). In this experiment the growth rate of the Star grass within each treatment determined clipping frequency. The time interval between harvests was determined mainly by the height to which herbage was allowed to grow before being grazed; but also to some extent, by applied nitrogen and by the amount and distribution of rainfall. Therefore within the environmental factors and the experimental constraints imposed Star grass should be grazed every 14 to 15 days when growth is no taller than 10 cm to obtain maximum amounts of herbage. From this it was deduced that either a 15 paddock rotational grazing system where each paddock would be grazed for one day and then rested for 14 days in rotation, or an eight paddock system where each paddock would be grazed for two days and then rested for 14 days, would maximise production from Star grass pastures.

Although the limited statistical analysis that could be carried out on the experimental results indicated that the effects of applied nitrogen were not significant, nitrogen had a marked effect on herbage yields in 1971-72 where grazing commenced where the herbage was 10 cm tall (Figure 35). This observation indicated that perhaps more than 510 kg N per ha should be applied to maximise herbage production when herbage is grazed whenever reaching this height. In 1970-71 applied nitrogen had little effect at the 10 cm height of grazing herbage possibly because pastures had not yet been conditioned for this system of management. This is indicated by the rapid increase in the daily rate of growth of herbage at the 10 cm grazing height for the first 100 days of the season. Similar observations were made at the 20 and 30 cm grazing heights but the increase in daily growth rates were not so marked in these cases. By the end of the 1970-71 growing season all pastures were conditioned to the management treatments being imposed on them and in 1971-72 results were more applicable.

Observations also indicated that treatments affected the character of swards. For example, grazing Star grass whenever growth reached 10 cm resulted in a dense, leafy sward, close to the ground. Where grazing commenced when herbage was 20 or 30 cm tall, swards were generally less dense with an apparent greater proportion of stem to leaf, particularly where herbage was grazed when 30 cm tall. Furthermore, when the residual herbage had been removed by mowing after grazing, little more than stem remained in the stubble causing the rate of regrowth to be slow because of lack of photosynthetic tissue. This observation was confirmed by the results obtained in Section 4.4. However, where swards were grazed whenever growth reached 10 cm, a green, leafy stubble remained, even after mowing, and rapid regrowth was therefore possible.

The results showed that at least 510 kg N per ha should be applied to prevent invasion of Star grass swards by Sporobolus pyramidalis, a coarse perennial grass unpalatable to livestock. At the end of the second year this grass comprised 57, 40 and 9% of swards where 170, 340 and 510 kg N per ha were applied, respectively. Henzell (1971) in Australia noted that Chloris gayana swards receiving less than 224 kg N per ha annually, became progressively invaded by Digitaria sp., Axonopus affinis and Glycine tabacina.

4.5.2 The effects of applied nitrogen on the herbage yields of Star grass grazed whenever growth reached a height of 10 cm above ground level

The preliminary observations carried out on the management of Star grass (Cynodon aethiopicus cv. No. 2) pastures, (Section 4.5.1) indicated that to produce maximum amounts of herbage this grass should be grazed rotationally, at approximately 15-day intervals, when growth or regrowth reaches a height of 10 cm above ground level. In 1971-72, results (Figure 35) indicated that more than 510 kg N per ha might be required to maximise production from Star grass managed in this way as herbage yields increased markedly over the range of levels of nitrogen applied (170 to 510 kg N per ha).

Experimental Objectives

To determine whether more than 510 kg N per ha should be applied to Star grass pastures grazed whenever growth reached 10 cm above ground level in order to produce maximum amounts of herbage.

Materials and Methods

The Star grass pastures that were fertilized with 340 and 510 kg N per ha and grazed whenever growth reached a height of 10 cm above ground level in the preliminary management studies (Section 4.5.1) were used for this experiment. These 0,4 ha pastures were both sub-divided into four 0,1 ha plots. Each growing season, 350, 500, 650 and 800 kg N per ha were applied in two replications of a randomised block design. The nitrogen was applied in four monthly dressings starting on 28 November 1972 and on 7 November 1973. In addition 90 kg P_2O_5 per ha were applied during October in both years as a basic dressing.

Plots were grazed whenever herbage in them reached a mean height of 10 cm above ground level. This was determined by walking through plots and measuring the height of herbage at 20 positions at random. When herbage had reached this height three 1 m^2 quadrats were cut to 5 cm and the dry matter content of herbage determined from oven-dried samples. Cows were then put in to graze for up to 24 hours at a stocking rate of 296 cow and calf units per ha. Immediately the cows were removed pastures were topped to 5 cm with a rotary mower. These procedures were carried out for as many times as growth reached 10 cm in each growing season.

The 1972-73 season was one of the lowest rainfall seasons on record. Only 565 mm of rain fell and this was poorly distributed. In contrast 1973-74 was one of the heaviest rainfall seasons on record with 1 310 mm being recorded (Appendix 1).

Results

The herbage yields obtained in the 1972-73 and in the 1973-74 growing seasons together with the two-year mean yields are shown in Figure 58.

In both growing seasons herbage increased with the first increment of nitrogen, decreased with the second and increased with the third increment. In the first season there was also an overall increase in herbage production over the range of nitrogen levels applied.

In both seasons yields were much lower than usually recorded and responses to applied nitrogen above 500 kg N per ha were small and inconsistent.

The mean number of days between grazings, that is, the time taken for regrowth of swards to reach a height of 10 cm after grazing, are shown in Table 33.

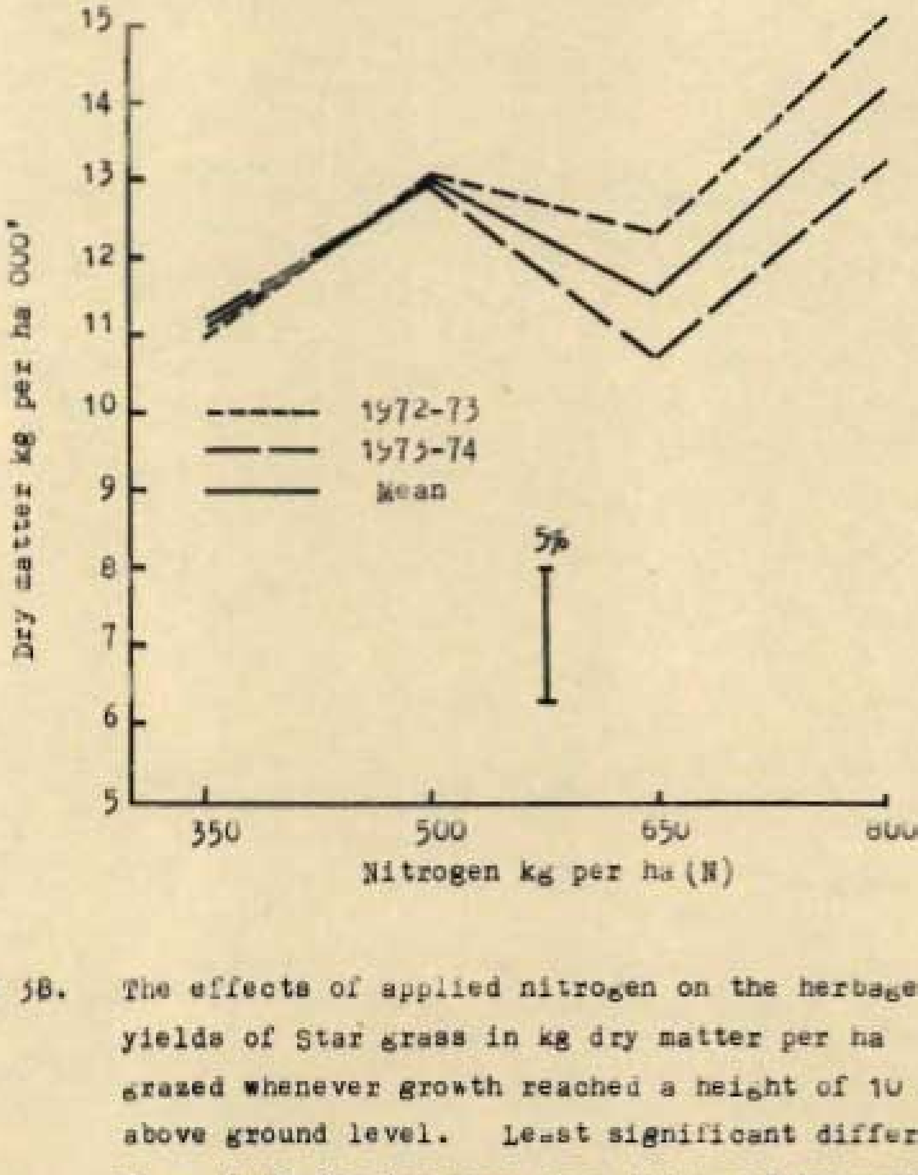


Figure 38. The effects of applied nitrogen on the herbage yields of Star grass in kg dry matter per ha grazed whenever growth reached a height of 10 cm above ground level. Least significant difference P = 0,05 for two-year mean indicated by vertical bar. (Analysis of variance tables Appendix 2.45)

Table 33. The time interval in days between grazings on Star grass pastures fertilized with various amounts of nitrogen and grazed whenever growth reached 10 cm above ground level.

Year	Nitrogen kg per ha			
	350	500	650	800
1972-73	30,8	27,6	25,0	25,7
1973-74	18,3	19,4	19,8	17,6

In 1972-73 periods between grazings were much greater than they were in 1973-74 and they became shorter with increasing amounts of applied nitrogen. Intervals between grazings at all rates of applied nitrogen were similar in 1973-74.

Discussion

In the first growing season (1972-73) the generally low herbage yields from Star grass in comparison with previous years (Section 4.5.1, 1971-72, Figure 35) can be attributed to poor rainfall (Appendix 1). The second season (1973-74) was an excessively wet one with long spells of cool, overcast weather. These conditions too, were not favourable for grass growth although loss of applied nitrogen through leaching might have been a factor contributing to poor herbage yields. Similar observations were made by Chheda and Mohamed Saleem (1973a)in Nigeria. They observed that poor responses of Cynodon sp. to applied nitrogen in terms of herbage yield were probably due to excessively wet conditions with little sunshine. Loss of applied nitrogen due to leaching, they stated, was also a possibility.

The responses of Star grass to applied nitrogen in the dry year (1972-73) and in the wet year were similar in that herbage yields increased with the first increment of applied nitrogen (350 to 500 kg N per ha), decreased with the second (500 to 650 kg N per ha) and increased with the third (650 to 800 kg N per ha) increments. No explanation can be advanced for the fall-off in herbage yield with the second increment of nitrogen. However, the results show that the responses to applied nitrogen in excess of 500 kg N per ha on Star grass pastures managed in this manner are likely to be small. Therefore for practical purposes not more than this amount should be applied to pastures.

4.5.3 The effects of height of stubble left after simulated rotational grazing on regrowth of Star grass

In Sections 4.5.1 and 4.5.2, Star grass (Cynodon aethiopicus cv. No. 2) was mown after each grazing to leave a stubble 5 cm in height. Regrowth rates may vary according to the amount and quality of herbage left in the stubble after grazing and it was not known whether a 5 cm stubble would produce maximum regrowth rates following grazing.

Experimental Objectives

To determine the effect of the height of stubble left after grazing on the production and quality of Star grass herbage.

Materials and Methods

Well-established Star grass pastures that had previously been heavily fertilized (350 kg N and 90 kg P_2O_5 per ha, annually) and that had been intensively grazed (12 yearling steers per ha each growing season) were used.

During the 1972-73 growing season the Star grass received 350 kg N and 90 kg P_2O_5 per ha. The nitrogen was applied in four monthly dressings starting on 28 November 1972. Plot size was 0,1 ha and the Star grass was grazed to leave a 5, 15 or 25 cm stubble after grazing. Treatments were replicated twice. Grazing started when there was 3 000 kg dry herbage per ha above the three specified heights and with this criterion grazing started on 18 December, 22 December and 11 January for the 5, 15 and 25 cm stubble heights, respectively. Immediately before each grazing, which was done at 15-day intervals, three 1 m^2 quadrats were clipped above the experimental stubble heights using a metal comb with adjustable legs to obtain the correct height. The dry matter content of the herbage was determined from oven-dried samples. When the quadrats had been clipped, 296 cow and calf units per ha were put in to graze for a limited time ; according to the amount of herbage available for grazing above the different stubble heights. After each grazing, a rotary mower with adjustable cutting height, cut each pasture at scheduled stubble height.

The experiment was repeated during the 1974-75 growing season except that 500 kg N per ha were applied in four equal monthly dressings starting on 17 November. During October 90 kg P_2O_5 per ha was applied. Nitrogen was increased from 350 kg N per ha in 1972-73 to 500 kg N per ha in 1974-75 because of the observations made in 1971-72 with 10 cm swards (Section 4.5.1). Grazing started in 1974-75 when there were 2 500 kg dry matter per ha above the 5, 15 and 25 cm stubble heights because in 1972-73 the swards had taken too long to produce 3 000 kg dry matter per ha. Immediately before each grazing in 1974-75 samples of herbage from above the different stubble heights were taken and separated into green leaf, dead or dying leaf (hereafter termed dead leaf) and stem. At the same time the amount of herbage below the scheduled stubble heights was determined by clipping three 1 m^2 quadrats at ground level. The amounts of dry green leaf, dead leaf and stem present were determined from oven-dried samples.

Poor rainfall in the 1972-73 growing season (Appendix 1) did not allow all the experimental grazings to be done at 15-day intervals because of periods of moisture stress during which growth was negligible. For the 5, 15 and 25 cm stubble heights four out of seven, two out of six and two out of five grazings were done at 15-day intervals, respectively. However, in 1974-75 a year of good rainfall, (Appendix 1) all the experimental grazings were carried out at 15-day intervals.

Results

The influence of the height of stubble left after grazing and mowing on total amounts of herbage harvested in both growing seasons, and the mean amounts of herbage present in the stubbles in 1974-75 are shown in Figure 39. Also shown are the contributions made by leaf and stem in the herbage harvested and in the stubbles in 1974-75.

In 1972-73 and in 1974-75 total herbage yields above the 5 cm stubble height were significantly greater ($P < 0,05$) than those above the 15 and 25 cm stubble heights. Differences between the latter two heights were not significant. In 1974-75 yields where a 5 cm stubble was left after grazing and mowing were considerably greater than in 1972-73 but yields where a 15 or a 25 cm stubble were left after grazing and mowing were similar in both seasons. In 1974-75 the mean total amounts of herbage left in the residue after grazing in the three stubble height treatments were all significantly different ($P < 0,05$). The amounts of green leaf ($P < 0,01$), dead leaf ($P < 0,05$) and stem ($P < 0,01$) were also all different for the three stubble height treatments. The mean total amounts of herbage in the stubble varied inversely with total herbage yield above the different stubble heights.

While differences were detected in the total amounts of herbage above the different stubble heights, proportions of green leaf, dead leaf and stem were similar in the 5 and 15 cm treatments being 39,4 ; 4,1 and 56,5 % of the total herbage respectively.

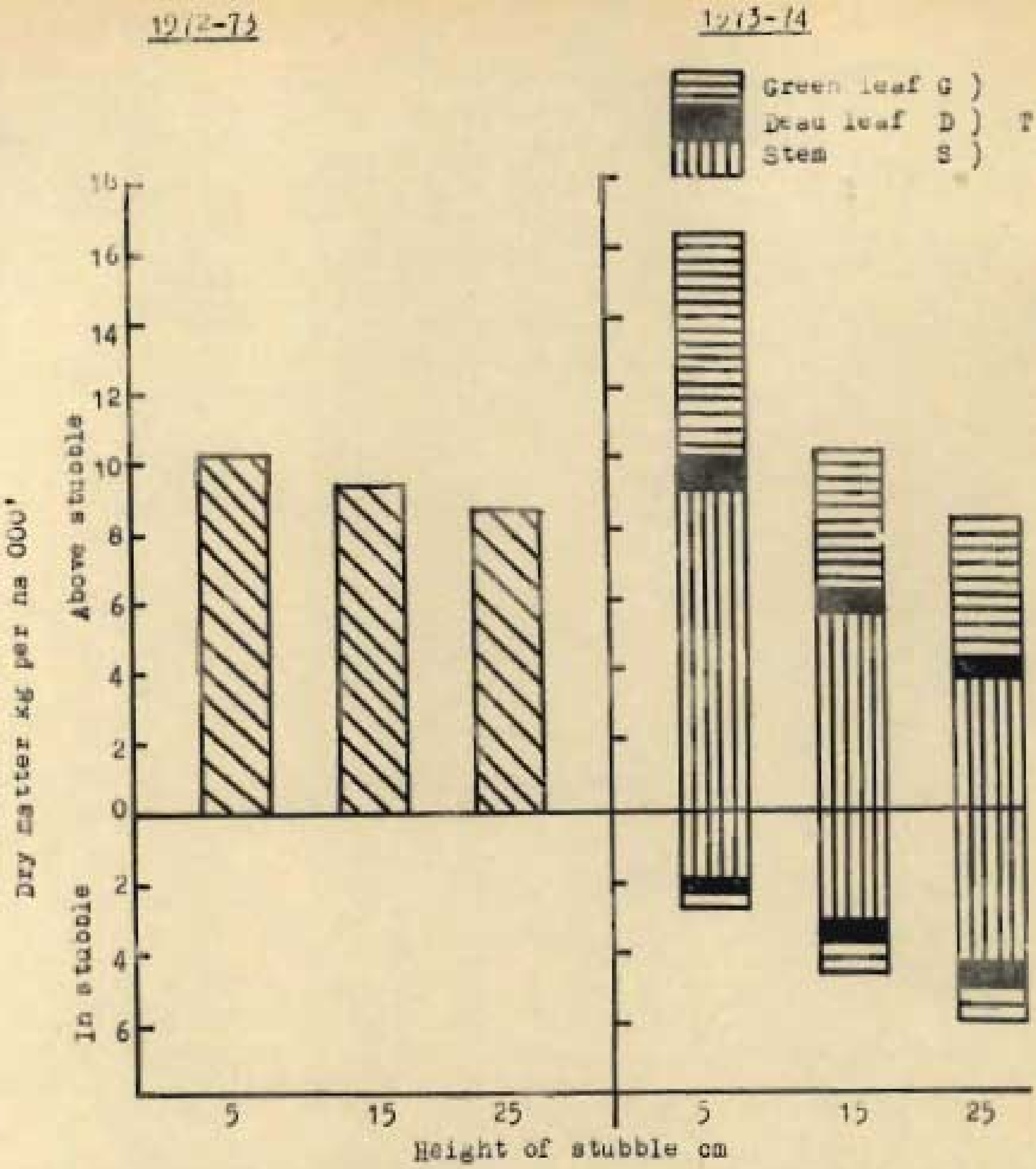


Figure 39. The effect of height of stubble left after simulated rotational grazing on regrowth of Star grass in 1972-73 and on the regrowth and components of that regrowth and of the stubble left after grazing and mowing in 1973-74, all in kg dry matter per ha. (Analysis of variance tables Appendix 2.46).

LSD

P = 0,05	1230
P = 0,01	2840

LSD

Herbage harvested above stubble

P = 0,05	G 1240	D 270
	S 2620	T 3800
P = 0,01	G 2870	D 620
	S 6050	T 8760

Herbage harvested in stubble

P = 0,05	G 310	D 150
	S 970	T 2450
P = 0,01	G 710	D 340
	S 2250	T 5660

In the 25 cm stubble height treatment the proportions were not very different being 47,3 ; 3,6 and 49,1% for green leaf, dead leaf and stem, respectively.

The relative proportions of green leaf, dead leaf and stem in the stubble left after grazing are shown in Table 34.

Table 34. The relative proportions of green leaf, dead leaf and stem in the different heights of stubble expressed as a percentage of the mean total amounts of herbage in the stubble.

Herbage component %	Stubble height cm		
	5	15	25
Green leaf	13,3	17,3	17,1
Dead leaf	9,7	9,3	8,3
Stem	77,0	73,4	74,6

The relative proportions of green leaf, dead leaf and stem in the stubble were similar with all three stubble-height treatments ; though in the 5 cm stubble, the proportion of green leaf was slightly lower, and the proportion of dead leaf slightly higher, than in the other two stubble heights.

Discussion

Elsewhere in the world, effects of leaving grass stubble of different heights after harvesting have given inconsistent results in terms of total herbage harvested above these heights. For example Evers and Holt (1972) cut _Panicum coloratum_ to leave stubble heights of 5 and 15 cm at intervals of three, four or five weeks and found that yields were greater with the 15 cm stubble height. Chheda and Mohamed Saleem (1973b)cut pastures of _Cynodon_ sp.(cv IB8) to leave stubble heights of 0 to 25 cm after grazing followed by rest periods of six weeks. They concluded that an 18 cm stubble left after grazing maintained quality and production of herbage. Somewhat contradictory results were obtained by Ethredge, Beaty and Lawrence (1973). They found that _Cynodon_ sp. cv Coastal Bermuda produced more herbage when clipped to ground level than when clipped to leave stubble heights of 7 and 14 cm. Clipping frequencies varied from three to seven weeks. Similar results were obtained by Richards (1965) with Bermuda grass and with _Digitaria decumbens_ but not with _Panicum maximum_. These grasses were clipped to leave stubble heights of 2,5 ; 7,5 and 9,0 cm at different intervals and with various fertilizer applications. It was observed that Bermuda grass and _D. decumbens_ should be grazed as low as possible for maximum herbage production, even to the point of overgrazing, but _P. maximum_ was killed by such treatment. The most suitable height for this grass was 7,5 to 9,0 cm. This indicates that the growth habit of a grass may influence the height of stubble that should be left after grazing because _P. maximum_ is a tufted grass whereas the other two are prostrate grasses. Hart, Carlson and McCloud (1971) experimenting with _Festuca arundinacea_ and _Dactylis glomerata_ and Knievel, Jacques and Smith (1971) with _Bromus inermis_ and _Phleum pratense_, found that total herbage yields of these grasses were greater when stubbles of 4 to 5 cm were left after clipping than where taller stubbles were left.

The results of this experiment show quite conclusively that to produce maximum amounts of herbage from Star grass grazed rotationally at 15-day intervals the stubble left after grazing should be no taller than 5 cm. Clearly, the generalisation so often quoted, that the rate of regrowth after defoliation will be proportional to the amount of photosynthetic tissue remaining after defoliation, is incorrect in this instance. In Figure 39 it can be seen that the 5 cm stubble had the least amount of herbage in it and in Table 34 that it had the lowest proportion of green leaf in it. Nevertheless this stubble height resulted in the highest herbage yields (Figure 39). The results indicate that either the efficiency of the photosynthetic tissue remaining in the stubble after grazing varied with treatments and that with the lower stubble heights was more efficient or reserve carbohydrate levels were influencing regrowth rates. However, a full explanation of the results would require a more detailed study where measurements of the assimilation rates of the various tissues involved <u>in situ</u> would be necessary and where reserve carbohydrates as an energy source for regrowth is taken into account.

Herbage yields in 1972-73 were lower than in 1974-75 (Figure 39) probably because of differences in rainfall. The first season was a drought whereas the second was a season of good rainfall (Appendix 1). However, more nitrogen was applied in the second season (500 instead of 350 kg N per ha) and this too, may have increased yields.

It is clear that for different grasses different stubble heights may be required after clipping or grazing for them to produce maximum amounts of herbage. Therefore grasses which show promise for intensive grazing purposes should first have their growth characterised as described for Star grass in Section 4.4. Such a characterisation study will indicate the length of the period during which quality of herbage is at an optimum, and growth and regrowth rates are at a maximum following clipping. This information could be used to plan further trials in which various stubble heights are left after grazing. Grazing should be done rotationally and the lengths of periods of rest between grazings should be within the period of most rapid growth or regrowth when quality of herbage is at an optimum as indicated by the characterisation study. Simultaneously, conditions for growth should be made as near optimum as possible by applying adequate nutrients for grass growth and ensuring that moisture stress is not a problem.

4.5.4 Rejuvenation of Star grass pastures

Star grass (Cynodon aethiopicus cv. No. 2) pastures grown on the silty clay soils on Henderson Research Station rapidly become invaded by Sporobolus pyramidalis (Rats Tail grass) when less than 510 kg N per ha is applied to them annually. Rats Tail grass is a tufted perennial which is coarse and unpalatable to livestock. An example of how rapidly Rats Tail grass invades Star grass pastures is given in Section 4.5.1 (Table 32). Where 170,340 and 510 kg N per ha were applied annually to Star grass pastures 57, 40 and 9%, respectively of the total basal cover was Rats Tail grass after only two years.

Experimental Objectives

To determine whether by increasing amounts of nitrogen applied to Star grass pastures already invaded by Rats Tail grass and by mowing and grazing, this grass could be eradicated from such pastures.

Materials and Methods

Three, four-year-old Star grass pastures were used for the experiment. These pastures had only received small dressings of nitrogen previously and had a mean total basal cover of 9,5% when the experiment started in December 1972. Of this basal cover 33,8% was Star grass and 66,2% was Rats Tail grass as determined by the point quadrat method. Whole plots, each 0,4 ha in area, were divided in half and one half was left unmown and the other was mown to 5 cm immediately following grazing which was done at 15-day intervals every growing season. Both unmown and mown plots were further sub-divided into four sub-plots to which 200, 350, 500 and 650 kg N per ha were applied at random, annually. In addition, 90 kg P_2O_5 per ha were applied each year in October as a basic dressing before the rains started.

The nitrogen was applied in four equal monthly dressings starting with the first good rains in each season. Grazing was done by 296 cow and calf units per ha for up to 24 hours, the object being to remove as much herbage through the animal as possible. The same half of each whole plot was mown for the duration of the experiment. Any residues following mowing were left *in situ*. At the end of each growing season in May or June, the basal cover and components of that cover were estimated by the point quadrat method. In each sub-plot a frame having 10 pins spaced 50,8 mm apart was placed in 100 stratified positions in each sub-plot so that the whole area was uniformly covered.

The experiment continued for three years. During the first year, 1972-73, little rain fell but 1973-74 and 1974-75 were seasons of good rainfall (Appendix 1).

Results

The total basal cover of the pastures and components of that cover are shown in Table 35.

Treatments during the first year did not affect the basal cover of either Star grass or Rats Tail grass in swards. However, the basal covers of both components were lower than when the experiment started in December 1972. This reduction in cover was probably caused by the poor rainfall during the 1972-73 season (Appendix 1).

During the second year, applied nitrogen significantly ($P < 0,01$) affected the amount of Rats Tail grass in swards in that as amount of applied nitrogen was increased basal cover of Rats Tail grass decreased.

The basal cover of Star grass was decreased ($P < 0,001$) by mowing in the third year and the basal cover of Rats Tail grass decreased ($P < 0,001$), although at a decreasing rate ($P < 0,05$), as amounts of nitrogen applied increased.

Table 35. The effects of applied nitrogen (N) and of mowing (M) on the mean basal cover of Star (S) and Rats Tail (R) grasses expressed as a percentage of total pasture area. (Analysis of variance table Appendix 2.47).

Year	Grass	Mowing (M) treatment	Nitrogen (N) kg per ha				M means	SE ±	Significant effects
			200	350	500	650			
1973	S	Mown Unmown	1,3 0,7	1,4 1,3	1,1 1,6	1,2 0,9	1,25 1,13	0,11	
		N means	1,00	1,35	1,35	1,05		0,21	
	R	Mown Unmown	4,3 5,6	3,8 4,1	3,2 3,6	3,8 3,9	3,78 4,30	0,20	
		N means	4,95	3,95	3,40	3,85		0,45	
1974	S	Mown Unmown	1,6 1,5	1,4 2,2	2,1 2,0	1,6 2,3	1,68 2,00	0,23	
		N means	1,55	1,80	2,05	1,95		0,37	
	R	Mown Unmown	3,9 3,9	2,4 2,3	1,8 1,7	1,7 1,0	2,45 2,23	0,15	
		N means	3,90	2,35	1,75	1,35		0,31	N'**
1975	S	Mown Unmown	2,4 2,7	3,4 4,2	2,7 4,3	2,9 4,6	2,85 3,95	0,06	M***
		N means	2,55	3,80	3,50	3,75		0,44	
	R	Mown Unmown	7,9 6,2	4,5 3,3	2,5 2,2	2,2 2,1	4,28 3,45	0,37	
		N means	7,05	3,90	2,35	2,15		0,54	N'*** N''*
Three-year means	S	Mown Unmown	1,77 1,63	2,07 2,57	1,97 2,63	1,90 2,60	1,93 2,36	0,12	M*
		N means	1,70	2,32	2,30	2,25		0,23	
	R	Mown Unmown	3,37 3,23	3,57 3,23	2,90 2,90	2,37 2,53	3,30 3,32	0,13	
		N means	3,30	3,40	2,90	2,45		0,21	N'**, N''**

The mean effects of treatments over the three years was that mowing decreased ($P < 0,05$) the basal cover of Star grass while the basal cover of Rats Tail grass was decreased by increasing amounts of applied nitrogen ($P < 0,001$) although at a decreasing rate ($P < 0,01$), as more nitrogen was applied.

Discussion

In 1972 when the experiment started 66,2% of the mean total basal cover (9,5%) of swards was Rats Tail grass and 33,8% was Star grass. By the end of the third year applications of 500 and 650 kg N per ha had reduced the proportions of Rats Tail grass to 40,2 and 36,4% of the basal cover of swards, respectively.

There is much experimental evidence that on grazed dryland Star grass pastures on Henderson Research Station the rate of response to applied nitrogen falls off rapidly at levels in excess of 350 kg N per ha. Therefore the cost of applying 500 to 650 kg N per ha as a means of controlling invasion of Rats Tail grass in Star grass pastures would be prohibitive. Thus, neither mowing nor fertilizing with nitrogen can be regarded as a practical means of controlling Rats Tail grass.

However, by applying a level of nitrogen which produces near maximum amounts of herbage, that is 350 kg N per ha, the rate of invasion will be slowed down compared to invasion where lower levels of nitrogen are applied. Invasion in these circumstances could be controlled by systematic hand hoeing during the dry season when labour requirements are not at a premium.

4.6 Yields of Maize Following Heavily Fertilized and Intensively Grazed Grass Pastures

When the late Dr. William Davies, the well known authority on grassland farming in the United Kingdom, visited Rhodesia in 1947 he stressed the importance of grass leys in farming systems in Rhodesia ; saying that leys would build-up soil fertility and bind the soil so preventing soil erosion (Davies, 1947). His visit had a marked influence on the development of research in Rhodesia for the next 16 years. Much of the research at both the Henderson and Grasslands Research Stations during this time was spent on developing grass leys for Rhodesian conditions and measuring the effects of these on yields of following crops.

At Henderson the grain yields of maize after four years of grass ley (Anonymous*, 1961) were no greater than those of maize grown for 12 successive years on the same land provided adequate fertilizers were applied to the maize and the maize stover was ploughed in annually (Thomas, 1963; Anonymous*, 1966). Therefore the belief that grass leys would improve the fertility of the silty clay soils on this Station was not substantiated by this early work. However, only relatively small amounts of fertilizers (up to 120 kg N and 45 kg P_2O_5 per ha, annually) were applied to the grass leys and they were lightly grazed during the growing season (2,5 yearling steers per ha).

Since 1963 grass pastures have been heavily fertilized with 350 kg N and 90 kg P_2O_5 per ha and grazed intensively at a stocking rate of 12 yearling steers per ha, over each growing season. Soil fertility was likely to be enhanced to a greater degree under such pastures than under the leys already described because of the larger applications of fertilizers and the greater amounts of nutrients being recycled in the excreta of grazing animals. It might well be expected that grain yields of maize grown after the pastures would be greater than those of maize grown after the lightly fertilized leys and of maize grown continuously on arable land.

Experimental Objectives

To determine whether maize grown after grass pastures that had been heavily fertilized and intensively grazed for several years would yield more grain than maize grown in successive years on the same land.

Materials and Methods

To achieve this objective the pastures in the experiments described in Section 4.3.3 were ploughed under and cropped with maize to determine whether or not the treatments applied to the pastures had any residual effects on maize production, and also what effect nitrogen applied directly to the maize would have on production. For a full description of the treatments applied to the grasses refer to Section 4.3.3.

There were three experiments to determine the various residual effects of previous treatments to grass pastures on maize grown after the pastures.

Experiment 1

This concerned the test cropping of the four grasses Chloris gayana (cv. Giant Rhodes), Cynodon nlemfuensis var. nlemfuensis (cv. Muguga Star), Panicum coloratum (cv. Bushman Mine) and P. repens (cv. Victoria Falls) that were grazed at a stocking rate of 9,88 steers per ha for three growing seasons prior to test croppings. These plots were taken as three randomised blocks of the four grasses, each containing five plots to accommodate different nitrogen applications.

Experiment 2

This concerned the test cropping of the plots previously occupied by Muguga Star, Bushman Mine Panicum and Victoria Falls Panicum that were grazed at stocking rates of 9,88; 12,36; 14,83 and 17,30 steers per ha for three growing seasons. These plots formed three replications of a split-plot design comprising three whole-plots (the former grass plots) each containing five sub-plots to accommodate different nitrogen applications to the maize.

Experiment 3

In the original experimental pasture lay-out (Section 4.3.3) provision was made for successive crops of maize to be grown annually on plots within the experimental area. This allowed yields of maize grown on the former grass plots to be compared with yields obtained after several years of cropping on the maize plots.

Maize was grown for the first time in these plots in 1966-67 and was followed by successive crops in the next four years. Annually, the maize received a standard fertilizer application of 135 kg N, 90 kg P_2O_5 and 70 kg K_2O per ha. In addition, on one-half of each plot maize stover was removed each year while on the other half it was ploughed into the soil. In 1971-72 the maize in these plots was treated similarly to that following grass except that maize stover was removed or ploughed into the soil on appropriate plots. The plots on which stover was removed or returned annually were divided into five sub-plots to accommodate different nitrogen applications. Thus the design was three replications of a split-plot design with each replicate having two whole-plots and each whole-plot having five sub-plots.

The pastures involved with Experiments 1 and 2 were ploughed under between 10 and 28 May 1971. During September 1971 the area was reploughed and then disc-harrowed. On 13 and 14 October 1971, 70 kg P_2O_5, 70 kg K_2O and 220 kg dolomitic limestone per ha were distributed over the entire area, including the plots previously planted to maize, and disced in. On 8 and 9 November 1971, SR52 hybrid maize seed was machine-planted into dry soil in rows 91,4 cm apart with seeds spaced 22,9 cm in the row. Soaking rains fell on 16 November 1971 (Appendix 1) and on the next day the herbicide Atrazine was applied by aircraft at the rate of 2,24 kg active ingredient per ha, as a weed control measure.

Nitrogen at rates of 67, 134, 201 and 268 kg N per ha was applied during the growing season to the sub-plots in all three experiments with one sub-plot left unfertilized as a control. On 19 November 1971 one-third of the experimental nitrogen was applied by hand on the soil surface over the ungerminated maize seed. This was followed five weeks later by the remaining two-thirds of the nitrogen dressings. This was distributed between the maize rows by hand. The pH of the soil was 5,14 (calcium chloride).

The maize was harvested during June 1972 from all sub-plots in all three experiments, the plots harvested being 0,005 ha in area. Before harvesting, plant stand counts were done in all experiments and the mean stand count was 36 674 plants per ha. The maize from each split-plot was shelled, the grain was weighed and a sample of grain oven-dried to determine dry matter content of grain.

During 1972-73 maize was again planted experimentally in all three experiments as a second test crop. However, only 568 mm of poorly distributed rain fell which resulted in poor growth of maize and grain formation. Therefore the maize was not harvested for experimental purposes. In contrast the 1971-72 season was a good one for growth of maize and 901 mm of well distributed rain fell (Appendix 1).

Results

Experiment 1

The effect of applying nitrogen to maize grown after Giant Rhodes, Muguga Star, Bushman Mine Panicum and Victoria Falls Panicum pastures that were grazed at a stocking rate of 9,88 steers per ha for three growing seasons, is shown in Table 36.

Responses to nitrogen applied to the maize were negligible, the yield without nitrogen being similar to the yields obtained with nitrogen. The mean yield of maize grown on the Bushman Mine Panicum plots was greater than the mean yield from the Giant Rhodes plots ($P < 0,01$).

Table 36. The effects of applying nitrogen (N) to maize in 1971-72 following four grasses (G) that had been heavily fertilized and grazed at a stocking rate of 9,88 steers per ha for the previous three growing seasons. Maize grain yields in 91 kg bags per ha containing 12,5% moisture. (Analysis of variance table Appendix 2.48).

Grasses (G)	Nitrogen (N) kg per ha					G means
	0	67	134	201	268	
Giant Rhodes	109,9	111,4	103,8	113,2	103,7	108,4
Mugoga Star	113,7	118,3	121,4	109,5	112,8	115,1
Bushman Mine Panicum	120,8	123,0	119,5	119,5	123,6	121,3
Victoria Falls Panicum	115,5	118,7	114,9	111,3	116,8	115,6
N means	115,0	117,9	114,9	113,4	114,6	115,2
SE ±	3,01					
Significant effects	G***					
LSD P = 0,05	8,0 bags per ha					
P = 0,01	11,2 bags per ha					
P = 0,001	15,8 bags per ha					

Experiment 2

The residual effects of treatments on three grasses, and the direct effects of applying nitrogen to maize grown after the grasses, are shown in Table 37.

Table 37. The effects of applying nitrogen (N) to maize in 1971-72 grown after three grasses (G) that were heavily fertilized and intensively grazed at different stocking rates (R) for the previous three growing seasons. Maize grain yields in 91 kg bags per ha containing 12,5 % moisture. (Analysis of variance table Appendix 2.49).

Grass (G)	Stocking rate (R) steers per ha	Nitrogen (N) kg per ha					R
		0	67	134	201	268	means
Muguga	9,88	113,7	118,3	121,4	109,5	112,8	115,1
Star	12,36	103,7	105,3	104,9	108,2	106,1	105,6
(G1)	14,83	118,7	116,3	112,6	121,3	122,4	118,3
	17,30	113,8	122,4	117,0	117,7	118,6	117,9
N means		112,5	115,6	114,0	114,2	115,0	114,3(G1)
Bushman	9,88	120,8	123,0	119,5	119,5	123,8	121,3
Mine	12,36	115,9	118,2	122,0	120,0	116,6	118,5
Panicum	14,83	122,5	112,9	113,6	124,0	114,8	117,6
(G2)	17,30	115,4	117,7	116,7	119,1	114,9	116,8
N means		118,7	118,0	118,0	120,6	117,5	118,6(G2)
Victoria	9,88	115,5	118,7	114,9	111,3	118,8	115,8
Falls	12,36	117,9	110,2	119,9	118,1	126,0	118,4
Panicum	14,83	125,8	114,7	118,5	125,2	120,8	121,0
(G3)	17,30	110,1	111,5	106,9	113,9	111,1	110,7
N means		117,3	113,8	115,1	117,1	119,2	116,5(G3)
N means three grasses		116,2	115,8	115,7	117,3	117,2	116,5

SE ± G 1,97; R 2,27; N 2,52; R x N 1,74

Significant effects N''' x SR'' **

N'''' x SR' *

A high degree of accuracy was achieved in this experiment (c.v. 5,46%). Probably because of this accuracy, two high order interactions between stocking rate on grasses and nitrogen on maize were detected. No applicable interpretation of these interactions was possible because of their complexity. However, differences were small and from a practical point of view, negligible. Yields of maize without nitrogen were similar to those where various amounts of nitrogen were applied.

Experiment 3

The effect of applying different amounts of nitrogen to maize grown on the same land in successive years and the effect of removing or ploughing under maize stover annually on maize yield, are shown in Table 58.

Table 58. Effects of applying different amounts of nitrogen (N) removing or ploughing under maize stover (S) annually, on maize grain yield where maize was grown on the same land for six successive years. Maize grain yields in 91 kg bags per ha containing 12,5% moisture. (Analysis of variance table Appendix 2.50).

Maize stover (S)	Nitrogen (N) kg per ha					S means
	0	67	134	201	268	
S removed	95,3	105,7	100,8	95,4	109,6	101,4
S returned	118,7	107,7	119,0	117,9	102,4	113,1
N means	107,0	106,7	109,9	106,7	106,1	107,3
SE ±		Significant effects				
Internal	2,16	S*				
S	0,19					
N	0,77					

Applying different amounts of nitrogen had little effect on maize yields, and yields without nitrogen were similar to those where nitrogen was applied. Where stover was ploughed back into the soil annually, maize yields were 11,7 bags per ha greater than where maize stover was removed annually. The mean maize yield following the four grasses grazed at a stocking rate of 9,88 steers per ha (Table 36) was only 2,1 bags per ha greater, and that following the three grasses grazed at different stocking rates (Table 37) only 3,4 bags per ha greater, than yields where maize was grown on the same land in successive years and stover was returned to the soil annually.

Discussion

The application of nitrogen to the maize following grass and to the maize grown on the same land in successive years, had a negligible effect on maize yields from a practical point of view. The lack of response to nitrogen can be explained by the fact that there was adequate nitrogen in the soil for the yields obtained, even where maize had been grown on the same land for six successive years. Soil analyses done before the maize was planted showed that the mean nitrogen content of the soil after incubation was 109 ppm following grass and 72 ppm where maize had been grown annually (Anonymous, 1971). These amounts of nitrogen in the soil would be adequate for the yields obtained both where maize was grown after grass and where it was grown annually, provided other plant nutrients were not lacking, management was good and there was sufficient available moisture in the soil (Fenner, 1977). Rainfall during 1971-72 was well-distributed and adequate for maize (Appendix 1).

Although the maize did not respond to applied nitrogen in all the experiments, maize grown after Bushman Mine Panicum in Experiment 1 produced 12,9 bags more per ha than maize grown after Giant Rhodes (Table 36). During the grazing experiment Bushman Mine Panicum provided 1 028 grazing days per ha and Giant Rhodes 847 grazing days per ha (Table 21). Therefore more plant nutrients in the excreta of steers would have been dropped on Bushman Mine Panicum pastures but whether this would have caused the greater yields on those pastures is not known.

Of particular practical significance was the fact that grain yields obtained where maize had been grown for six successive years and where stover was returned to the soil annually, were similar to those achieved after grass. However, where maize was grown annually and stover removed, yields were about 10 % lower. Normal farm practice is to graze maize stover <u>in situ</u> and then plough it under, or to plough it under without grazing. Clearly the results show that heavy fertilization and intensive grazing of grass pastures did not influence soil fertility for maize production. Growing successive crops of maize on the same land on silty clay soils apparently is feasible, provided adequate fertilizers are applied and the maize stover is ploughed back into the soil annually.

These conclusions confirm the views expressed by Ellis (1953) who stated that maintenance of soil fertility would better be achieved by proper management and fertilizer practices than by the use of grass leys. The main reason for planting leys is to control soil erosion and to maintain soil structure. This applies mainly to sandy soils and not to silty clay soils. Therefore on silty clay soils it is clear that grass pastures must be economically viable in their own right to find application in farming practice.

4.7 Management of Veld in Relation to Pasture Management

During the dry season (April to November) veld grass herbage contains low levels of crude protein. For example, Elliott and Folkersten (1961) found that in the early dry season the crude protein content of veld was as low as 3,1% of the dry matter. Furthermore, Elliott and Fokkema (1960) showed that the digestibility of the crude protein varied directly with the crude protein content of the herbage. When the crude protein content was 10,6% of the dry matter digestibility was 56,9% and when it was 3,8% a negative digestibility coefficient was recorded.

It is well known that if cattle grazing on veld during the dry season are not supplemented with small amounts of protein-rich supplements they lose body mass. Where such supplements are fed body mass may be maintained and even increased due to greater intake of herbage and more efficient digestion of the coarse dry roughage by cattle (Murray, Romyn, Haylett and Eriksson, 1936 ; Murray and Romyn, 1939 ; Rhodes, 1956 ; Elliott, 1960).

Addison (1963) was the first to suggest that fertilized grass pastures should be used for grazing during the growing season and that the veld should be rested during this time. This would also allow the veld grasses to grow out, set seed and accumulate root reserves; all factors favouring the maintenance of plant vigour. The herbage that would accumulate during the growing season would provide a satisfactory maintenance food for cattle during the dry season, provided protein-rich supplements were fed to them. Where the veld was protected during the growing season, competition from the grasses would inhibit bush encroachment and would produce large amounts of herbage for grazing. This herbage could be heavily grazed during the dry season without deleterious effects on the grasses, because they were in a dormant state. Furthermore fewer paddocks would be needed to effect correct veld management.

Boultwood (1969) showed that veld grasses harvested once at the end of the rainy season, produced as much herbage as, or more herbage than, veld grasses harvested more frequently during the season. Therefore if veld was rested for the whole of the growing season and grazed only in the dry season maximum amounts of herbage would be available for grazing.

Addison (1965) noted that bush encroachment and sward deterioration of veld were closely associated with frequent and intensive grazing during the growing season. Before this it had been found that body mass gains in cattle grazing on veld could only be expected during the period December to mid-April when veld grass contained adequate amounts of crude protein for ruminants (Elliott, 1956a,b, 1960 ; Anonymous*, 1960). Although a three herd four paddock rotational grazing system on the veld stocked at a rate of 1 cow to 1,6 ha during the growing season had been found satisfactory, invasion by the unpalatable grass <u>Sporobolus</u> <u>pyramidalis</u> invariably occurred (Anonymous*, 1957).

Numerous experiments have been done on veld management in many parts of Rhodesia in the medium to low rainfall areas. In these experiments, which were all designed to use veld throughout the year the effects of rotational grazing, stocking rates and fire on the vegetation were assessed (Kennan, Staples and West, 1955 ; Kennan, 1966, 1969 ; West and Rattray, 1947 ; West, 1947, 1948, 1954, 1958, 1969) ; the effects of removing trees using ringbarking or arboricides on the production of natural grass herbage were measured (Ward and Cleghorn, 1964 ; Ivy, 1969 ; Wilson, 1969), and the seasonal growth and changes in the chemical composition of veld grasses were determined (Weinmann, 1948). None of these experiments gave any information on the effects of fire and stocking rate on veld grazed only during the dry season. Accordingly, a trial was laid down in 1959 to study the long-term effects of these factors on veld used in this manner.

Experimental Objectives

The objective of this trial was to investigate the long-term effects of resting veld during the growing season followed by different intensities of grazing during the dry season and different frequencies of burning in the late dry season. More specifically, these treatments were to be assessed in terms of :

(i) the effects of grazing and fire on the botanical composition and basal cover of the veld

(ii) the effects of grazing and fire on the productivity of the veld in terms of herbage yields and in terms of body mass gains of cattle grazing the veld during the dry season at different intensities, and

(iii) the effects of grazing and fire on bush control and development.

Materials and Methods

The experimental site was stumped in 1959. Only a few large shade trees were left. A botanical survey of the area prior to stumping showed that Brachystegia boehmii (muFuti), Julbernardia globiflora (muNhondo) and B. spiciformis (muSasa) were present at densities of 1485, 726 and 180 trees per ha, respectively. These trees are the most important encroachment species in the area and indeed over most of the high rainfall areas of Rhodesia. Total tree density was 3012 trees per ha. The total basal cover of the herbaceous layer was 5,56% comprising mainly grasses dominated by Eragrostis racemosa, Digitaria diagonalis, Sporobolus stapfianus, Microchloa kunthii, Hyparrhenia spp. and Heteropogon contortus.

During the 1960 dry season the trial was accidentally burnt. Starting with the 1961 dry season, the following treatments were applied annually, using three replicates of a 3 x 3 + 1 design in three randomised blocks, until the end of the 1975 dry season when the trial was terminated.

Control treatment

No burning and no grazing of veld.

Grazing treatments

Graze the veld each dry season between June and October for 60 ; 90 or 120 grazing days per ha.

Burning treatments

Burn at the end of October after grazing and just before the commencement of the rainy season either every year, every second year or every third year.

The plots, each 0,2 ha in area, were grazed every dry season by non-lactating Africander-type cows, which were fed 800 g cottonseed meal (± 40% crude protein) per head, daily. The body mass changes of the cows were determined by weighing them before and after they grazed each plot. Every plot was grazed by three cows, the number of days being adjusted to give the correct number of grazing days per ha. The mean body mass of cows when going in to graze was 385,4 kg per head.

The botanical composition of the herbaceous layer and the number of trees by species was estimated in 1961 and again in 1975. The herbaceous vegetation was analysed by means of a point quadrat to measure basal cover by species. Heights of trees were measured in 1975, but not in 1961 when all the trees were below 0,5 m in height, except for the few large shade trees that remained after stumping.

The amount of herbage available for grazing in each treatment was determined by cutting two 1 m^2 quadrats in every plot immediately before grazing started each year. Immediately after cutting the herbage was weighed and the dry matter content determined from oven-dried samples.

Results

(i) Effects of treatments on the total basal cover of the herbaceous plants

The changes in the total basal cover of the herbaceous vegetation between 1961 and 1975 are shown in Table 39.

Table 39. The changes in percentage basal cover of the herbaceous plants between 1961 and 1975 with the various grazing intensities (G) and burning treatments (B). (Analysis of variance table Appendix 2.51).

Grazing intensity (G) grazing days per ha	Grazing (G) and burning (B) treatments				G means
	Not burned or grazed	Grazed; burned every year	Grazed; burned every second year	Grazed; burned every third year	
0	-0,32				-0,32
60		+2,05	+0,93	+0,72	+1,23
90		+2,17	+1,43	+0,63	+1,41
120		+1,27	+1,07	+1,03	+1,12
B means	-0,32	+1,83	+1,14	+0,79	
SE ±	Internal		0,53		
	Marginal		0,31		
Significant effects			Control vs rest**		

Protection from burning and grazing resulted in a slight reduction in basal cover, while in all other treatments, cover increased.

The basal cover of the protected plots was significantly lower ($P < 0.01$) than the mean cover of all of the other plots. Neither frequency of burning nor grazing intensity affected basal cover and although cover tended to decrease with decreasing burning frequency this was not significant.

(ii) Effects of treatments on grass species composition

The mean basal covers of the grass species in the control plots, and in the burned and grazed plots in 1961 and in 1975 is shown in Table 40. The treated plots had very similar compositions in 1975 regardless of stocking intensity or burning frequency. Therefore only the means for all the treated plots are shown.

The species composition of the control plots and the grazed and burned plots in 1961, was similar. However, there was a lesser amount of the _Hyparrhenia/Hyperthelia_ spp. group and a greater amount of each of _Microchloa kunthii_ and _Eragrostis racemosa_ in the plots scheduled for grazing and burning than in the control plots. Notable differences in 1975 were the very much greater amount of _Digitaria diagonalis_, the greater amounts of _Diheteropogon amplectens_, _Themeda triandra_ and _Heteropogon contortus_, and the lesser amounts of _Sporobolus pyramidalis_ and _Microchloa kunthii_ in the grazed and burned, as compared with the control plots. _Eragrostis racemosa_ disappeared in both treatments and was replaced by _Eragrostis capensis_.

(iii) Effects of treatments on the trees

The percentage change in the number of trees present in 1975 as compared with 1961, and the actual number of trees present in 1961 are shown in Table 41. Data for the three most important encroachment species are shown separately.

Table 40. The percentage basal cover by species, and percentage species composition of the herbaceous cover on the control plots and the grazed and burned plots in 1961 and 1975.

Species	Percentage basal cover by species				Percentage composition on basis of basal cover			
	Control plots		Grazed and burned plots		Control plots		Grazed and burned plots	
	1961	1975	1961	1975	1961	1975	1961	1975
Hyparrhenia filipendula		0,55		0,54		11,58		7,96
Hyparrhenia spp.	0,68	0,45	0,48	0,46	13,41	9,47	8,70	6,78
Hyperthelia dissoluta		0,25		0,40		5,26		5,90
Diheteropogon amplectens		0,50		1,08		10,53		15,93
Themeda triandra	0,31	0,05	0,18	0,47	6,11	1,05	3,26	6,93
Monocymbium ceresiiforme				0,14				2,08
Digitaria diagonalis	0,52	0,05	0,75	0,75	10,26	1,05	13,59	11,06
Heteropogon contortus	0,34	0,05	0,39	0,40	6,71	1,05	7,07	5,90
Sporobolus pyramidalis	0,58	0,55	0,49	0,21	11,44	11,58	8,88	3,10
Sporobolus stapfianus	0,72	0,30	0,65	0,64	14,20	6,32	11,78	9,44
Microchloa kunthii	0,25	0,50	0,57	0,15	4,93	10,53	10,33	2,20
Eragrostis racemosa	0,31		0,82		6,11		14,86	
Eragrostis capensis		0,40	0,01	0,44		8,42	0,15	6,49
Other grasses	1,24	0,45	0,88	0,34	24,46	9,47	15,94	5,01
Sedges	0,05	0,35	0,13	0,62	0,99	7,37	2,36	9,14
Forbs	0,07	0,30	0,17	0,14	1,38	6,32	3,08	2,08
Total basal cover	5,07	4,75	5,52	6,78	100,00	100,00	100,00	100,00

Table 41. The percentage changes in the numbers of trees present in 1975 as compared with 1961 with different grazing intensity (G) and burning (B) treatments. Actual numbers of trees in 1961 showed in parenthesis. (Analysis of variance table Appendix 2.52)

Grazing intensities (G) grazing days per ha	Grazing intensity (G) and burning (B) treatments				G means
	Not burned or grazed	Grazed : burned every year	Grazed : burned every second year	Grazed : burned every third year	
Brachystegia boehmii					
0	+26(234)				+26(234)
60		-17(319)	+13(208)	+12(331)	+ 3(286)
90		-14(341)	+ 7(395)	+38(307)	+10(346)
120		-14(260)	+31(303)	+22(309)	+13(291)
B means	+26(234)	-15(307)	+17(302)	+24(316)	+ 9(308)
S.E. ± Internal 17 Marginal 10 L.S.D. P=0,05 28,3			Significant effects : Control vs rest ** B*		
Julbernardia globiflora					
0	+73(69)				+73(69)
60		-63(109)	-39(135)	-23(191)	-42(145)
90		-59(234)	-27(127)	-24(178)	-37(180)
120		-63(115)	- 2(177)	+28(134)	-12(142)
B means	+73(69)	-62(153)	-23(146)	- 6(166)	-30(156)
S.E. ± Internal 13 Marginal 7 L.S.D P=0,05 22,6 P=0,001 42,2			Significant effects : Control vs rest *** B*** G*		
Brachystegia spiciformis					
0	+38(28)				+38(28)
60		-83(50)	-41(38)	-13(52)	-46(47)
90		-71(28)	-35(56)	- 9(37)	-38(40)
120		-76(22)	-22(31)	- 3(24)	-34(26)
B means	+38(28)	-77(33)	-33(42)	- 8(38)	-39(38)
S.E. ± Internal 21 Marginal 12 L.S.D. P=0,05 11,4 P=0,01 15,6			Significant effects : Control vs rest *** B**		
All tree species					
0	+87(427)				+87(427)
60		-31(589)	-24(542)	- 7(694)	-21(608)
90		-26(723)	-18(761)	+10(636)	-11(707)
120		-27(531)	+10(623)	+18(570)	+ 1(575)
B means	+87(427)	-28(614)	-11(642)	+ 7(633)	-10(630)
S.E. ± Internal 17 Marginal 10 L.S.D. P=0,05 17,6			Significant effects : Control vs rest *** B*		

The number of trees in the control plots increased by 87% over the 15-year period. Most of the encroaching trees in the control plots were Parinari curatellifolia, Cussonia sp. and Terminalia stenostachya and not the main encroachment species Brachystegia boehmii, Julbernardia globiflora and B. spiciformis. No reason can be advanced for this but aspect may have had some influence.

Grazing and burning every year or every second year resulted in a decrease in the numbers of trees of all species, although in the case of Brachystegia boehmii there was an increase with the two-year burning frequency. With grazing and burning very third year most trees were controlled but B. boehmii increased.

Only with Julbernardia globiflora was the number of trees significantly decreased ($P < 0,05$) by increasing the grazing intensity. Although there was a similar trend with Brachystegia boehmii and with all tree species, differences were not significant.

The mean percentage frequency distribution by height classes of the trees Brachystegia boehmii, Julbernardia globiflora and B. spiciformis in 1975 is shown for the different grazing and burning treatments in Table 42.

Table 42. The percentage frequency distribution by height classes of Brachystegia boehmii, Julbernardia globiflora and B. spiciformis in 1975 with different grazing and burning treatments.

Tree height class m	Grazing and burning treatments			
	Not burned or grazed	Grazed; burned every year	Grazed; burned every second year	Grazed; burned every third year
< 0,3	3,8	20,5	9,7	14,3
0,3-2,0	24,7	67,4	65,9	49,7
2,0-4,0	67,8	11,2	23,8	35,2
> 4,0	3,7	0,9	0,6	0,8

In the control treatment the majority of trees present fell into the 2,0 to 4,0 m height class, whereas in the three grazing and burning treatments the majority fell into the 0,5 to 2,0 m height class. There was a distinct shift in frequency distribution by height in the three grazing and burning treatments. With annual burning most of the trees were short while there was a progressive increase in mean tree height with the two and three year burning frequencies.

(iv) The effects of treatments on the herbage yield of veld grasses

The mean herbage yields of the veld grasses in the different treatments over the 15-year period are presented in Table 43.

Table 43. The effects of complete protection and of various grazing intensity (G) and burning (B) treatments on the 15-year mean annual herbage yield of veld grasses in kg per ha dry matter. (Analysis of variance table Appendix 2.53).

Grazing intensity (G) grazing days per ha	Burning frequency (B)					SE ±	Significant effects
	No burning	Every year	Every second year	Every third year	G means		
0	4300				4300	Internal	
60		3280	3870	3800	3650	170	
90		2750	3320	3400	3160	Marginal	
120		4280	3700	3870	3950	100	
B means	4300	3440	3630	3690			

Although more herbage was harvested from control plots as compared with the grazed and burnt plots, the differences were not significant. Differences between the grazed and burned plots were small.

(v) Changes in the body mass gains of cows grazing the different treatments

The effects of the different grazing and burning treatments on the body mass changes of cows are shown in Table 44.

Table 44. The effects of various grazing intensity (G) and burning (B) treatments on veld on the 15-year mean body mass changes in kg of Africander-type cows. (Analysis of variance table Appendix 2.54).

Grazing intensity (G) grazing days per ha	Burning frequency (B)				S E ±	Significant effects
	Every year	Every second year	Every third year	G means		
60	+ 8,87	-14,17	-7,17	-4,16	Internal	
90	- 9,33	- 4,30	-1,23	-4,95	51,6	
120	-10,50	+ 1,47	-3,07	-4,03	Marginal 29,8	
B means	- 3,65	- 5,67	-3,82	-4,38		

Neither the intensity of grazing the veld during the dry season nor frequency of burning the veld in the late dry season after grazing, had any effect on the body mass changes of the cows. The mean body mass of cows when going into graze was 385,4 kg per cow and when they finished grazing it was 381,0 kg per cow, the body mass loss per cow being 4,38 kg over the grazing period.

Discussion

In this experiment there was no evidence that grazing during the dry season and burning at any of the frequencies used in the late dry season resulted in a deterioration in grass species composition and in yield of grass herbage. In fact in the burning and grazing treatments there was a distinct improvement in basal cover and in the species composition of the grasses between 1961 and 1975.

For example the Hyparrhenia/Hyperthelia group of grasses had increased from 8,70 to 20,64 % (Table 40) of the total basal cover during this time while the unpalatable species Sporobolus pyramidalis decreased from 8,88% in 1961 to 3,10% in 1975. Further examples of improvement were the disappearance of the annual grass weed Eragrostis racemosa by 1975 and the reduction in amounts of Microchloa kunthii and Sporobolus stapfianus which produce insignificant amounts of herbage and are unpalatable to cattle. The appearance of Diheteropogon amplectens and the increase in amount of Themeda triandra, both grasses high in sub-climax stage of vegetation of the area, although the latter grass is not very palatable, are further indications of the improvement in grass species composition. The results obtained from the protected plots are of academic interest only. In these the amounts of Hyparrhenia/Hyperthelia increased but overall the basal cover of grasses decreased.

Clearly burning may be used to control the number of trees and their height in veld grazed only during the dry season. However, the dominant tree species in the area Brachystegia boehmii, was only reduced in numbers with annual burning and increased with less frequent burning while the other species were controlled even with a tri-annual burn.

The cows grazing on the veld during the dry season lost on average only 4,38 kg per cow in body mass and there were no differences due to grazing intensity or burning frequency. This is an insignificant loss. Clearly it is possible to maintain cows during the dry season on the coarse dry herbage that accumulates as a result of resting veld during the growing season, but as the protein content of the herbage is low a protein supplement must be fed to cattle to promote intake and digestion.

The results show that resting the veld annually during the growing season and grazing only during the dry season is a simple and effective way of managing veld. The veld was improved in species composition and produced maximum amounts of herbage which was efficiently used to maintain cattle during the dry season.

Furthermore grazing during the dry season requires a minimum of fencing and watering points. A single paddock per herd for the dry season is all that is needed. However, the fire hazard in managing veld in this manner would be high and adequate protection would be needed against accidental fires.

4.8 Assessing Productivity of Pastures in Production Systems

The experimental results described in Section 4.7 showed that if the veld on Henderson Research Station was rested during the growing season and grazed only during the dry season, the veld was improved in species composition and produced adequate amounts of herbage to provide for at least 120 grazing days per ha, annually. Furthermore cattle that are fed small amounts of protein-rich supplements while grazing dry coarse roughages during the dry season will gain slightly in body mass (Elliott, 1963). On maize farms there is also stover that can be used in this manner.

By 1972 it had been shown that Star grass (Cynodon aethiopicus cv. No. 2) pastures could carry large numbers of cattle during the growing season. Experimental results had shown that when 350 kg N and 90 kg P_2O_5 per ha were applied to Star grass pastures grazed on a set-stocked basis, herbage production was at a maximum (Section 4.3.2). It had also been found (Section 4.3.3) that by stocking similar pastures with 12 yearling steers per ha, efficient use of the herbage was achieved compared to where lighter or heavier stocking rates were imposed on them. Another experiment (Section 4.5.1) showed that if Star grass was grazed rotationally at 15-day intervals and a stubble of 5 cm was left after grazing, more herbage was produced than when the intervals between grazings were longer and the same height of stubble was left after grazing.

Also by 1972 a high energy diet had been developed for fattening of beef cattle that contained 13% crude protein and comprised 70% maize meal, 20% roughage and 10% of a protein-rich concentrate (Reed, Elliott and Topps, 1966, 1968; Elliott and Reed, 1968). Steers of about 300 kg initial body mass gained approximately 140 kg in body mass after about 100 days of feeding in pens and were in slaughter condition.

An analysis of this accumulated knowledge indicated that an intensive system of beef production for the maize growing areas of Rhodesia could be developed. The system would be suitable for beef steers or heifers, and would make use of available veld, crop residues, pastures and maize as follows.

(i) Six-to-eight-month-old calves would be weaned during May and June of each year at between 180 and 200 kg body mass. For the remainder of the dry season they would be carried on veld rested during the previous growing season and on crop residues. While on these forages the weaners would be fed a protein-rich supplement to maintain slight body mass gains so that they would be approximately 240 kg body mass in November at the end of the dry season.

(ii) From the end of November or beginning of December, with the onset of the rains, yearling cattle would be carried on fertilised Star grass pastures until approximately mid-April depending on rainfall. By this time they should have gained up to 60 kg in body mass and weigh approximately 300 kg body mass per head.

(iii) From mid-April, which is the beginning of the dry season, the 18-month-old cattle would be fattened in pens on a high energy diet. After about 100 days of feeding they should be 400 to 430 kg in body mass and thus ready for slaughter at 20 to 24 months of age.

4.8.1 The effects of management and stocking rate on carcass mass gains of steers on Star grass pastures and the effects of treatments on their performance when fattened for slaughter in pens

The experimental results obtained between 1964 and 1972 on fertilized dryland grass pastures needed testing on a larger scale than had been possible at the time, and preferably so as to fulfil some role in a production system. This appeared to be necessary before further advances could be made in research. Up to 1972 the productivity of pastures had been measured in terms of amounts of herbage harvested and/or the body mass gains of the live animals grazing them. Both these criteria are, at best, only estimates of productivity because, with grazing, not all available herbage is consumed and this material is not of constant digestibility and quality. Also, the amount of food in the digestive tract of the animal when weighed can cause variations in its body mass of up to 15,9% (Johnson and Elliott, 1969). By measuring the carcass mass of cattle, as opposed to their body mass, while grazing pastures, a precise measurement of the productivity of pastures would be obtained.

Circa 1972, it was common practice for farmers to supplement cattle with energy-rich food (up to 5 kg per head daily) while grazing on veld or pastures during the growing season. The efficiency with which this supplement, in addition to the grass, was used for gain in carcass mass was not known, but it was well known that roughage and concentrate foods are used with different efficiencies for fattening cattle ; also that for most efficient utilization of food it is necessary to maximise intake (Elliott and Reed, 1968). It might be more efficient to feed an equal amount of concentrate to cattle in pens at the end of the growing season, rather than during it.

Experimental Objectives

The objectives of this trial were

(i) to test the practical application of the knowledge gained from research on the management and stocking rates of pastures in a beef production system

(ii) to obtain a precise measurement of production from Star grass pastures in terms of carcass mass gains of steers

(iii) to test the effects of treatments on steers on pasture and on their performance when fattened in pens on a concentrate diet after coming off pastures, and

(iv) to investigate the advisability of supplementing animals with small amounts of energy-rich concentrate while grazing pastures.

Materials and Methods

For the experiment 100 Sussex x Africander weaner steers were obtained during June 1972. The mean body mass per steer was 203 kg. For the remainder of the dry season the steers grazed on maize stover and on veld that had been rested from grazing the previous growing season. The steers were supplemented with 700 g cottonseed meal (± 40% crude protein) per steer daily to maintain slight gains in body mass.

A well-established Star grass pasture was used for the experiment. The pasture had been heavily fertilized (350 kg N and 90 kg P_2O_5 per ha, annually) and intensively grazed (4 to 7 cows and calves per ha) for the previous three growing seasons. During the 1972-73 growing season the pastures were again dressed with 350 kg N and 90 P_2O_5 per ha. The nitrogen was applied in four equal monthly dressings starting on 27 November 1972 while the phosphate was applied during October.

On 12 December 1972 the steers were divided into five groups of 20 steers each. The mean body mass per steer group was 243 kg.

One group of steers was slaughtered to measure mean carcass mass at that time and the remaining four groups were allotted at random to one of four treatments.

(i) Pasture set-stocked at a stocking rate of 12 steers per ha.

(ii) Pasture rotationally grazed using 15 paddocks at a stocking rate of 12 steers per ha. Each paddock was grazed for one day and then rested for 14 days.

(iii) Pastures rotationally grazed as in (ii), but at a stocking rate of 20 steers per ha.

(iv) Pastures rotationally grazed as in (iii), but steers were supplemented with 3 kg concentrate per steer daily containing 13% crude protein.

The steers were dipped weekly to control external parasites and were weighed fortnightly to determine changes in body mass. Towards the end of the growing season steers were weighed weekly and groups of steers were removed from the different treatments when they had lost body mass for two consecutive weeks.

The 1972-73 season was a drought and only 568 mm of rain fell (Appendix 1). The growing season was therefore shorter than usual and the steers grazed on pasture for a shorter period than in previous years (Section 4.3.1). Steers in Treatment (iii) were removed from pasture on 5 March, those in Treatment (i) on 12 March and those in Treatments (ii) and (iv) on 19 March 1973. From 5 March to 19 March steers coming off the experimental pastures grazed on adjacent and similar pastures to maintain body mass.

On 19 March 10 steers from each treatment with mean body mass similar to that of the whole group of steers were slaughtered for assessment of carcass mass gains while on pasture.

The remaining 10 steers from each treatment were put into pens and fed with a high energy diet comprising 70% maize meal, 20% milled hay and 10% of a protein-rich concentrate. Steers from Treatments (ii), (iii) and (iv) remained in pens until their mean body mass was 430 kg per steer. At this mass they were slaughtered. Steers in Treatment (i) were fed a similar amount of concentrate (315 kg per steer) in pens as had been eaten by the steers in Treatment (iv) while on pasture. The object of this comparison was to assess the relative efficiency of concentrate when fed to steers either on grass or later in the pens.

Estimates of the amounts of herbage on offer to the steers in the different treatments were made at 15-day intervals during the grazing period. This was done by cutting three 1 m^2 quadrats to 5 cm at random in each of paddocks 1, 6 and 11 of the treatments involving rotational grazing and three quadrats in the set-stocked treatment. The herbage was weighed after cutting and its dry matter content determined from oven-dried samples. From the results the mean amount of herbage available to the steers in the different treatments over the grazing period was calculated.

Results

The carcass gains of the steers while on pasture are shown in Table 45.

Table 45. The carcass mass gains in kg of steers managed in different ways on Star grass pastures fertilized with 350 kg N and 90 kg P_2O_5 during the 1972-73 growing season.

Treatment	Stocking rate steers per ha	Carcass mass per steer		Carcass mass gain	
		12.12.1972	19. 3.1973	per steer	per ha
(i)	12	109,6	144,8	35,2	422,4
(ii)	12	109,6	143,4	33,8	405,6
(iii)	20	109,6	127,4	17,8	356,0
(iv)	20	109,6	172,6	63,0	1260,0

Carcass mass gains of steers that were set-stocked or rotationally grazed at 12 steers per ha were similar. Steers that were grazed rotationally at 20 per ha gained only 17,8 kg carcass mass per head while those grazed in like manner and given a concentrate supplement gained 63,0 kg per head.

Estimates of the mean amounts of herbage on offer to the steers during the grazing period showed that there was 1 610 kg dry matter per ha (134 kg per steer) in Treatment (i), 1 830 kg per ha (153 kg per steer) in Treatment (ii), 1 400 kg per ha (70 kg per steer) in Treatment (iii) and 2 240 kg per ha (112 kg per steer) in Treatment (iv).

The gains in carcass mass made by the groups of steers in pens following the different treatments on pasture are shown in Table 46.

Table 46. The carcass mass gains in kg of steers fed a concentrate (conc.) diet in pens after being subjected to various treatments on Star grass pasture.

Treatment	Carcass mass per steer			No. of days in pens	Daily gain carcass mass per steer	Conc. consumed per steer kg	Kg conc. consumed per kg carcass gain
	19.3.1973	Final	Gain				
(i)	144,8	187,4	42,6	42	1,01	315	7,4
(ii)	143,4	233,6	90,2	98	0,92	789	8,7
(iii)	127,4	232,2	104,8	105	1,00	863	8,2
(iv)	172,6	232,3	59,7	70	0,85	566	9,5

Note : The concentrate consumed excludes the 20% milled hay added to the ration.

During the residual fattening phase in pens, the most efficient conversion of concentrate into carcass mass was in steers (Treatment (i))which were fed with the same amount of concentrate in pens (315 kg per steer) as had been consumed by the steers supplemented on pasture in Treatment (iv). This amount of food resulted in

42,6 kg carcass gain and was used with an efficiency of 7,4 kg concentrate per kg carcass gain. The least efficient conversion of concentrate into carcass mass was in steers (Treatment (iv)) that had been supplemented with concentrate while on pasture. These steers were the heaviest steers when going into pens and they consumed 566 kg concentrate per steer while in pens, representing an efficiency of 9,5 kg concentrate per kg carcass gain.

Discussion

In this experiment steers which were set-stocked at a stocking rate of 12 steers per ha on pasture gained slightly more in carcass mass than steers grazed rotationally over 15 paddocks at similar stocking rate. A stocking rate of 20 steers per ha which grazed rotationally over 15 paddocks (Treatment (iii)) was clearly too heavy under the prevailing weather conditions and gains in carcass mass both per steer and per ha were lower than steers which grazed at the lighter stocking rate. Estimates of the mean amounts of herbage available to the steers in the different treatments showed that least herbage (70 kg per steer) was available to steers in Treatment (iii) and so gains in carcass mass would be expected to be lower.

Elsewhere in the world experiments have shown that pastures grazed on a set-stocked or continuous basis have produced as much gain in body mass of cattle as have multi-paddock, rotational systems. For example Stobbs (1969) found that a continuous grazing and a three paddock system on Panicum maximum/Macroptilium atropureum pasture was more productive than a six paddock system. Hood and Baillie (1963) stated that a two field set-stocked system on a Lolium perenne/Phleum pratense pasture, where the fields were alternately grazed and then rested for a silage cut, could be grazed at similar stocking rates to, and produced body mass gains as great as, multi-paddock rotational systems.

The effect of feeding 3 kg concentrate per steer daily where steers were stocked at 20 steers per ha and grazed rotationally on pasture (Treatment (iv)), resulted in a 354% increase in carcass gain per ha compared with the unsupplemented steers grazing rotationally at similar stocking rate (Treatment (iii)). Mott, Kaiser, Peterson, Peterson and Rhykerd (1971) also found that by supplementing steers with grain at the rate of 1 kg grain per 100 kg body mass, stocking rate on Festuca arundinacea pastures could be increased by 15% and body mass gains per ha by 253% compared to where steers were unsupplemented. Clearly feeding the supplement reduced the intake of grass by steers and this resulted in a mean of 112 kg dry herbage per steer being available to the supplemented steers while only 70 kg per steer was available to the unsupplemented steers. The apparent efficiency with which the concentrate was converted into carcass mass by steers can be calculated by a comparison of the supplemented and unsupplemented steers which grazed at a stocking rate of 20 steers per ha. The advantage of supplementing was 45,2 kg (63,0 - 17,8, Table 45) resulting in a ratio of 7,0 kg concentrate per kg additional gain in carcass mass. This however, is not a true comparison of the effects of supplementing steers on pasture because the unsupplemented steers had only 62,5% (70 kg per steer) as much herbage as the unsupplemented steers (112 kg per steer) to graze and select from. It would be more realistic to compare Treatments (i) and (ii) with Treatment (iv) where more herbage was available to steers. Although less grass was available to steers in Treatment (iv) there was still ample grass for them considering that the steers were unlikely to consume more than 10 kg dry matter per steer daily. There would be 102 kg left (± 400 kg green herbage assuming a 25% dry matter content) of which a proportion would be fouled and trampled. This comparison shows that the response to concentrate supplement was 28,5 kg (63,0 - 34,5, Table 45), resulting in a calculated efficiency of 11,1 kg concentrate per kg carcass gain. This indicates that it was probably less efficient to feed concentrate to steers on pasture than to use the concentrate during the fattening phase when steers are in pens and where concentrates are used more efficiently (Table 46). The feeding of concentrates to steers grazing veld or pasture during the growing season is still practised despite the apparent lower efficiency with which it is used, because of the higher prices paid for beef during the mid-to-late growing season. The results show that when no concentrate supplements are fed on pasture set-stocking rather than rotational grazing should be used.

Observations on the system of production indicated that carrying weaner steers through the dry season on veld grazing, grazing them intensively on pastures during the growing season and then finishing them in pens on a high energy concentrate diet was a practical and highly intensive system of beef production. Not only did the system take cognisance of the needs of the veld (i.e. a growing season rest) to maintain vigour but it made efficient use of pastures and maize.

Furthermore calculations of the gross margins from the different treatments within the system of beef production used showed that the system as a whole was very profitable. For these calculations the following current (1979) costs of production and prices for beef were used (Ashton 1978, 1979; Murphy 1978, 1979).

V(1) The purchase price of weaner steers was 33c per kg body mass.

V(2), V(3) and V(4) were the carcass mass values of the steers at the end of the dry season, at the end of the period on fertilized pasture, and at the end of the fattening period in pens, respectively. The value per kg of carcass mass was taken as 81,4 c in each case.

C(1) Were the variable costs (dips, veterinary, labour, interest, etc.) to maintain a weaner steer through the dry season including the protein-rich concentrate (cottonseed meal) fed. The cost of cottonseed meal was 14,20c per kg.

C(2) Were the variable costs to maintain a yearling steer on fertilized pasture during the growing season and included the cost of both nitrogenous and phosphatic fertilizers applied to the pasture. The cost of fertilizers was $179,22 per ha.

C(3) Were the variable costs to maintain an 18-to-24-months-old steer in pens during fattening and included the cost of the high energy concentrate ration fed. The cost of maize in the ration was $63,00 per tonne.

G(1), G(2) and G(3) were the gross margins per steer for the veld, pasture and fattening stages of the production system, respectively. These were obtained by subtracting the variable costs per steer in each stage from the value of each steer at the end of each stage. G(4) was the gross margin per steer in the whole system obtained by summing G(1), G(2) and G(3).

The costs and gross margins per steer in each part of the production system and in the whole system are shown in Table 47.

Table 47. The gross margins in $ per steer during the periods they grazed on veld, on pasture and then during the fattening phase, and the gross margin per steer resulting from the whole beef production system in 1972-73.

	Treatment on pasture			
	(i)	(ii)	(iii)	(iv)
V(1)	66,99	66,99	66,99	66,99
V(2)	89,21	89,21	89,21	89,21
C(1)	22,73	22,73	22,73	22,73
G(1)	- 0,51	- 0,51	- 0,51	- 0,51
V(2)	89,21	89,21	89,21	89,21
V(3)	117,86	116,72	103,70	140,49
C(2)	18,27	18,27	18,27	41,67
G(2)	10,38	9,24	- 3,78	9,61
V(3)	117,86	116,72	103,70	140,49
V(4)	152,54	190,15	189,01	189,09
C(3)	19,58	48,88	53,41	35,05
G(3)	15,10	24,55	31,90	13,55
G(4)	24,97	33,28	27,61	22,65

Note : Treatments

(i) Steers set-stocked at 12 steers per ha.

(ii) Steers rotationally grazed over 15 paddocks at 12 steers per ha.

(iii) Steers grazed as in (ii) but at 20 steers per ha.

(iv) Steers grazed as in (iii) but received 3 kg concentrate per steer, daily.

Costs and returns

V(1), (2), (3) and (4) were the values per steer when purchased, at the end of the dry season, at the end of the grazing period on pasture and when slaughtered, respectively.

C(1), (2) and (3) were the variable costs to maintain a steer during the dry season, while it grazed on pasture and during the time it was fattened for slaughter in pens, respectively.

G(1), (2) and (3) were the gross margins for the dry season, the period on pasture and for the pen fattening phase, respectively, while G(4) was the total gross margin of the whole production system.

During the dry season when all steers received identical treatment on veld a loss of 51c per steer was incurred. The greatest gross margin per steer on pasture was obtained where steers were set-stocked at a stocking rate of 12 steers per ha. (Treatment (i)). The gross margins per steer were less where steers were rotationally grazed at stocking rates of 12 (Treatment (ii) and 20 (Treatment (iv)) where a concentrate supplement was fed) head per ha. A loss of $3,78 per steer resulted where they were rotationally grazed at a stocking rate of 20 head per ha without a supplement (Treatment (iii)).

In the pen fattening phase the carcass mass gains made by steers from the pasture Treatments (ii), (iii) and (iv) were comparable. Steers in Treatment (i) were only fed 375 kg of concentrate in pens for reasons already stated. This was about half or less than half the amounts consumed by steers from other treatments (Table 46). Of the three treatment groups of steers that were comparable in pens, those which made the least carcass mass gains on pasture (Treatment (iii)) produced the greatest gross margins in pens. The steers that made the greatest carcass mass gains on pasture (Treatment (iv)) made the smallest gross margins in pens. This confirms that the body mass of a steer when going into pens for fattening affects not only the efficiency with which concentrate is converted into beef but also the profitability of fattening a steer.

An examination of the effects of the different pasture treatments ((ii), (iii) and (iv)) on the gross margins in the system of production shows that the greatest gross margins were from steers that were carried on pasture during the growing season without being fed on energy-rich supplements. The lowest gross margins resulted from steers which did receive an energy-rich supplement. Therefore it is not advisable to feed these supplements to steers while on pasture in this system of beef production.

4.8.2 The effects of stocking rate on steer gains on Star grass pasture and on their subsequent performance when fattened for slaughter in pens

It is well established that stocking rate has a profound effect on production from pastures in terms of body mass gains of cattle (Section 4.3.3), Ruane and Raftery (1964); Bryant, Hammes, Blaser and Fontenot (1965); Stobbs and Whitting (1970); Bryan and Evans (1971); Mears and Humphreys (1974) though there is a need to determine specific responses in given situations.

With a stocking rate of 12 steers per ha in the experiment described in Section 4.8.1 where steers were either set-stocked or grazed rotationally over 15 paddocks, there was more herbage available per steer (153 kg) where steers were rotated than where they were set-stocked (134 kg). The steers that were set-stocked gained more in carcass mass (35,1 kg per steer) than those that were rotationally grazed (33,6 kg per steer). But where steers were rotationally grazed at a stocking rate of 20 steers per ha there was less herbage available per steer (70 kg) and carcass gains were lower (17,8 kg per steer). The fact that more herbage was available per steer where steers were rotationally grazed at a stocking rate of 12 steers per ha than where they were set-stocked indicates that probably more than 12 steers per ha could have been carried with rotational grazing. Gains in carcass mass per steer might be no greater than steers set-stocked at 12 steers per ha but gains per ha would be higher because of the heavier stocking rate. Although a stocking rate of 20 steers per ha was too heavy in the experiment described in Section 4.8.1 this was a drought year and therefore in a good rainfall year gains might be greater at this stocking rate. In practice a lower carcass mass gain per steer might be acceptable because there was apparently a relation between carcass mass gains on pasture and the efficiency of feed conversions in pens ; steers that gained less on pasture were found to convert feed into carcass more efficiently during the pen fattening phase (Section 4.8.1).

There was therefore reason to do another experiment which would determine the effects of a range of stocking rates between 12 and 20 steers per ha, on the carcass gains of steers and on the subsequent efficiency of feed conversion of steers when being fattened in pens.

Experiment Objectives

The objectives of the experiment were

(i) to determine the effects of stocking rate on steer carcass mass gains on Star grass pasture grazed rotationally over 15 paddocks

(ii) to determine the effects of treatments on steers on pasture on the efficiency of use of concentrates by steers in pens during the subsequent fattening phase, and

(iii) to make observations on the overall efficiency of the beef production system outlined in Section 4.8.1.

Materials and Methods

For the experiment 100 mixed weaner steers (Hereford x Africander, Africander x Shona and Aberdeen Angus) of mean body mass 184 kg per steer were obtained during June 1973. Between June and mid-November 1973 the steers grazed on veld that had been rested the previous growing season and were fed 700 g cottonseed meal per head, daily, to gain slightly in body mass.

On 20 November 1973 the steers were divided into five uniform groups of 20 steers with the breeds equally represented in each group. The mean body mass per steer was 212,8 kg. One group of steers was slaughtered immediately to obtain the mean carcass mass of steers going onto pasture. The remaining four groups were allotted at random to four stocking rate treatments namely 12,0 ; 14,7 ; 17,3 and 20,0 steers per ha. For each stocking rate there were 15 paddocks which were grazed in rotation, each paddock being grazed for one day and then rested for 14 days. The Star grass pastures used for the experiment described in Section 4.8.1 were also used for this experiment except that the paddock previously set-stocked was divided into 15 paddocks. During the growing season 350 kg N and 90 kg P_2O_5 per ha were applied to all treatments. The nitrogen was applied in four equal dressings at monthly intervals starting on 7 November 1973 while the phosphate was applied during October.

The steers were dipped weekly to control external parasites and weighed fortnightly to determine changes in body mass. Biting flies (<u>Stomoxis</u> sp.) worried the steers incessantly during daylight hours throughout the season which was exceptionally wet (1 314 mm of rain was recorded (Appendix 1)). Attempts to control these flies by spraying the steers with insecticides failed. Towards the end of the growing season the steers were weighed weekly and the groups of steers in the different treatments were removed from pasture when they had lost body mass for two consecutive weekly weighings. With this criterion the groups of steers stocked at the rate of 17,3 and 20,0 steers per ha were removed on 28 March 1974 and those stocked at rates of 12,0 and 14,7 steers per ha on 4 and 16 April, respectively. The groups of steers that were removed before 16 April were held on adjacent and similar grazing in order to maintain body mass.

On 16 April 10 steers from each treatment group were slaughtered to assess carcass mass gains while on pasture. The remaining 10 steers from each treatment were then fattened in pens on a high energy diet containing 13% crude protein and comprising 70% maize meal, 20% milled hay and 10% of a protein-rich concentrate until the mean body mass per steer in each group was approximately 390 kg when they too were slaughtered.

Herbage production from the different pastures was estimated during the period the steers grazed on pasture. This was done by placing two herbage crates in each of paddocks 1, 6 and 11 (i.e. three replications) of each stocking rate treatment and cutting 1 m^2 quadrats of herbage within the crates to 5 cm above ground level at 15-day intervals from the time grazing started. Following each cut the herbage crates were moved to new sites at random within the paddocks which were also cut to 5 cm before the crates were placed on them. Immediately following cutting the herbage was weighed and the dry matter content determined from oven-dried samples.

Initially the carcass mass gain (CMG) per steer and per ha were statistically analysed using a constant initial carcass mass (CM) of steers when going on to pasture estimated from the control slaughter of 20 animals and from the final carcass mass (FCM) of steers when coming off pastures estimated from the slaughter of half of each group of steers. By using a constant ICM, the CMG for larger steers was considerably over-estimated and that of the smaller steers under-estimated. Thus the variability of CMG for steers within treatments was over-estimated and the increase in error variance reduced the apparent significance of treatment effects.

Therefore the data was re-analysed using an estimated ICM for each animal based on the regression of ICM on initial body mass (IBM) obtained from the control slaughter of 20 steers. Similarly the data for the 40 steers slaughtered when coming off pastures were used to estimate the carcass mass of the unslaughtered animals coming off pasture.

The regressions used were

ICM = 5,10 + 0,442 IBM $\quad R^2$ = 0,86

FCM = -4,62 + 0,497 FBM $\quad R^2$ = 0,93

Results

The carcass mass gains both per steer and per ha made on the pastures are shown in Figure 40 together with the theoretical carcass gains calculated from the linear regression model for carcass gain per steer.

Carcass mass gains both per steer and per ha decreased linearly ($P < 0{,}001$) with increasing stocking rate. Steers that grazed at 17,3 head per ha on pastures barely improved on their initial carcass mass when they went onto pasture at the beginning of the grazing period. The steers that grazed at a stocking rate of 20 head per ha lost carcass mass over the grazing period. In the prevailing weather conditions pastures stocked at 17,3 and 20,0 steers per ha frequently became puddled, but more severely at the latter rate. Puddling did not occur where the stocking rate was 12,0 or 14,7 steers per ha.

The stocking rate (R) at which carcass gains per ha would have been theoretically at a maximum was calculated from the model for carcass gain per ha (Yh).

$$Yh = 59{,}47\,R - 3{,}13\,R^2$$

Yh is at a maximum when $\frac{dYh}{dR} = 0$

$$\text{when } 59{,}47 - 6{,}26\,R = 0$$

$$6{,}26\,R = 59{,}47$$

$$R = \frac{59{,}47}{6{,}26}$$

$$R = 9{,}50 \text{ steers per ha}$$

The stocking rate of 9,50 steers per ha lies outside the range of stocking rates used and therefore no further comment is warranted. Clearly in the prevailing circumstances the stocking rates imposed were too heavy.

Herbage production amounted to 10 430, 11 590, 11 580 and 11 370 kg dry matter per ha for the 12,0; 14,7; 17,3 and 20,0 steer per ha stocking rate treatments, respectively. Differences in herbage production were negligible and not significant.

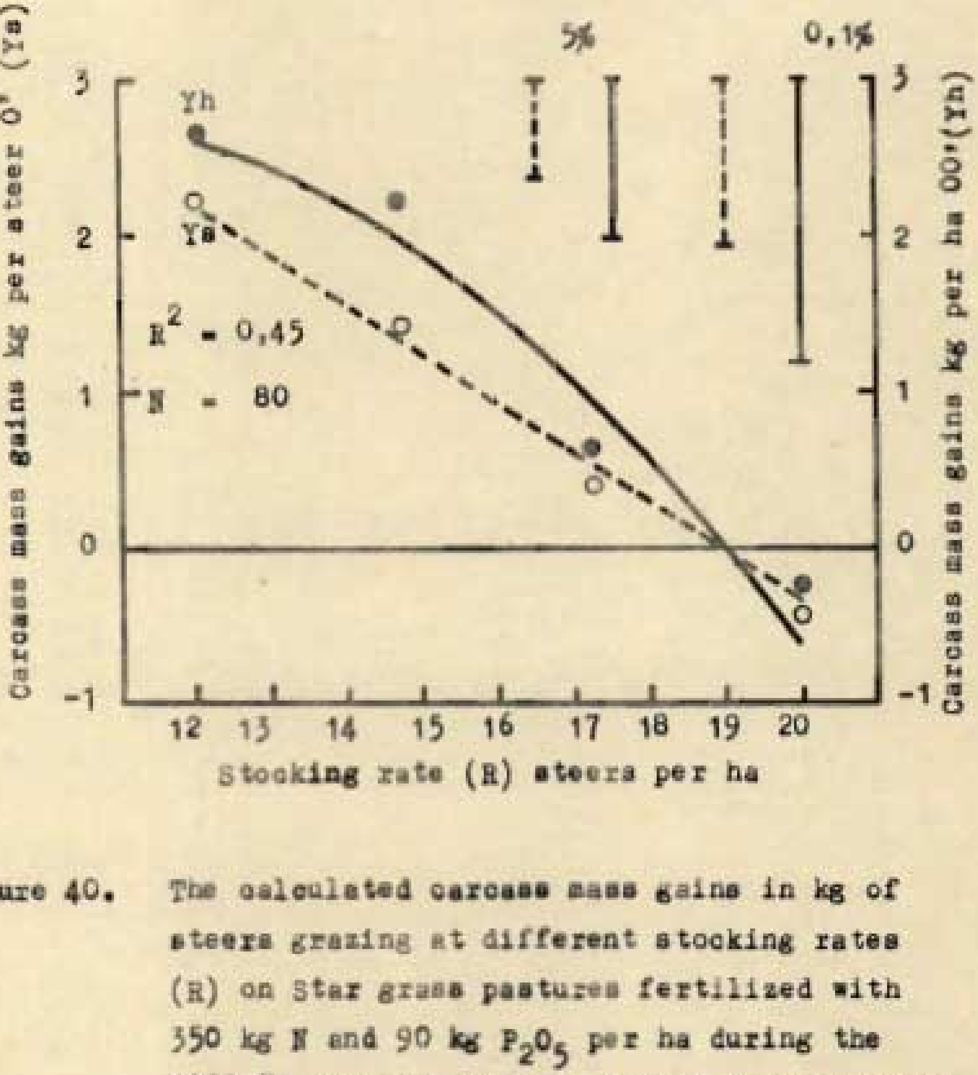


Figure 40. The calculated carcass mass gains in kg of steers grazing at different stocking rates (R) on Star grass pastures fertilized with 350 kg N and 90 kg P_2O_5 per ha during the 1973-74 growing season. Actual mean carcass mass gains per steer (Ys○) and per ha (Yh●) shown. Least significant differences for carcass mass gains indicated by vertical bars. (Analysis of variance table Appendix 2.55).

Ys = 59,47 - 3,130 R (Jones and Sandland, 1974)

The gains in carcass mass made by the groups of steers in pens after coming off pastures are shown in Table 48.

Table 48. Gains in carcass mass in kg of steers fed a concentrate (conc.) diet in pens after grazing on Star grass pasture at different stocking rates.

Stocking rate on pasture steers per ha	Carcass mass per steer			No. days in pens	Daily gain carcass mass per steer	Conc. consumed per steer kg	Kg conc. consumed per kg carcass gain
	16.4.74	Final	Gain				
12,0	117,5	213,0	95,5	105	0,91	837	8,8
14,7	114,6	211,2	96,6	119	0,81	877	9,1
17,3	104,3	211,3	107,0	112	0,96	894	8,4
20,0	95,7	216,1	120,4	133	0,91	988	8,1

Note : The concentrate consumed by steers excludes the 20% milled hay added to the ration.

Steers that grazed at a stocking rate of 20,0 steers per ha on pasture and which were the lightest steers when going into pens converted concentrate into carcass most efficiently and required 8,2 kg of concentrate for every 1 kg carcass gain. There was a tendency for efficiency of concentrate utilization to decrease the greater the carcass mass of steers going into pens. However, the steers that grazed at a stocking rate of 14.7 steers per ha on pasture and that were the second heaviest steers when going into pens converted concentrate into carcass mass, least efficiently.

The length of the feeding period for the groups of steers to reach similar final slaughter mass generally increased the lighter the steers were, when going into pens. One exception was where steers grazed at a stocking rate of 14,7 head per ha on pasture. These steers took longer to finish compared with the other group of steers that grazed at 12,0 head per ha on pasture and that were of similar carcass mass when going into the pens.

Discussion

Body and carcass mass gains both per steer and per ha were markedly affected by stocking rate and were considerably lower than those recorded in previous experiments (Section 4.3.1 and 4.8.1). The cool, overcast, wet weather during most of the season (Appendix 1) affected the steers adversely. At the two heaviest stocking rates, 17,3 and 20,0 steers per ha, herbage was often fouled with mud from the trampling of the steers making the herbage unpalatable to them. Furthermore the trampling and puddling of the pastures at these stocking rates resulted in bare areas, particularly near access gates. The biting flies also added to the discomfort of the steers and they were often observed to be standing in groups with their heads together as a means of escaping from them.

Clearly the high rainfall during the season affected steers grazing intensively on pastures far more than during the previous season, one of low rainfall. In 1972-73 when only 568 mm of rain fell, steers grazing on Star grass at a stocking rate of 20,0 steers per ha gained 17,8 kg in carcass mass per head and 356 kg per ha (Section 4.8.1). During 1973-74 when 1 314 mm of rain fell, steers grazing the same pastures at similar stocking rates and similar fertilizer application (350 kg N and 90 kg P_2O_5 per ha) lost 2,2 kg in carcass mass per steer resulting in a 44,8 kg loss in carcass mass per ha. The results indicate that in the prevailing adverse weather conditions the stocking rates were too heavy. A range of stocking rates from 6 steers to 15 steers per ha would have been more satisfactory.

Estimates of the amounts of herbage produced by the different pastures showed that these were very similar regardless of stocking rate and much lower by comparison with yields produced by similar pastures in previous years (Section 4.3.2; 4.5.1 and 4.5.3). It was also observed in another experiment (Section 4.5.2) done during the same season (1973-74)that herbage yields were lower than usual and this was also attributed to the cool, overcast, wet weather. Similar observations were made by Chheda and Mohamed Saleem (1973b) in Nigeria on the effects of cool, wet weather on the herbage production of grass.

Steers that were the lightest when coming off the experimental pastures converted concentrates into carcass mass in pens more efficiently than steers that were heavier when coming off pastures. This confirms the observations made in Section 4.8.1.

Although the results with the pasture treatments were disappointing under the abnormal circumstances, the results with the production system as a whole including pastures, as in Section 4.8.1, was still practical and profitable. This is indicated in Table 49 where the gross margins for the veld, pasture and fattening phases of the production system are shown. The calculations are based on the same costs of production and prices for beef used in Section 4.8.1. The abbreviations used are also the same.

In the dry season when the weaner steers all received similar treatment while grazing veld, a loss of 37c per steer was incurred. During the growing season the costs of grazing the steers on pasture were greater than the value of their carcass mass gains, the losses becoming larger with increasing stocking rate. In pens the value of the carcass mass gains of steers was greater than the costs and very satisfactory gross margins per steer were obtained. As the results in Section 4.8.1 indicated, the lighter the steers were when going into pens, the greater the efficiency of concentrate use and therefore the greater the gross margin per steer.

Table 49. The gross margins in $ per steer for the periods they grazed on veld, grazed at different stocking rates on Star grass pasture and then were fattened in pens, and the gross margin resulting from the whole beef production system in 1973-74.

	Stocking rate on pasture, steers per ha			
	12,0	14,7	17,3	20,0
V(1)	60,72	60,72	60,72	60,72
V(2)	80,30	80,30	80,30	80,30
C(1)	19,95	19,95	19,95	19,95
G(1)	- 0,37	- 0,37	- 0,37	- 0,37
V(2)	80,30	80,30	80,30	80,30
V(3)	98,14	91,97	83,83	78,06
C(2)	19,95	16,80	14,72	13,31
G(2)	- 2,11	- 5,13	-11,19	-15,55
V(3)	98,14	91,97	83,83	78,06
V(4)	175,87	170,60	170,92	176,06
C(3)	51,86	54,55	55,39	61,43
G(3)	25,87	24,08	31,70	36,57
G(4)	23,39	18,58	20,14	20,65

Note : Costs and returns

V(1), (2), (3) and (4) were the values per steer when purchased, at the end of the dry season, at the end of the grazing period on pasture, and when slaughtered, respectively.

C(1), (2) and (3) were the variable costs to maintain a steer during the dry season, while it grazed on pasture, and during the time it was fattened for slaughter in pens, respectively.

G(1), (2) and (3) were the gross margins for the dry season, the period on pasture, and for the pen fattening phase, respectively, while G(4) was the total gross margin of the whole production system.

4.8.3. The effects of combinations of stocking rate and levels of fertilizing with nitrogen on carcass mass gains of steers grazing Star grass pasture and on their subsequent performance when fattened for slaughter in pens

Experimental results during 1972-73 indicated that a stocking rate between 12,0 and 20,0 yearling steers per ha might have produced maximum carcass gains of steers on Star grass (Cynodon aethiopicus cv. No. 2) pastures grazed rotationally over 15 paddocks and fertilized with 350 kg N and 90 kg P_2O_5 per ha (Section 4.8.1). In 1973-74 stocking rates of 12,0; 14,7; 17,3 and 20,0 steers per ha were imposed on Star grass fertilized at the same levels and managed in a like manner (Section 4.8.2). Carcass mass gains of steers were at a maximum at the lightest stocking rate and decreased linearly with increasing stocking rate. However, the 1973-74 season was excessively wet and cool, pastures were puddled and the herbage was fouled with mud at the two heaviest stocking rates. Biting flies (Stomoxis sp.) worried the steers continuously during the daylight hours. Herbage production also was low in comparison with previous years. Consequently, the steers made poor gains on pasture and the results were clearly not a true reflection of production from pastures. Therefore the experiment was repeated in 1974-75 with certain modifications.

In 1971-72 Star grass that was grazed every 15 days and then mown to leave a 5 cm stubble immediately after each grazing produced greatest amounts of herbage where 510 kg N and 90 kg P_2O_5 per ha were applied (Section 4.3.1). Where 340 kg and 170 kg N per ha were applied yields of herbage were propotionately lower when pastures were grazed and mown in this manner.

These results indicated that possibly too little nitrogen had been applied to Star grass for the heavier stocking rates imposed in the two experiments described in Sections 4.8.1 and 4.8.2. In these experiments 350 kg N per ha were applied but stocking rates from 12,0 to 20,0 yearling steers per ha were imposed. Logically, as the rate of stocking of pastures increased so the rate at which nitrogen was applied to pasture should have increased assuming that the rate of increase in herbage production would be proportionate to the nitrogen applied and stocking rates imposed. This supposition appeared to be correct as experimental results (Section 4.5.1 , 10 cm grazing height) in 1971-72 indicated that herbage yields increased proportionately to nitrogen applied between applications of 170 and 510 kg N per ha. The results of the experiment in Section 4.5.2 indicated that no more than 500 kg N per ha should be applied to Star grass pastures. Thus at a stocking rate of 20 steers per ha the nitrogen application should have been 500 ÷ 20 = 25 kg N per steer per ha. Therefore for stocking rates of 12,0; 14,7; 17,3 and 20,0 steers per ha 300,0; 367,5; 432,5 and 500,0 kg N per ha, respectively should have been applied. Earlier experiments (Section 4.3.3) had shown that a stocking rate of 12,0 yearling steers per ha on pastures fertilized with 350 kg N per ha gave satisfactory utilization and production from pastures. Therefore differences between an application of 300 and one of 350 kg N per ha to pastures both grazed at a stocking rate of 12,0 steers per ha, were likely to be small.

Experimental Objectives

The objectives of this experiment were

(i) to determine the effect of stocking rate on carcass mass gains of steers grazing rotationally over 15 paddocks on Star grass pastures

(ii) to determine the effect of increasing the nitrogen applied to pasture in proportion to stocking rate on carcass mass gains of steers

(iii) to determine the effects of treatment to steers on pasture on their subsequent performance in pens when being fattened for slaughter, and

(iv) to make observations on the overall beef production system as outlined in Section 4.8 .

Materials and Methods

For the experiment 90 Hereford x Africander weaner steers of 189 kg mean body mass per steer were obtained during June 1974. Between June and 4 December 1974 they grazed on veld that had been rested the previous growing season and were fed 700 g cottonseed meal per head, daily, to gain slightly in body mass.

On 4 December 1974 when the mean body mass per steer was 209 kg, the steers were divided into five uniform groups, one of 10 steers and four of 20 steers each. The group of 10 steers was slaughtered immediately to obtain an estimate of carcass mass of those entering pasture and each of the four remaining groups were allocated at random to one of four stocking rate treatments, namely 12,0; 14,7; 17,3 and 20,0 steers per ha. The Star grass pastures used for the experiment described in Sections 4.8.1 and 4.8.2 were also used for this experiment. Nitrogen was applied at the rate of 25 kg per ha per steer so that for the four stocking rates applications amounted to 300,0; 367,5; 432,5 and 500,0 kg N per ha. A basic dressing of 90 kg P_2O_5 per ha was applied during October while the nitrogen was applied in four equal dressings at monthly intervals starting on 20 November 1974.

Each group of steers grazed 15 paddocks in rotation, staying one day in each paddock. The steers were dipped weekly to control external parasites and were weighed fortnightly to determine changes in body mass. Towards the end of the grazing season the steers were weighed weekly. The different groups were removed from pasture in the late growing season at different times, the criterion being loss of body mass for two consecutive weeks. On this basis the groups of steers which grazed at 20,0 and 17,3 steers per ha were removed on 18 April 1975 and those that grazed at 14,7 and 12,0 steers per ha on 29 April 1975.

When each group of steers was removed from pasture half of each group was slaughtered to assess the carcass mass gains of the group. The remaining 10 steers were then fattened in pens on a diet comprising 70% maize meal, 20% milled hay and 10% of a protein-rich concentrate until the mean mass per steer in each group was approximately 425 kg, when they too were slaughtered.

During the grazing season estimates of herbage production were made. This was done by protecting herbage from grazing with cages and then clipping quadrats within the cages at the end of each complete grazing cycle. Two such cages were placed in each of paddocks 1, 6 and 11 of each treatment giving three replications. Quadrats were clipped initially to 5 cm but subsequently to the mean height to which the grass was grazed outside the cages in paddock 1 of each treatment. The height of herbage was measured immediately steers were removed from these paddocks in each grazing cycle. The mean height to which the herbage was grazed was determined by measuring the height of herbage in 20 random positions on each occasion. After each cycle the cages were removed to new sites where herbage was clipped to the average height to which herbage was grazed in paddock 1 of each treatment before siting the cage.

The carcass mass data were analysed in a similar manner to the data in Section 4.8.2. That is, initial carcass mass (ICM) of each steer was estimated from the regression of ICM on initial body mass (IBM) obtained from the control slaughter of 10 steers. Similarly the data for the 40 steers slaughtered when coming off pasture were used to estimate the final carcass mass (FCM) of the steers that were not slaughtered from the regression of FCM on final body mass (FBM) of steers. The regressions used were

$$\text{ICM} = 33{,}17 + 0{,}320\ \text{IBM} \qquad R^2\ 0{,}44$$
$$\text{FCM} = 6{,}62 + 0{,}449\ \text{FBM} \qquad R^2\ 0{,}88$$

The R^2 value of 0,44 for ICM is low because only 10 steers were slaughtered whereas in the experiment described in Section 4.8.2 20 steers were slaughtered initially resulting in an R^2 value of 0,86 for ICM. The reason for slaughtering fewer animals in this experiment was one of economy, the carcass value of the steers slaughtered before entering the experiment being less than their value six months earlier as weaners. Clearly for experimental accuracy at least 20 steers should be slaughtered to estimate ICM.

Results

The carcass mass gains made on the pastures both per steer and per ha are shown in Figure 41 together with the theoretical carcass gains calculated from the quadratic regression model for carcass gain per ha.

The greatest actual carcass mass gains per steer and per ha were made at a stocking rate of 14,7 steers per ha. Carcass gains were 37,5 kg per steer or 551 kg per ha. The carcass mass gains per steer at the stocking rate of 14,7 steers per ha were significantly greater ($P < 0{,}05$) than those of steers grazing at a stocking rate of 17,3 steers per ha and also greater ($P < 0{,}001$) than those steers grazing at 20,0 steers per ha. Carcass mass gains of steers which grazed at 12,0 steers per ha were greater ($P < 0{,}01$) than those which grazed at 20,0 steers per ha. Carcass gains per ha at stocking rates of 14,7 steers and 17,3 steers per ha were greater ($P < 0{,}05$) than those obtained at a stocking rate of 12,0 steers per ha. No other significant differences between carcass gains were found.

Using the quadratic regression model for carcass mass gain per ha (Yh) (Figure 41) the stocking rate (R) at which maximum carcass gains per ha would theoretically have been at a maximum was calculated. By differentiation

$$Yh = -992 + 183{,}4\,R - 5{,}424\,R^2$$

$$Yh \text{ is at a maximum when } \frac{dYh}{dR} = 0$$

$$\text{when } 183{,}4 - 10{,}848\,R = 0$$

$$10{,}848\,R = 183{,}4$$

$$R = \frac{183{,}4}{10{,}848}$$

$$R = 16{,}9 \text{ steers per ha}$$

At a stocking rate of 16,9 steers per ha the carcass mass gains were calculated to be 33 kg per steer and 558 kg per ha.

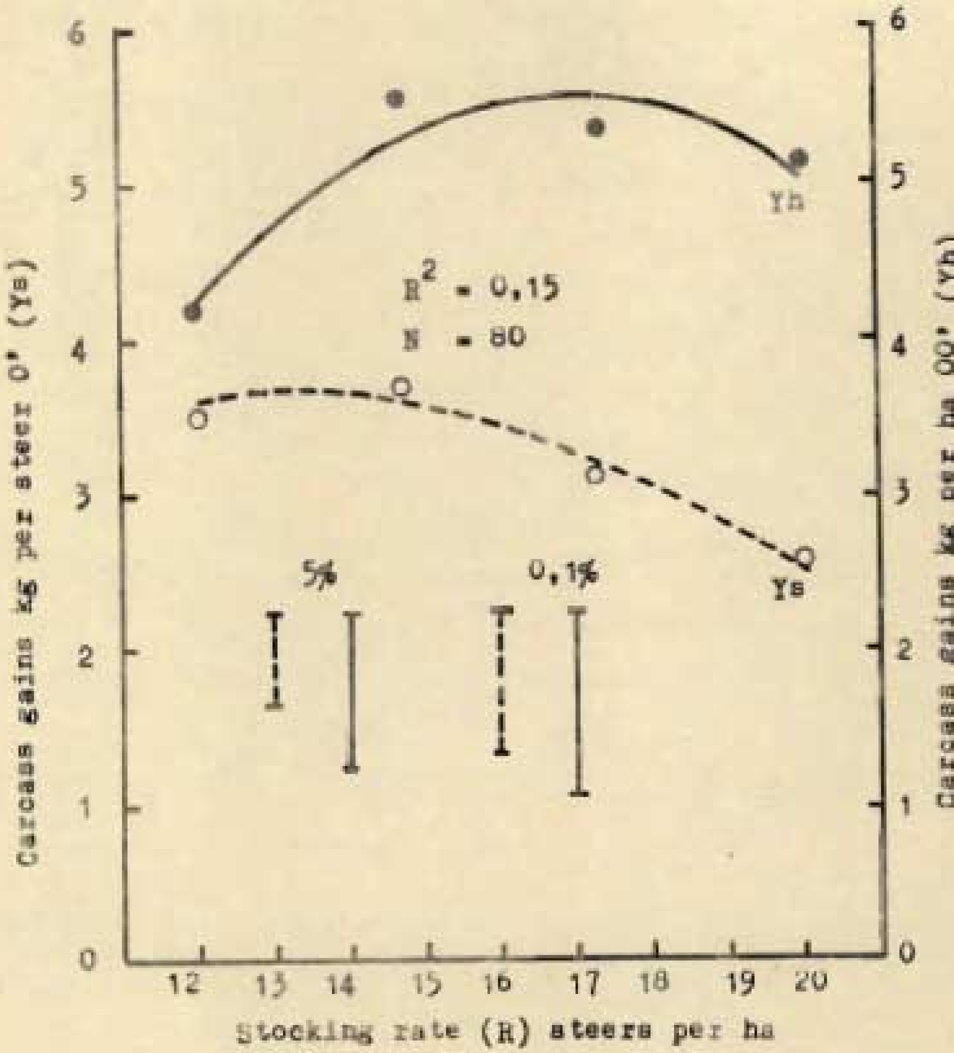


Figure 41. The calculated carcass mass gains per steer (Ys) and per ha (Yh) in kg of steers grazing at different stocking rates (R) on Star grass pastures fertilized with 25 kg N per steer per ha and 90 kg P_2O_5 per ha during the 1974-75 growing season. Actual mean carcass mass gains for Ys(O) and Yh(●) shown. Least significant differences for carcass mass gains indicated by vertical bars. (Analysis of variance table Appendix 2.56).

$$Yh = -992 + 183,4\ R - 5,424\ R^2$$ (Jones and Sandland, 1974)

Yh is at a maximum (558 kg) where R = 16,9 steers per ha.

The stocking rate at which the maximum profit per ha could have been expected was calculated using Booysens (1975) method. The formula used was

$$R = \frac{br - m}{2\ cr}$$ where b and c are constants, r is the price of the product per kg in cents and m is the variable costs.

$$R = \frac{(183,4 \times 81,4) - 7}{2 \times 5,424 \times 81,4}$$

$$R = \frac{14921,76}{883,027}$$

R = 16,9 steers per ha

Therefore the stocking rate that would have produced the maximum profit and that which would have given the maximum carcass mass gain per ha were in this instance, the same.

The production of herbage during the grazing period was 11 760, 12 920, 11 960 and 14 180 kg dry matter per ha for the 12,0; 14,7; 17,3 and 20,0 steers per ha stocking rate treatments, respectively.

The results of the steers when being fattened for slaughter in pens are shown in Table 50.

The steers that grazed at a stocking rate of 20,0 steers per ha on pasture fertilized with 500,0 kg N per ha and which were the lightest steers when going into pens converted concentrate into carcass mass most efficiently. However, the differences in the efficiency of concentrate utilization were small between all the groups of steers.

The 1974-75 season was a good one for growth of both grass and cattle. Above average rain (914 mm, Appendix 1) fell during the season but this was well distributed. The beef production system practiced (Section 4.8.1) proved once again to be an efficient one effectively using veld, pastures and maize.

Table 50. Gains in carcass mass in kg of steers fed a concentrate (conc.) diet in pens after being subjected to various treatments on Star grass pasture.

Treatment on pasture		Carcass mass per steer			No. of days in pens	Daily gain carcass mass per steer	Conc. consumed per steer kg.	Kg conc. consumed per kg carcass gain
Stocking rate steers per ha	Nitrogen kg per ha	Initial	Final	Gain				
12,0	300,0	134,0	233,7	99,7	124	0,80	1043	10,5
14,7	367,5	136,1	229,6	93,5	112	0,83	935	10,0
17,3	432,5	129,8	222,8	93,0	112	0,83	988	10,6
20,0	500,0	124,7	226,4	101,7	119	0,85	1010	9,9

Note. The concentrate consumed by steers excludes the 20% milled hay added to the ration.

Discussion

Where Star grass pastures are fertilized with 350 kg N and 90 kg P_2O_5 per ha the stocking rate can be increased from 12 steers per ha where pastures are set-stocked (Section 4.3.3) to 15 steers per ha where pastures are rotationally grazed over 15 paddocks, each paddock being grazed for one day and then rested for 14 days. Carcass gains of steers per ha at this level of fertilization are near maximum for the two systems of grazing at these two stocking rates. Therefore rotational grazing in this manner allows the stocking rate on pastures to be increased by 25 %, but it does not follow that carcass mass gains per ha will increase by a similar amount. In Section 4.8.1 Star grass that was fertilized with the same amounts of fertilizers and that was set-stocked and rotationally grazed at a stocking rate of 12 steers per ha produced similar carcass gains per steer and per ha with both systems. Although stocking rate can be increased by 25 % by rotational grazing the cost of fencing and stock watering facilities will be approximately 325 % greater than on set-stocked pastures. This would have to be taken into consideration when determining whether to set-stock or rotationally graze pastures.

The application of increasing amounts of nitrogen with increasing stocking rate at the rate of 25 kg N per steer per ha did not result in a proportional increase in herbage production. Estimates showed that production of herbage increased as nitrogen applications increased from 300,0 to 367,5 kg per ha but decreased between nitrogen applications of 367,5 to 432,5 kg per ha. With further applications of nitrogen (432,5 to 500,0 kg per ha) herbage production again increased. Although the effects of stocking rate and nitrogen on herbage production could not be analysed statistically because nitrogen levels and stocking rate were confounded, the responses to increasing amounts of nitrogen were similar to those observed in Section 4.5.2. No explanation could be advanced for the nature of these responses and none can be advanced in this case. But it is clear that on Star grass pastures that are set-stocked or rotationally grazed over 15 paddocks no more than 350 kg N per ha should be applied for maximum production in terms of carcass gains of steers per ha.

The carcass mass gains made by the steers during 1974-75 were considerably greater than those made by the steers during 1973-74 at similar stocking rates (Section 4.8.2). For example in 1974-75 steers which grazed at 20,0 steers per ha gained 25,6 kg per steer in carcass mass whereas in the previous year steers grazing at this stocking rate lost 2,2 kg in carcass mass per steer. Furthermore the carcass mass gains made by the steers grazing at a stocking rate of 20,0 steers per ha during 1974-75 gained more in carcass mass than the steers grazing at a stocking rate of 12,0 steers per ha in 1973-74 (Section 4.8.2). The large differences in carcass gains of steers between the two years are clearly due to weather, particularly rainfall. The 1973-74 season was very wet and cool whereas the 1974-75 season was warmer and not as wet (Appendix 1). Furthermore the biting flies (Stomoxis sp.) that were a nuisance to steers in 1973-74 were not so prevalent in 1974-75.

In pens there was relatively little difference in the efficiency of use of concentrates by the steers which grazed at different stocking rates on pasture although steers which were lightest in carcass mass when going into pens converted concentrates most efficiently into carcass mass. The results from the fattening phase show that the aim on pastures should be to obtain maximum carcass gains per ha and not necessarily maximum gains per steer, as differences in efficiency of use of concentrates in pens due to differences in carcass mass of steers coming off pastures, were small. The steers from the different treatments on pasture all graded Chiller 1, the best grade of beef at the time, after being fattened on the concentrate ration.

The beef production system where weaner steers were carried on veld during the dry season and were supplemented with protein-rich supplements, grazed on fertilized Star grass pastures during the growing season and were then fattened for slaughter in pens on a high energy ration after coming off pastures, again proved, as in Sections 4.8.1 and 4.8.2, to be a practical, intensive and efficient system of beef production that is highly economical in present (1979) circumstances (Table 51). The same costs of production, prices for beef and abbreviations were used as in Section 4.8.1.

Table 51. The gross margins in $ per steer for the periods steers grazed on veld, on different treatments on Star grass pasture and then were fattened for slaughter in pens, and the gross margin resulting from the whole beef production system in 1974-75.

	Stocking rate on pasture, steers per ha			
	12,0	14,7	17,3	20,0
V(1)	62,37	62,37	62,37	62,37
V(2)	80,41	80,41	80,41	80,41
C(1)	21,71	21,71	21,71	21,71
G(1)	- 3,67	- 3,67	- 3,67	- 3,67
V(2)	80,41	80,41	80,41	80,41
V(3)	109,04	110,88	105,78	101,27
C(2)	18,59	18,06	17,34	17,06
G(2)	10,04	12,41	8,03	3,80
V(3)	109,04	110,88	105,78	101,27
V(4)	190,23	186,89	181,35	184,28
C(3)	64,48	57,82	60,94	62,40
G(3)	16,71	18,19	14,63	20,61
G(4)	23,08	26,93	18,99	20,74

Note : Costs and returns

V(1), (2), (3) and (4) were the values per steer when purchased, at the end of the dry season, at the end of the grazing period on pasture, and when slaughtered, respectively.

C(1), (2) and (3) were the variable costs to maintain a steer during the dry season, while it grazed on pasture, and during the time it was fattened for slaughter in pens, respectively.

G(1), (2) and (3) were the gross margins for the dry season, the period on pasture, and for the pen fattening phase, respectively, while G(4) was the total gross margin of the whole production system.

A loss of $3,67 per steer was incurred during the dry season when all steers received similar treatment while grazing on veld. On pasture the gross margins per steer increased as stocking rate increased from 12,0 to 14,7 steers per ha and then decreased with further increases in stocking rate. During the fattening phase steers which were the lightest when going into pens (20 steers per ha treatment on pasture) made the greatest gross margins in this part of the production system. In the production system as a whole steers that were stocked at the rate of 14,7 head per ha on pasture made the greatest gross margin.

Although the carcass mass gains made by the steers on pasture during the growing season were considerably more than those made by steers during the 1972-73 (Section 4.8.1) and 1973-74 (Section 4.8.2) growing seasons the final gross margin per steer was similar. Therefore it is concluded that the system of beef production used as outlined in Section 4.8 is an efficient and profitable one in current economic circumstances in both good and poor rainfall seasons.

5 INTEGRATION OF DRYLAND GRASS PASTURES INTO THE CURRENT FARMING SITUATION IN THE MAZOE VALLEY

Early attempts to integrate cultivated grasses as grass leys into farming in the Mazoe Valley were not successful. The reasons for this failure were outlined by Ellis (1953) and Rowland (1953) who both stated that yields of crops grown after leys were disappointing. Rowland (1953) believed that the failure of leys to improve the yields of crops grown after them was due to a disregard of the fertilizer and cultural requirements of leys and a failure to incorporate suitable legumes with the grass. Yields of maize following grass leys were no better than where maize was grown on the same land annually and the stover ploughed back into the soil each year. Many management studies on grass leys were carried out between 1953 and 1963 (Anonymous*, 1953 - 1966) but maize yields following leys that were fertilized and either grazed in the growing season or in the dry season, or cut for hay, or subjected to various combinations of these treatments, were no better than where maize was grown on the same land annually (Thomas, 1963; Anonymous*, 1966).

The Mazoe Valley has been primarily a cash cropping area since the early days of European occupation and even today is one of the most intensively cropped areas in Rhodesia. Consequently, livestock have been, and still are, of secondary importance and the available veld on farms has been more than adequate to carry the livestock population. There has been little incentive to intensify in livestock production, although there has been an increase in numbers during the last decade. The Mazoe Valley is one of the most important maize growing areas of Rhodesia (Hannington 1972; Buttress 1973; Davis 1974) and the potential for beef production through a combination of veld, nitrogen fertilized grass pastures and maize grain is great. There has been some development of pastures in the area (Hannington, 1972; Buttress, 1973) but in terms of the potential the area established is insignificant. There is considerable scope for developing systems of farming incorporating pastures to make more efficient use of the land but the successful utilisation and expansion of pasture is dependent upon improved profits from cattle (Davis, 1974).

During the early 1960's general opinion was that pastures would have to be economically viable in their own right, would have to be permanent and would only be planted on marginal soils because the best soils would be planted to cash crops. Comparisons were made between the profitability of maize and of pastures. For example Robertson (1970) compared the profitability of maize and of pastures over a six-year period (1964 to 1970). The gross margins from pastures were only 5,4% lower than from maize. The mean yield of maize over the period was 60 bags (91 kg) per ha and production from pastures 917 kg of body mass gain in cattle per ha. Robertson (1970) concluded that pastures produced a more stable gross return compared with maize because pastures were not affected to the same extent as was maize by adverse (dry) weather conditions.

The comparison made by Robertson (1970) was misleading because in a farming system integrating maize and pastures for beef production, they would not be in competition, but complementary to one another. Therefore the most important criterion is the output of the production system as a whole and not of each facet of the system. The fairest way in which to assess the contribution of pastures to a production system is to compare the total output with and without pastures in the system. This section of this dissertation describes such an assessment.

Four systems of beef production are scheduled (Tables 52, 54, 56 and 58) and then compared. Table 52 shows the 1976 position regarding the size of farms, crops grown, numbers of livestock carried and the potential use of maize for fattening slaughter stock. Table 54 indicates the number of cattle that could be carried year-round using veld and available maize stover stocked to their full capacity, and maize for fattening the slaughter stock. Table 56 shows the theoretical numbers of cattle that could be supported if the breeding herd were carried year-round on veld and maize stover ; their progeny carried on heavily fertilized, intensively grazed, dryland Star grass pastures in the growing season, and all slaughter cattle were fattened on a high energy diet. Table 58 shows the estimated numbers of cattle that could be carried if pastures were used for all cattle during the growing season and the veld and maize stover for the dry season and all slaughter cattle fattened on a high energy diet.

The 1976 details of farms have been taken as a base for comparison because since this time the general situation in the areas concerned has become abnormal because of terrorism and its accompanying problems. Therefore the 1976 figures represent the "normal" situation.

For the four systems certain assumptions were made.

(i) The calving rate in each case was 85% of the total number of cows.

(ii) Cows in the herd were replaced at the rate of 15% per annum. All cows not in calf were culled.

(iii) Heifers that replaced cull cows were bulled at the age of two-and-a-quarter years.

(iv) Cows and heifers were bulled during December to February and calved down between September and November each year. Calves were weaned in June.

(v) All progeny except for replacement heifers were fattened for slaughter at 18-24 months of age on a high energy ration comprising 70% maize meal, 20% roughage and 10% of a protein-rich concentrate. The crude protein content of the ration was 13%.

(vi) All cull cows were fattened for slaughter on the same ration as in (v).

(vii) The slaughter cattle consumed maize at the following rates during fattening; cows 3 bags, heifers 5 bags and steers 7 bags (91 kg) per head.

(viii) There was no mortality.

(ix) All Star grass pastures were fertilized for maximum production per ha in terms of body mass and carcass mass gains i.e. 350 kg N and 90 kg P_2O_5 per ha per growing season. The carrying capacity of pastures was 7 LU's per ha from December to April; 1 LU (livestock unit) being equivalent to 500 kg body mass of cattle.

(x) The potential carrying capacity of the veld in the different Intensive Conservation Areas (I.C.A's) year-round was Barwick 3,5, Bindura 6,0 Glendale 4,0 and Marodzi/Tatagura 6,0 ha per LU. (Anonymous 1972; Carew, 1977; Hannington, 1977). Differences in the potential carrying capacity of the I.C.A's is due mainly to topography. Barwick and Glendale are relatively flat while Bindura and Marodzi/Tatagura are relatively hilly.

(xi) Where the veld was rested during the growing season and grazed only during the dry season the carrying capacity was double that on a year-round basis i.e. Barwick 1,75, Bindura 3,00, Glendale 3,00 and Marodzi/Tatagura 3,00 ha per LU.

(xii) Maize production was 65 (91 kg) bags grain per ha. About 30% of farmers in the four I.C.A's obtain yields of this order (Anonymous, 1977).

(xiii) The carrying capacity of maize stover was 220 LU grazing days per ha.

(xiv) The area taken up by the homestead, farm buildings and roads on each farm was 5% of the total farm area.

(xv) The standard of farming in all cases was similar.

Livestock equivalents (LU).

For calculating LU's the following equivalents were used (Anonymous, 1976b)

Class of animal	LU
Bull	1,27
Cow	0,91
Calf (male or female)	0,36
Weaner (male or female)	0,45
Steer 1 to 2 years old	0,64
Heifer 1 to 2 years old	0,54
Heifer 2 to 3 years old	0,73

Herd composition

The herd composition of 100 LU's based on the assumptions made and the equivalents of various classes of livestock in the herd for different seasons of the year were

Growing season (December to April)

No. of head	LU
53 cows	48,2
45 calves	16,2
8 two-year-old heifers	5,8
22 15-to-18-month-old heifers	11,8
23 15-to-18-month-old steers	14,7
3 (2,6) bulls	3,3
154	100,0

Dry season (May to August)

No. of head	LU
45 cows in calf	41,0
8 2½-to-3-year-old heifers in calf	5,8
8 18-month-old heifers	4,3
45 weaners	20,3
3 (2,6) bulls	3,3
109	74,7

Fattened for slaughter in pens during dry season

No. of head	LU
8 cull cows	7,3
14 18-month-old heifers	7,6
23 18-month-old steers	14,7
45	29,6

Dry season (September to November)

No. of head	LU
53 cows	48,2
45 calves	16,2
8 two-year-old heifers	5,8
22 12-to-15-month-old heifers	11,8
23 12-to-15-month-old steers	14,7
3 (2,6) bulls	3,3
154	100,0

Economic assessments

An economic assessment of the costs and returns of each of the potential beef production systems was made and compared with the "normal" situation in 1976. For these assessments current (July 1979) costs of production and prices paid for maize, beef, feeds and fertilizers were used (Anonymous, 1978, 1979 ; Murphy, 1978, 1979).

Maize

The cost of production of maize at a yield of 65 (91 kg) bags per ha was $218,71 per ha or $36,98 per tonne.
The selling price was $63,00 per tonne.

Cattle feeds

The cost of protein concentrate in the high energy fattening ration was $164,68 per tonne.
The cost of maize in the fattening ration was $36,98 per tonne. The roughage in the fattening ration had no value. The whole maize cob including sheaths when milled provides the 20% roughage in the ration.

Variable costs to maintain cattle

The variable costs (dips, veterinary, maintenance feeds, labour etc.) to maintain 1 LU for a year was $16,50.

Grass pastures

The fertilizer costs at an application of 350 kg N and 90 kg P_2O_5 per ha was $179,22 per ha.

Values of cattle when sold (July 1979 prices)

Cull cows	$140,70
Heifers 18-24 months old	$160,60
Steers 18-24 months old	$179,08
Bulls	$195,00

(i) The farming situation in 1976

The mean size of farms in the four Intensive Conservation Areas, the areas of the different crops grown, and the numbers of livestock carried during 1976, and the potential use of maize grain for fattening slaughter stock are shown in Table 52 (Anonymous, 1977b).

The mean size of all farms in the four I.C.A's was 828 ha of which 119 ha was cropped in 1976 and 667 ha was available for grazing of which 182 ha was potential arable land and 42 ha was occupied by farm buildings and roads. The mean area of maize planted for grain was 59 ha and the mean production was 3 835 (91 kg) bags grain per farm. The mean number of livestock carried was 125 LU of which 117 LU were beef cattle. The stocking rate on veld and maize stover was 5,83 ha per LU. The estimated potential stocking rate was 4,19 ha per LU (Anonymous, 1972; Carew, 1977; Hannington, 1977). Farms in general were therefore understocked.

Table 52. The mean size of farms, crops grown, number of livestock and stocking rates in 1976 and the potential use of maize for fattening beef cattle in four Intensive Conservation Areas (I.C.A's) in the Mazoe Valley.

Details of farms		Means I.C.A's
Size of farms	ha	828
Arable land cropped	ha	119
Arable land uncropped (veld)	ha	140
Other land suitable grazing	ha	527
Buildings, roads etc.	ha	42
Crops : Maize grain	ha	59
Maize for seed, silage	ha	3
Tobacco	ha	12
Cotton	ha	31
Soya beans	ha	8
Other crops	ha	6
Total crops	ha	119
Maize grain produced (91 kg)	bags	3 835
Livestock : Beef cattle no. head		185
Beef cattle no. LU		117
Dairy cattle no. LU		6
Sheep no. LU		2
Total no. LU		125
Available veld	ha	667
Maize stover	ha	62
Total	ha	729
Stocking rate on veld and maize stover, ha per 1 LU		5,83
Annual offtake of beef cattle for slaughter no. head		55
Potential use of maize for fattening cattle, bags		311
Percentage maize used for fattening of total produced		8,1

The annual offtake of beef cattle was 55 head which would require 311 bags of maize grain to fatten them to slaughter condition. This is only 8,1% of the total maize grain produced. Therefore there is adequate maize available for fattening cattle should the carrying capacity of farms be increased.

The gross margins from maize and cattle in the "normal" situation are shown in Table 53.

Table 53. The estimated gross margins from maize and from cattle based on maize produced and cattle carried in 1976 (Table 52).

Item	Costs $	Sales $
Maize		
3524 bags sold		20 203
Cost of production 3524 bags maize	11 857	
Gross margin from maize		8 346
Cattle		
55 head sold		9 187
Variable costs 177 LU	1 931	
Cost of production 311 bags maize	1 046	
Cost of 4,043 t protein concentrate	666	
Gross margin from cattle		5 544
Gross farm margin from maize and cattle		13 890

In these circumstances the sale of maize would contribute 60,1% and cattle 39,9% of the gross farm margin.

(ii) The situation if farms were stocked to their full potential on veld and available maize stover

The position on farms if the veld and crop residues were stocked to their estimated full potential is shown in Table 54.

Table 54. The potential numbers of beef cattle that could be carried on farms in four Intensive Conservation Areas (I.C.A's) in the Mazoe Valley if the veld and maize stover were stocked to their full capacity year-round and all slaughter cattle are finished on a high energy diet, based on the details presented in Table 52.

Details of farms		Means four I.C.A's
Mean size of farms	ha	828
Available veld	ha	667
Buildings, roads etc.	ha	42
Maize	ha	62
Total maize yield (91 kg bags)		3 835
Other crops	ha	57
Potential stocking rate on veld year-round ha per LU		4,88
No. of LU on veld year-round	LU	137
Carrying capacity maize stover no.	LU	37
Total no. LU		174
Total no. head		267
Overall stocking rate on veld and maize stover, ha per LU		4,19
Annual offtake of cattle for slaughter no. head		79
No. bags maize to fatten cattle for slaughter		444
Maize grain used for fattening as a percentage of total produced		11,6

The mean number of beef cattle that could be carried would be 174 LU's (267 head) if the veld and maize stover were stocked to their potential carrying capacity to give a stocking rate of 4,19 ha per LU. This represents a 48,7% increase over numbers actually carried on farms in 1976 (Table 52). As a result of this increase the annual offtake of cattle for slaughter would rise from 55 to 79 head and the amount of maize grain used for fattening would increase from 8,1 to 11,6% of the mean amount of maize grain produced per farm.

The gross margins from maize and cattle if the veld and crop residues were stocked to their full carrying capacity are shown in Table 55.

Table 55. The estimated gross margins from maize and from cattle if the veld and maize stover were stocked to their full carrying capacity year-round and all slaughter cattle are finished on high energy diets based on details in Table 52.

Item	Costs $	Sales $
Maize		
3391 bags sold		19 441
Cost of production 3391 bags maize	11 410	
Gross margin from maize		8 031
Cattle		
79 head sold		13 182
Variable costs 174 LU	2 871	
Cost of production 444 bags maize	1 494	
Cost of 5,811 t protein concentrate	951	
Gross margin from cattle		7 866
Gross farm margin from maize and cattle		15 897

If the veld and maize stover were stocked to their full capacity and all slaughter cattle fattened on a high energy diet, maize would contribute 50,5% and cattle 49,5% to the gross farm margin. The total gross farm income in this case is 14,4% greater than the income shown in Table 53 where the position in 1976 is simulated (Table 52).

(iii) The situation if fertilized dryland Star grass (<u>Cynodon aethiopicus</u> cv. No. 2) pastures were introduced into the system and used to carry all the progeny of a breeding herd in the growing season

By introducing Star grass pastures for grazing by the 15-to-18-month-old steers and heifers during the growing season and by carrying the breeding herd on the veld and maize stover year-round, the carrying capacity of farms could be increased (Table 56).

Table 56. The potential numbers of beef cattle that could be carried on farms in four Intensive Conservation Areas (I.C.A's) in the Mazoe Valley if breeding herds were carried year-round on veld and maize stover stocked to their full capacity and all progeny are carried on fertilized dryland Star grass pastures during the growing season and all slaughter cattle are finished on high energy diets.

Details of farms		Means four I.C.A's
Mean size of farms	ha	828
Available veld	ha	658
Buildings, roads etc.	ha	42
Maize	ha	62
Total maize yield (91 kg bags)		3 835
Other crops	ha	57
Fertilized grass pasture	ha	9
Carrying capacity veld year-round ha per LU		4,88
No. of LU on veld year-round		135
Carrying capacity maize stover no. LU		37
Total no. LU		172
Total no. head		255
No. of LU's on pastures during the growing season		63
No. of head		106
Annual offtake of cattle for slaughter no. head		107
No. bags maize to fatten cattle for slaughter		603
Maize grain used for fattening as a percentage of total produced		15,7

The use of 9 ha of Star grass pasture increased the carrying capacity by 35,1% over the system without pastures (Table 54). Consequently the number of cattle for slaughter would increase by a similar amount and 15,7% of the maize produced would be used for fattening.

The gross margins that could be expected from maize and cattle where only the progeny of a breeding herd are carried on 9 ha of pasture, are shown in Table 57.

Table 57. The estimated gross margins from maize and cattle if the breeding herd are carried year-round on veld and maize stover and their progeny on fertilized dryland Star grass pastures in the growing season and all slaughter cattle are finished on high energy diets.

Item	Costs $	Sales $
Maize		
3232 bags sold		18 529
Cost of production 3232 bags maize	10 874	
Gross margin from maize		7 655
Cattle		
107 head sold		17 820
Variable costs mean 204 LU	3 366	
Cost of production 603 bags maize	2 029	
Cost of 7,839 t protein concentrate	1 291	
Cost of 9 ha pasture	1 613	
Gross margin from cattle		9 521
Gross farm margin from maize and cattle		17 176

Where all the progeny of the breeding herd are carried on pasture during the growing season maize would contribute 44,6% and cattle 55,4% of the gross farm income. The gross farm income would be 8,0% higher than that from the system where only veld and maize stover stocked to their full year-round carrying capacity were available for grazing (Tables 54 and 55).

(iv) The situation if the veld and maize stover were grazed only in the dry season and all cattle are grazed on Star grass pastures during the growing season

If all cattle, including the breeding herd, were carried on Star grass pastures during the growing season and on the veld and maize stover during the dry season the carrying capacity of farms, and therefore the number of cattle for slaughter could be markedly increased (Table 58).

Table 58. The potential numbers of beef cattle that could be carried on farms in four Intensive Conservation Areas (I.C.A's) in the Mazoe Valley if the veld and maize stover were used for grazing during the dry season and fertilized dryland grass pastures were used during the growing season and all the slaughter cattle are finished on high energy diets.

Details of farms		Means four I.C.A's
Mean size of farms	ha	828
Available veld	ha	612
Buildings, roads etc.	ha	42
Maize	ha	62
Total maize yield (91 kg bags)		3 835
Other crops	ha	57
Fertilized grass pasture	ha	55
Carrying capacity veld dry season only ha per LU		2,44
No. of LU's dry season only		250
Carrying capacity maize stover no. LU		37
Total no. LU		287
Total no. head		420
Stocking rate on veld and maize stover dry season only, ha per LU		2,35
No. of LU on pastures during growing season		387
No. of head		592
Annual offtake of cattle for slaughter no. head		176
No. bags maize required to fatten cattle for slaughter		992
Maize grain used for fattening as a percentage of total produced		25,9

The number of cattle would be increased from 174 LU's (267 head) where veld and maize stover were stocked to their full year-round capacity (Table 54) to 387 LU's (592 head) during the growing season and 287 LU's (420 head) during the dry season where pastures were introduced into the beef production system (Table 58). This represents a mean increase of 93,6% in numbers carried compared to the system without pastures (Table 54). Consequently, the use of maize grain for fattening purposes would rise from 11,6 to 25,9% of the total maize grain produced per farm. However, there would still be 74,1% of the maize remaining that would have to be sold, or alternatively also used for fattening cattle if some other means of increasing carrying capacity further could be found.

The gross margins that could be expected from maize and cattle in this system are shown in Table 59.

Table 59. The estimated gross margins from maize and from cattle if the veld and maize stover were stocked to capacity and grazed only in the dry season and all cattle grazed on fertilized dryland Star grass pastures during the growing season and all slaughter cattle are finished on high energy diets.

Item	Costs $	Sales $
Maize		
2843 bags sold		16 299
Cost of production 2843 bags maize	9 566	
Gross margin from maize		6 733
Cattle		
176 head sold		29 360
Variable costs mean 337 LU	5 561	
Cost of production 992 bags maize	3 338	
Cost of 12,896 t protein concentrate	2 124	
Cost of 55 ha pasture	9 905	
Gross margin from cattle		8 432
Gross farm margin from maize and cattle		15 165

In this system maize would contribute 44,4% and cattle 55,6% of the gross farm margin. Gross farm margin however, would be $732 less than that obtained if the veld and maize stover were stocked to their potential on a year-round basis (Tables 54 and 55).

Discussion

The comparisons of the different beef production systems show that farms in the Mazoe Valley do not support the numbers of cattle that they could do on the veld and maize stover available. The estimates of potential carrying capacity on veld and maize stover with the maize used in a high energy ration to fatten all slaughter stock, show that a mean of 174 LU could be carried per farm whereas in 1976 only 117 LU were being carried. In 1976, therefore, 8,1% of the maize produced could have been used to fatten slaughter cattle on the high energy diet. Despite the increase in numbers of cattle carried if the potential of veld and maize stover was exploited, only 11,6% of the maize would be needed. Therefore 88,4% of the maize would have to be sold. This maize could be used for fattening more cattle if the carrying capacity of farms could be increased. The schedules (Tables 56 and 58) where Star grass pastures were introduced into hypothetical beef production systems for grazing during the growing season, clearly show that the carrying capacity of farms could be increased.

The economic assessments of the different systems show, however, that progressive intensification through the use of pastures for grazing during the growing season does not necessarily mean that profitability of the production systems also increases. In the first stage of intensification where the progeny of a breeding herd are carried on pasture, the gross farm margin from maize and cattle would be increased by 8,0% in comparison with the veld and stover system stocked to its potential carrying capacity without pastures, and that production costs would be 14,6% higher. Where all cattle are carried on pasture during the growing season and on the veld and maize stover in the dry season, the gross farm margin would be 4,6% less than that from the veld and maize stover system, but production costs would be 82,3% greater. In current circumstances therefore, pastures for carrying the entire beef herd during the growing season cannot be recommended. The reason for the large increases in costs of production with reduced gross farm margin where all cattle are carried on pasture, are clear. Experimental results on Henderson Research Station have shown that Star grass pastures fertilized with 350 kg N and 90 kg P_2O_5 per ha have a carrying capacity of 7 cows and 7 calves per ha during the growing season. At this stocking rate about 1 000 kg of body mass gain per ha can be expected over the season, approximately one-third to one-half the gain being from the cows and the remainder from the calves (Rodel and Boultwood 1971; Parkin, Rodel, Holness and Boultwood 1977; 1978). As the gains made by the cows cannot be looked upon as production, only the value of the gain of the calves can be offset against the costs of pastures. If the value of the gain in body mass of calves is 33c per kg the value of their gain per ha would be $165,00 where half the gain per ha is from calves. Current fertilizer costs at the foregoing rates of application are $179,22 per ha. A loss of $14,22 per ha would therefore be incurred.

The calculations do show that pastures can be recommended in current circumstances for use by the progeny of a breeding herd and that the increased production costs to achieve this degree of intensification, which are 14,6% higher than the veld and maize stover system without pastures, would be acceptable in practice. Before this degree of intensification would be recommended however, it would be logical to use the available veld and maize stover to near their potential year-round carrying capacity before such intensification is contemplated. These grazing resources are clearly the cheapest sources available.

Although carrying the entire beef herd including breeding cows on pastures is not economically viable in current economic circumstances, the results from Section 4 show that a production system where weaners are purchased and not bred on farms, is highly profitable. In this system weaners are purchased in June, carried on veld and maize stover supplemented with protein-rich concentrates during the dry season, graze fertilized Star grass pastures during the growing season and then are fattened for slaughter on a high energy diet. Using the data in Table 58 the mean potential carrying capacity per farm in the Mazoe Valley during the dry season is 287 LU which is equivalent to 638 weaners of both sexes. For this number 54 ha of pasture would be needed during the growing season and 3 828 bags of maize for fattening purposes. The mean production of maize per farm is 3 835 bags (Table 52) which is sufficient to fatten 639 head (320 steers and 319 heifers). Therefore in this system the following gross margins from maize and from cattle would result (Table 60).

Table 60. The gross margins per farm from maize and from cattle if weaner cattle were bought annually in June, carried on veld and maize stover during the dry season, graze on Star grass pastures during the growing season and are subsequently fattened for slaughter on high energy diets.

	Costs £	Sales £
Cattle		
Cost of purchasing 639 weaners at 33 c per kg body mass.	40 487	
Cost of 54 ha pasture	9 678	
Cost to produce 3835 bags maize	12 904	
Cost of 16,468 t protein concentrate	8 210	
Variable costs to maintain a mean of 332 LU for a year	5 478	
Sale of 639 slaughter cattle		108 537
Gross farm margin		31 780

The gross farm margin from this system of production would be 99,9% greater than where the veld and maize stover were stocked to their potential year-round carrying capacity with no pasture in the system (Table 55), 85,0% greater than where all progeny are carried on Star grass pasture in the growing season (Table 57) and 109,6% greater than the system where all cattle are carried on pastures in the growing season (Table 59).

The development of this system in the Mazoe Valley would be dependent upon an adequate and regular supply of suitable beef weaners which does not exist at present. In the future, within the maize growing areas, farms with large areas of veld might produce weaners for sale to farms where the carrying capacity could cope with them but not with breeding herds as well. Alternatively the ranching areas of Rhodesia (Regions III, IV and V, Figure 3) could be a source of supply. In this case transport costs of the animals to the maize growing areas, or alternatively the transport costs of the maize to the ranching areas, would have to be taken into consideration.

The use of nitrogen fertilized grass pastures is not the only possibility for increasing the carrying capacity of farms. Research since 1972 with tropical and sub-tropical pasture legumes has shown that if they are used to reinforce veld, carrying capacity, and therefore output of beef, can be increased. Various methods of establishing legumes into veld have been used successfully. These have included discing veld in the late dry season immediately after a burn and then oversowing the seed, seeding into ripped strips and also using specially adapted seeders. Generally 100 to 200 kg single superphosphate per ha is applied at seeding.

Clatworthy (1976, 1977, 1978) has shown that veld on granite sand at Grasslands Research Station, when reinforced with Stylosanthes guianensis (cv. Fine Stem) has a greater carrying capacity and output of beef than similar untreated veld. Fine Stem Stylo does not grow well on the silty clay soils on Henderson Research Station but Desmodium uncinatum (Silverleaf) and

Macroptilium atropurpureum (Siratro) do grow well. There is reason to believe that they will also grow well in the Mazoe Valley. Therefore the possibility exists for increasing the carrying capacity of farms through veld reinforced with legumes, especially on land where machinery can be used. The average area of potential arable land per farm that remained as veld in 1976 was 140 ha (Table 52). The year-round potential carrying capacity of this veld is estimated as 1 LU per 2 ha. By reinforcing this veld with legumes its carrying capacity could be raised by at least 30% allowing an additional 21 LU to be carried per farm. Thus the potential carrying capacities of the different beef production systems outlined would be increased by 12,1% in the veld and maize system (Table 54), by 11,4% where the progeny of a beef herd are carried on pastures (Table 56) and by 4,4% where all cattle including the breeding herd are carried on pasture (Table 58).

6 GENERAL CONCLUSIONS

The examination of the possibilities of integrating fertilized dryland grass pastures for grazing during the growing season into various systems of beef production in the Mazoe Valley (Section 5) show that the research objectives of the programme started in 1963 and completed in 1975 were largely attained. The primary purpose of this work was to increase the carrying capacity of grass pastures so that their productivity, in terms of beef, would be increased to a point where they could be profitably integrated into intensive beef production systems on maize farms. The various systems of beef production outlined in Section 5, together with economic assessments, show that pastures can be profitably used in two of the beef production systems described in this Section in current (1979) economic circumstances and can therefore be recommended. These are

(i) the system where a breeding herd is carried on veld and available maize stover on a year-round basis, all cattle are supplemented with protein-rich concentrates during the dry season, all progeny are carried on fertilized dryland grass pastures during the growing season, and all cattle for slaughter are finished on a high energy diet containing 70% maize and

(ii) the system where weaner cattle are purchased annually in June, graze on veld and maize stover during the dry season while they receive protein-rich supplements, graze on fertilized dryland grass pastures during the growing season and then are finished for slaughter on a high energy diet containing 70% maize after coming off pasture.

The productivity of grass pastures was increased by selecting grasses firstly for their herbage yielding ability when heavy dressings of nitrogenous fertilizers were applied to them, secondly for their ability to withstand intensive grazing, and thirdly by determining the productivity of the most promising grasses in terms of body mass and carcass mass gains of cattle grazing on them over the growing season.

Several grasses were selected initially on their herbage yielding ability but all except Cynodon aethiopicus (cv. No. 2 Star) were discarded for various reasons. Some of the grasses that responded well to heavy nitrogen applications (up to 650 kg N per ha were applied on some experiments) were unable to withstand intensive grazing. Others were affected adversely by drought and one by disease. Of all the grasses tested Star grass was found to be the most suitable and is therefore recommended for heavily fertilized, intensively grazed dryland pastures on both clay and sandy soils.

The responses of grasses to applied nitrogen were determined. Where grasses were not grazed maximum herbage yields were attained with 450 kg N per ha on silty clay soils and 225 kg per ha on a sandy soil. When grasses were grazed maximum herbage yields on silty clay soil were attained with 350 kg N per ha but this was not determined on sandy soils. It is recommended that the nitrogen be applied in four equal dressings at monthly intervals starting with the first good rains of the season. Splitting the nitrogen into four applications gives a greater measure of control in drought years although research results indicated there was little difference between applying the same amount of nitrogen in three or four dressings. An annual application of 90 kg P_2O_5 per ha should be topdressed before the rains start each year when this level of nitrogen is applied.

Stocking rate and management studies showed that when pastures were set-stocked the most satisfactory stocking rate was 12 yearling steers per ha. This stocking rate gave satisfactory body and carcass mass gains of steers and resulted in the efficient utilization of herbage. Where steers were rotationally grazed over 15 paddocks where each paddock was grazed for one day and then rested for 14, the most productive stocking rate was 15 steers per ha. Although only one direct comparison was made between steers that were set-stocked and steers that were rotationally grazed, body mass and carcass mass gains were not affected to any extent by system of management at a stocking rate of 12 steers per ha. Therefore set-stocking is preferred to rotational grazing. The cost of fencing and water are also factors that have to be taken into consideration. For example the fencing requirements of a 15-paddock rotational grazing system are estimated to be 471% greater than of a set-stocked system.

Although carcass mass gains of more than 500 kg per ha were obtained over the growing season the output of beef and final gross farm margin from cattle and from maize in the system outlined in Section 5, was hardly affected by the gains made by steers on pasture in the growing season. For example in the 1973-74 growing season, an excessively wet one, with 1 314 mm of rain (Appendix 1), gains of steers were the poorest on record and a mean loss of $8,50 per steer was incurred on pasture (Figure 40, Table 49). However, in the beef production system as a whole the gross margin per steer was on average $20,69 (Table 49). By comparison, in the 1974-75 season when 910 mm of rain fell (Appendix 1) and which was a good season for growth of both cattle and grass, the gross margin per steer over all pasture treatments was $8,57 (Figure 41, Table 51). In this case the gross margin per steer in the system was $22,44. The reason for the small difference in the gross margin between steers in 1973-74 as compared with 1974-75, was that the compensatory growth made by steers in the first year when finished on the high energy diet resulted in greater efficiency of concentrate usage and therefore greater profitability in this facet of the production system, than in the second year. As stated previously it is not the profitability of each facet of the production system that is most important, but it is the combined output and profitability of the system as a whole.

While all the research described in this dissertation shows that in current economic circumstances beef production is practical and profitable where nitrogen fertilized dryland grass pastures are used in production systems, it is emphasised that the frequent changes that occur in the costs of fertilizers, maize and beef could materially affect future profitability of nitrogen fertilized pastures for beef production. Furthermore, while there is a surplus of maize at present that can be used for the fattening of slaughter cattle, the demand for maize by an expanding human population, could reduce and eventually eliminate its use for cattle. Nevertheless once the terrorist war has stopped and peace and stability restored, nitrogen fertilized grass pastures could have a major role to play in producing beef in the future Zimbabwe-Rhodesia.

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8 REFERENCES

Addison, K.B., 1956a. The effect of various cultural and manurial treatments on Napier Fodder. Part 1. Rhod. agric. J. 53 : 491-506.

Addison, K.B., 1956b. The effect of various cultural and manurial treatments on Napier Fodder. Part 2. Rhod. agric. J. 53 : 657-666.

Addison, K.B., 1957. The effect of fertilizing, espacement and date of planting on the yield of Jack bean. Rhod. agric. J. 54 : 521-532.

Addison, K.B., 1958a. The effect of various cultural and manurial treatments on Napier Fodder. Part 3. Rhod. agric. J. 55 : 33-39.

Addison, K.B., 1958b. The effect of various cultural and manurial treatments on Napier Fodder. Part 4. Rhod. agric. J. 55 : 187-191.

Addison, K.B., 1963. Forage use in the high and low rainfall regions of Southern Rhodesia. Proc. 6th Annual Conference Professional Officers, Dept. of Research and Specialist Services, Min. of Agric., Rhodesia.

Ahmad, N., Tulloch-Reid, L.I. & Davis, C.E., 1969. Fertilizer studies on Pangola grass (Digitaria decumbens Stent.) in Trinidad. Trop. agric. Trin. 46 : 179-186.

Anonymous, 1919. Gwebi Experiment Farm. Report on crop experiments 1918-19. Rhod. agric. J. 16 : 535-541.

Anonymous, 1935. Rhodes grass for the Rhodesian tobacco grower. Rhod. agric. J. 32 : 699-701.

Anonymous, 1940-1962. Annual Reports, Salisbury Research Station, Dept. of Research and Specialist Services, Min. of Agric., Rhodesia.

Anonymous*, 1950-1966. Annual Reports, Henderson Research Station, Dept. of Research and Specialist Services, Min. of Agric., Rhodesia.

Anonymous+, 1953-1963. Annual Reports, Grasslands Research Station, Dept. of Research and Specialist Services, Min. of Agric., Rhodesia.

Anonymous, 1957-1959. Annual Reports, Matopos Research Station, Dept. of Research and Specialist Services, Min. of Agric., Rhodesia.

Anonymous, 1971. Chemistry and Soil Research Institute, Dept. of Research and Specialist Services, Min. of Agric., Rhodesia. Unpublished data.

Anonymous, 1972. Dept. of Conservation and Extension, Mazoe, Min. of Agric., Rhodesia. Unpublished data.

Anonymous, 1976a. Dept. of Conservation and Extension, Mazoe, Min. of Agric., Rhodesia. Unpublished data.

Anonymous, 1976b. Farm Management and Work Study Section, Dept. of Conservation and Extension, Min. of Agric., Rhodesia. Personal communication.

Anonymous, 1977a. Dept. of Conservation and Extension, Marandellas, Min. of Agric., Rhodesia. Unpublished data.

Anonymous, 1977b. Dept. of Conservation and Extension, Mazoe, Min. of Agric., Rhodesia. Unpublished data.

Anonymous, 1978. Farm Management and Work Study Section, Dept. of Conservation and Extension, Min. of Agric., Rhodesia. Personal communication.

Anonymous, 1979. Farm Management and Work Study Section, Dept. of Conservation and Extension, Min. of Agric., Rhodesia. Personal communication.

Arnold, H.C., 1929a. Annual Report of the Salisbury Agricultural Experiment Station 1927-28. Rhod. agric. J. 26 : 458-469.

Arnold, H.C., 1929b. Annual Report of the Salisbury Agricultural Experiment Station 1927-28. Rhod. agric. J. 26 : 704-714.

Arnold, H.C., 1936. Dryland pasture grass investigations. Rhod. agric. J. 32 : 236-242.

Arnold, H.C., 1939. The management and utilization of natural pastures. Rhod. agric. J. 36 : 376-391.

Ashton, W.B., 1978. The Conex Budget Guide No. 5, Summer Crops 1978-79. Dept. of Conservation and Extension, Min. of Agric., Rhodesia.

Ashton, W.B., 1979. Principal Farm Management Specialist, Dept. of Conservation and Extension, Min. of Agric. Rhodesia. Personal communication.

Atkinson, F.J.B., 1963. Improved pastures the key to meat production. Rhod. agric. J. 60 : 168-169.

Barnes, D.L., 1955. Pasture Section Progress Report, Gwebi College of Agriculture, 1950-1954. Rhod. agric. J. 52 : 132-143.

Barnes, D.L., 1960a. Some studies on nitrogen fertilizing of dryland ley grasses on sandveld. Rhod. agric. J. 57 : 311-317.

Barnes, D.L., 1960b. Growth and management studies on Sabi Panicum and Star grass. Part I. Rhod. agric. J. 57 : 399-411.

Barnes, D.L., 1960c. Growth and management studies on Sabi Panicum and Star grass. Part II. Rhod. agric. J. 57 : 451-459.

Barnes, D.L., 1961. Residual effects of cutting frequency and fertilizing with nitrogen on root and shoot growth, and the available carbohydrate and nitrogen content of the roots of Sabi Panicum. Rhod. agric. J. 58 : 365-369.

Barnes, D.L. & Hava, K., 1963. Effects of cutting on seasonal changes in the roots of Sabi Panicum (Panicum maximum Jacq.) Rhod. Zamb. Mal. J. agric. Res. 1 : 107-110.

Barnes, D.L., 1966. Studies on the use of Sabi Panicum for foggage. Rhod. agric. J. 63 : 144-154.

Barnes, D.L. & Clatworthy, J.N., 1969. Experiments in growing Sabi Panicum. Rhod. J. agric. Res. 7 : 135-147.

Bate, G.C., 1962. A fertilizer trial on veld. Rhod. agric. J. 59 : 14-19.

Blackshaw, G.N., 1922. Grasses of agricultural importance in Southern Rhodesia. Part 2. Composition of grasses. Rhod. agric. J. 19 : 143-149.

Birch, E.B., 1967. Nitrogen fertilization of Weeping Love grass (Eragrostis curvula) at Dohne. Proc. Grassld. Soc. Sth. Afr. 2 : 39-43.

Booysen, P. de V., 1966. A physiological approach to research in pasture utilization. Proc. Grassld. Soc. Sth. Afr. 1 : 77-85.

Booysen, P. de V., 1975. Economic optimization of stocking rate and grazing management. Paper presented at 6th General Meeting of the European Grassland Federation, Madrid.

Boultwood, J.N., 1969. Some effects of fertilizers and cutting frequencies on Giant Rhodes and veld grasses. Rhod. agric. J. 66 : 61-64.

Boyd, F.T., Schroder, V.N. & Perry, V.G., 1972. Interaction of nematodes and soil temperature on growth of three tropical grasses. Agron. J. 64 : 497-500.

Brockman, J.S., Rope, C.M. & Stevens, M.T., 1971. The effect of the grazing animal on the N status of grass swards. J. Brit. Grassld. Soc. 26 : 209-212.

Bryan, W.W. & Evans, T.R., 1971. A comparison of beef production from nitrogen fertilized Pangola grass and from a Pangola grass legume pasture. Trop. Grasslds. 5 : 89-98.

Bryant, H.T., Hammes, R.C., Blaser, R.E. & Fontenot, J.P., 1965. Effect of stocking pressure on animal and acre output. Agron. J. 57 : 273-276.

Burns, J.C., Gross, H.D., Woodhouse, W.W. & Nelson, L.A., 1970. Seasonal dry matter distribution and annual yields of a cool-season sward as altered by frequency and rate of nitrogen application. Agron. J. 62 : 453-458.

Burton, G.W., Jackson, J.E. & Hart, R.H., 1963. Effects of cutting frequency and nitrogen on yield, in vitro digestibility and protein, fibre and carotene content of Coastal Bermuda grass. Agron. J. 55 : 500-502.

Buttress, M.H., 1973. Agricultural land use in the Mazoe Valley during the period 1966 - 1971. Rhod. agric. J. 70 : 105-106.

Cameron, J., 1908a. Land settlement - Premier Estate, Umtali. Rhod. agric. J. 5 : 388-393.

Cameron, J., 1908b. Manurial experiments in maize growing at Premier Estate, Umtali. Rhod. agric. J. 5 : 517-520.

Cameron, J., 1908c. The cattle industry in Rhodesia. Rhod. agric. J. 6 : 7-13.

Cameron, J., 1909a. Maintenance of fertility in Rhodesian soils. Rhod. agric. J. 6 : 247-255.

Cameron, J., 1909b. Hay making. Rhod. agric. J. 6 : 260-264.

Carew, G.W., 1977. Assistant Provincial Conservation and Extension Officer, Dept. of Conservation and Extension, Min. of Agric. Rhodesia. Personal communication.

Chheda, H.R. and Mohamed Saleem, M.A., 1973a. Effects of heights of cutting after grazing on yield, quality and utilization of Cynodon 1 B 8 pasture in Southern Nigeria. Trop. Agric. Trin. 50 ; 113-119.

Chheda, H.R. and Mohamed Saleem, M.A., 1973b. Effects of K fertilizers on Cynodon 1 B 8 and on soil K in Southern Nigeria. Exp. Agric. 9 : 249-255.

Clatworthy, J.N., 1967. The response of Giant Rhodes grass (Chloris gayana Kunth.) to heavy dressings of nitrogenous fertilizer. Rhod. Zamb. Mal. J. agric. Res. 5 : 87-95.

Clatworthy, J.N., 1976. Annual Report for 1975-76. Division of Livestock and Pastures, Dept. of Research and Specialist Services, Min. of Agric., Rhodesia. 184-185.

Clatworthy, J.N., 1977. Annual Report for 1976-77. Division of Livestock and Pastures, Dept. of Research and Specialist Services, Min. of Agric., Rhodesia. 179-181.

Clatworthy, J.N., 1978. Annual Report for 1977-78. Division of Livestock and Pastures, Dept. of Research and Specialist Services, Min. of Agric., Rhodesia. 57-62.

Cochran, W.G. and Cox, Gertrude M., 1950. Experimental designs. John Wiley and Sons, New York.

Corby, H.D.L., 1955. The work of the Grasslands Research Station, Marandellas. Rhod. agric. J. 52 : 302-314.

Crook, A.O., 1956. A preliminary vegetation map of the Melsetter Intensive Conservation Area, Southern Rhodesia. Rhod. agric. J. 53 : 3-25.

Daulton, R.A.C., 1956. Annual Report, Tobacco Research Board of Rhodesia and Nyasaland. 146-147.

Daulton, R.A.C., 1963. Controlling M. javanica in Southern Rhodesia. Rhod. agric. J. 60 : 150-152.

Daulton, R.A.C., 1965. Senior Nematologist, Tobacco Research Board of Rhodesia. Unpublished data.

Davis, A.G., 1974. Agricultural land use in the Mazoe Valley. Rhod. agric. J. 71 : 149-155.

Davies, W., 1947. The grassland problem in Southern Rhodesia. Rhod. agric. J. 44 : 694-708.

Edwards, P.J., 1966. Veld replacement by improved grasslands in Natal. Proc. Grassld. Soc. Sth. Afri. 1 : 63-67.

Edwards, P.M. & Mappledoram, B.D., 1972. The response of Eragrostis curvula (Schrad.) Nees to fertilizers in the highland sourveld of Natal. Proc. Grassld. Soc. Sth.Afr. 7 : 122-125.

Elias, F., 1965. Melsetter Pasture Sub-station, Dept. of Research and Specialist Services, Min. of Agric., Rhodesia. Unpublished data.

Ellis, B.S., 1953. The soil and farming systems in Southern Rhodesia with special reference to grass leys. Rhod. agric. J. 50 : 379-390.

Elliott, R.C., 1956a. Digestion trials on Rhodesian feedstuffs. Rhod. agric. J. 53 : 538-545.

Elliott, R.C., 1956b. Steer feeding trials. Rhod. agric. J. 53 : 596-614.

Elliott, R.C. & Fokkema, K., 1960. Digestion trials on Rhodesian feedstuffs, Part III. Rhod. agric. J. 57 : 252-256.

Elliott, R.C., 1960. The utilization of low quality roughages by cattle. Rhod. agric. J. 57 : 412-419.

Elliott, R.C. & Folkertsen, K., 1961. Seasonal changes in composition and yields of veld grass. Rhod. agric. J. 58 : 186-187.

Elliott, R.C., 1963. A preliminary study of protein requirements of African cattle. J. agric. Sci. 61 : 417-420.

Elliott, R.C. & Reed, W.D.C., 1968. Studies of high-concentrate diets for cattle. 1. Growth and food intake of steers fed on diets containing different levels of low-quality roughage. S. Afr. J. agric. Sci. 11 : 713-722.

Eriksson, K.B., 1972. Nematode diseases of pasture legumes and turf grasses. Economic Nematology, Academic Press , London and New York.

Ethredge, J., Beaty, E.R. & Lawrence, R.M., 1973. Effects of clipping height, clipping frequency and rates of nitrogen on yield and energy content of Coastal Bermuda grass. Agron. J. 65 : 717-719.

Evans, T.R., 1969. Beef production from nitrogen fertilized Pangola grass (Digitaria decumbens) on the coastal lowlands of Southern Queensland. Aust. J. exp. Agric. Anim. Husb. 9 : 282-286.

Evans, T.R., 1973. Animal production from nitrogen fertilized pastures. Proc. Trop. Grasslds. 7 : 345-349.

Evers, G.W. & Holt, E.C., 1972. Effects of defoliation treatments on morphological characteristics and carbohydrate reserves in Kleingrass (Panicum coloratum L). Agron. J. 64 : 17-20.

Fenner, H.J. & Rattray, A.G.H., 1966. The residual effect of nitrogen applied to a Panicum coloratum (Makarikari) ley. Rhod. agric. J. 63 : 93-96.

Fenner, R.J., 1977. Principal Soil Chemist, Chemistry and Soil Research Institute, Dept. of Research and Specialist Services, Min. of Agric., Rhodesia. Personal communication.

Ford, C.W. & Williams, W.T., 1973. In vitro digestibility and carbohydrate composition of Digitaria decumbens and Setaria anceps grown at different levels of nitrogenous fertilizer. Aust. J. agric. Res. 24 : 309-316.

Fribourg, H.A., Edwards, N.C., and Barth, K.M., 1971. In vitro dry matter digestibility of 'Midland' Bermuda grass grown at several levels of N fertilization. Agron. J. 63 : 786-788.

Gillard, P., 1967. Coprophagous beetles in pasture ecosystems. J. Aust. Inst. agric. Sci. 33 : 30-34.

Gomide, J.A., Noller, C.H., Mott, G.O., Conrad, J.H. & Hill, D.L., 1969. Effect of plant age and nitrogen fertilization on the chemical composition and in vitro cellulose digestibility of tropical grasses. Agron. J. 61 : 116-119.

Goodey, J.B., 1963. Laboratory methods for work with plant and soil nematodes. Min. of Agric., Fish and Food Tech. Bull. 2., H.M.S.O. London : 9-10.

Griffiths, J., 1960. Bioclimatology and the meteorological services. Proc. of a symposium sponsored by the World Meteorological Organisation and Munitalp Foundation, Nairobi, Kenya.

Hacker, J.B. & Minson, D.J., 1972. Varietal differences in in vitro dry matter digestibility in Setaria and the effects of site, age and season. Aust. J. agric. Res. 23 : 959-967.

Hallock, D.L., Brown, R.H. & Blaser, R.E., 1965. Relative yield and composition of Ky 31 Fescue and Coastal Bermuda grass at four nitrogen levels. Agron. J. 57 : 539-542.

Hampton, J.H., 1911. Second report on experiments, Botanical Experiment Station, Salisbury. Rhod. agric. J. 9 : 16-23.

Hannington, R.C., 1972. Report on a Mazoe Valley Agricultural Survey, Planning Branch, Dept. of Conservation and Extension, Min. of Agric. Rhodesia.

Hannington, R.C., 1977. Land Use Planning Specialist, Planning Branch, Dept. of Conservation and Extension, Min. of Agric. Rhodesia. Personal communication.

Harlan, J.R., 1970. Cynodon species and their value for grazing and hay. Herb. Abs. 40 : 233-237.

Harlan, J.R., de Wet, J.M.J. & Rawal, K.M., 1970. Geographic distribution of the species Cynodon L.C. Rich (Gramineae). E. Afr. agric. For. J. 34 : 220-226.

Harlan, J.R., de Wet, J.M.J., Huffine, W.W. & Deakin, J.R., 1970. A guide to the species of Cynodon (Gramineae) Oklahoma State Univ., Agric. Expt. Stn. Bull. B. 673.

Hart, R.H., Carlson, G.E. & McCloud, D.E., 1971. Cumulative effects of cutting management on forage yields and litter densities of Tall Fescue and Orchad grass. Agron. J. 63 : 895-898.

Henzell, E.F., 1971. Recovery of nitrogen from four fertilizers applied to Rhodes grass in small plots. Aust.J. exp. Agric. Anim. Husb. 11 : 420-429.

Herrington, M.D., Elliott, R.C., & Brown, Jill E., 1971. Diagnosis and treatment of thyroid dysfunction occurring in sheep fed on Cynodon plectostachyus. Rhod. J. agric. Res. 9 : 87-93.

Hood, A.E.M. & Bailie, J.H., 1973. A new grazing system for beef cattle - the two field system. J. Brit. Grassld. Soc. 28 : 101-108.

Hoveland, C.S., Rodriguez - Kabana, R & Berry, C.D., 1975. Phalaris and Tall Fescue forage production as affected by nematodes in the field. Agron. J. 67 : 714-717.

Hudson, N.W., 1957. Erosion control research. Progress report on experiments at Henderson Research Station 1953 - 1956. Rhod. agric. J. 54 : 297-323.

Husband, A.D., 1928. The importance of research on pasture improvement in Southern Rhodesia. Rhod. agric. J. 25 : 992-1002.

Husband, A.D., 1929. The mineral aspects of pasture nutrition in relation to the livestock industry. Rhod. agric. J. 26 : 1000-1018.

Husband, A.D. & Taylor, A.P., 1931. Studies on the improvement of natural veld pastures. Rhod. agric. J. 28 : 154-169.

Husband, A.D., 1933. Report of the Chemistry Branch year ending December 1932. Rhod. agric. J. 30 : 453-468.

Husband, A.D., 1935. Report of the Branch of Chemistry for the year ending 31 December 1934. Rhod. agric. J. 32 : 262-284.

Husband, A.D., 1936. Annual report of the Branch of Chemistry for the year ending 31 December 1935. Rhod. agric. J. 32 : 252-272.

Husband, A.D., 1937. Report of the Branch of Chemistry for the year ending 31 December 1936. Rhod. agric. J. 34 : 473-495.

I'Ons, J.H., 1974. Performance of Cynodon species in the Natal Tall Grassveld. Proc. Grassld. Soc. Sth.Afr. 9 : 169-173.

Ivy, P., 1969. Review of Conex bush control demonstrations. Proc. Veld Mgmt. Conf., Dept. of Conservation and Extension, Bulawayo, Rhodesia. 188-198.

Ivy, P., 1975a. Map of Rhodesia showing rainy pentades. Chief Planning Officer, Dept. of Conservation and Extension, Min. of Agric., Rhodesia. Unpublished map.

Ivy, P., 1975b. Map of Rhodesia showing natural regions. Chief Planning Officer, Dept. of Conservation and Extension, Min. of Agric., Rhodesia. Unpublished map.

Johnson, P.T.C. & Elliott, R.C., 1969. Growth and food intake of Friesland calves weaned at different ages and offered dry food containing different proportions of roughage. Rhod. J. agric. Res. 7 : 43-50.

Jones, R.J. & Sandland, R.L., 1974. The relation between animal gain and stocking rate. J. agric. Sci., Camb. 83 : 606-611.

Jung, G.A., Balasko, J.A., Alt, F.L., & Stevens, L.P., 1974. Persistence and yield of 10 grasses in response to clipping frequency and applied nitrogen in the Allegheny Highlands. Agron. J. 66 : 517-521.

Kennan, T.C.D., 1952. The improved West African Napier Fodders. Rhod. agric. J. 49 : 221-228.

Kennan, T.C.D., Staples, R.R. & West, O., 1955. Veld management in Southern Rhodesia. Rhod. agric. J. 52 : 4-21.

Kennan, T.C.D., 1956. Matopos Research Station. Rhod. agric. J. 53 : 26-40.

Kennan, T.C.D., 1966. Veld management in the medium and low rainfall areas of Rhodesia. Rhod. Fmr. 37 : 11-27.

Kennan, T.C.D., 1969. A review into the cattle/grass relationship in Rhodesia. Proc. Veld Mgmt. Conf., Dept. of Conservation and Extension, Bulawayo, Rhodesia. 1-50.

Knievel, D.P., Jacques, A.V.A. & Smith, D., 1971. Influence of growth stage and stubble height on herbage yields and persistence of smooth Bromegrass and Timothy. Agron. J. 63 : 430-434.

Laredo, M.A. & Minson, D.J., 1973. The voluntary intake, digestibility and retention time by sheep of leaf and stem fractions of five grasses. Aust. J. agric. Res. 24 : 875-888.

Laver, G.L., 1967. Horticulturist, Henderson Research Station, Dept. of Research and Specialist Services, Min. of Agric., Rhodesia. Personal communication.

t'Mannetje, L. & Shaw, N.H., 1972. Nitrogen fertilizer responses of a Heteropogon contortus and a Paspalum plicatulum pasture in relation to rainfall in Central Coastal Queensland. Aust. J. exp. Agric. Anim. Husb. 12 : 28-35.

Mathias, E.L., Bennett, O.L. & Lundberg, P.E., 1973. Effect of rates of nitrogen on yield, nitrogen use, and winter survival of 'Midland' Bermuda grass (Cynodon dactylon (L) Pers.) in Appalachia. Agron. J. 65 : 67-71.

Meade, W.E., 1929. Pasture research in Southern Rhodesia. Rhod. agric. J. 28 : 619-623.

Mears, P.T. & Humphreys, L.R., 1974. Nitrogen response and stocking rate of Pennisetum clandestinum pastures. II. Cattle growth. J. agric. Sci., Camb. 83 : 469-478.

Meikle, G.J., 1978. Principal Research Engineer, Institute of Agricultural Engineering, Dept. of Conservation and Extension, Min. of Agric., Rhodesia. Personal communication.

Metelerkamp, H.R.R., 1971. Senior Soil Physicist, Chemistry and Soil Research Institute, Dept. of Research and Specialist Services, Min. Agric., Rhodesia. Personal communication.

Mills, P.F.L., 1962. Effects of fertilizers on growth of Nile grass in a granite sandveld vlei. Rhod. agric. J. 59 : 227-228.

Mills, P.F.L., 1964. Effects of fertilizer on the botanical composition of veld grassland at Matopos. Rhod. agric. J. Bull. 2263.

Mills, P.F.L., 1966. Effects of nitrogen on the yields and quality of hay from three types of veld at Matopos. Rhod. J. agric. Res. 63 : 9-21.

Mills, P.F.L., 1968. Effects of fertilizers on the yield and quality of veld grassland in the dry season. Rhod. J. agric. Res. 6 : 27-39.

Mills, P.F.L., 1976. A comparison of the preference of cattle and sheep for different grasses. Rhod. agric. J. 74 : 41-43.

Minson, D.J., 1972. The digestibility of voluntary intake by sheep of six tropical grasses. Aust. J. exp. Agric. Anim. Husb. 12 : 21-27.

Morris, H.D. & Celecia, J.F., 1964. Effect of time and fertilizer application on yield and nutrient uptake of Coastal Bermuda grass on Cecil sandy loam. Agron. J. 56 : 335-338.

Mott, G.O., Kaiser, C.J., Peterson, R.C., Peterson, R. & Rhykerd, C.L., 1971. Supplemental feeding of steers on Festuca arundinacea Schreb. pastures fertilized at three levels of nitrogen. Agron. J. 63 : 751-754.

Mundy, H.G., 1910. Possible rotation crops for Southern Rhodesia. Rhod. agric. J. 7 : 59-68,

Mundy, H.G., 1914. Report on certain experiments carried out on the Matabeleland Experiment Farm, Lochard, season 1913-14. Rhod. agric. J. 11 : 1161-1169.

Mundy, H.G., 1920. Improvement of Rhodesia pastures. Rhod. agric. J. 17 : 113-117.

Mundy, H.G., 1922. Annual Report of experiments 1920-21. Rhod. agric. J. 19 : 45-52.

Mundy, H.G., 1924. Maize production on the sandveld. Rhod. agric. J. 21 : 277-282.

Mundy, H.G., 1930. The Sandveld Experiment Station, Marandellas. Rhod. agric. J. 27 : 970-975.

Mundy, H.G., 1932a. Twenty-one years of plant introduction and trial in Southern Rhodesia. Part 1. Rhod. agric.J. 29 : 503-516.

Mundy, H.G., 1932b. Twenty-one years of plant production and trial in Southern Rhodesia. Part 2. Rhod. agric. J. 29 : 606-619.

Mundy, H.G., 1932c. Improved pastures and grazing experiments. Rhod. agric. J. 29 : 959-964.

Murphy, P.T.W., 1978. The Eleventh Annual Report of Farm Management Data. Farm Management Research Section, Economics and Markets Branch, Min. of Agric.,Rhodesia.

Murphy, P.T.W., 1979. Senior Economist, Farm Management Research Section, Economics and Markets Branch, Min. of Agric., Rhodesia. Personal communication.

Murray, C.A., Romyn, A.E., Haylett, D.G. & Ericksson, F.T., 1936. The supplementary feeding of mineral and protein supplements to growing cattle in Southern Rhodesia and its relation to the production of beef steers. Rhod. agric. J. 33 : 422-441.

Murray, C.A. & Romyn, A.E., 1939. Feeding young stock in winter. The effect of different planes of protein intake during the winter months on the growth of beef steers under ranching conditions in Southern Rhodesia. Rhod. agric. J. 36 : 441-451.

Nobbs, E.A., 1916. Reports on the crop experiments at the Government Farm, Gwebi, 1915-16. Rhod. agric. J. 13 : 474-488.

Ng, T.T., 1972. Comparative responses of some tropical grasses to fertilizer nitrogen in Sarawak, East Malaysia. Trop. Grasslds. 6 : 229-236.

Oakes, A.J. & Skov, O., 1964. Response of four pasture grasses to nitrogen in the dry tropics. Agron. J. 56 : 176-178.

Olsen, F.J., 1972. Effect of large applications of nitrogen fertilizer on the productivity and protein content of four tropical grasses in Uganda. Trop. agric. Trin. 49 : 251-260.

Olsen, F.J., 1974. Effects of nitrogen fertilizer on yield and protein content of Brachiaria mutica (Forsk.) Stapf, Cynodon dactylon (L.) Pers and Setaria splendida Stapf in Uganda. Trop. agric. Trin. 51 : 523-529.

Parkin, D.D., Rodel, M.G.W., Holness, D.H. & Boultwood, J.N., 1977. Annual Report for 1976-77. Division of Livestock and Pastures, Dept. of Research and Specialist Services, Min. of Agric., Rhodesia. 179-182.

Parkin, D.D., Rodel, M.G.W., Holness, D.H. & Boultwood, J.N., 1978. Annual Report for 1977-78. Division of Livestock and Pastures, Dept. of Research and Specialist Services, Min. of Agric., Rhodesia. 57-62.

Plucknett, D.L., 1970. Productivity of tropical pastures in Hawaii. Proc. 11th Int. Grassld. Congr., Surfers Paradise, Australia. A38-A49.

Rattray, J.M., 1948. Programme and progress report of the Marandellas Pasture Research Station. Rhod. agric. J. 45 : 255-275.

Rattray, J.M., 1957. The grasses and grass associations of Southern Rhodesia. Rhod. agric. J. 54 : 197-234.

Reed, W.D.C., Elliott, R.C. & Topps, J.H., 1966. Digestibility and rate of passage of high-concentrate diets through the digestive tract of young steers. Rhod. Zamb. Mal. J. agric. Res. 4 : 77 - 80.

Reed, W.D.C., Elliott, R.C. & Topps, J.H., 1968. Effects of level of intake and roughage content of cattle diets on digestibility, urinary energy and mineral losses, and certain aspects of rumen function. Rhod. J. agric. Res. 6 : 81-91.

Reid, R.L., Post, Amy J., Olsen, F.J. & Mugerwa, J.S., 1973. Studies on the nutritional quality of grasses and legumes in Uganda. 1. Application of in vitro digestibility techniques to species and stage of growth effects. Trop. agric. Trin. 50 : 1-15.

Rhodes, F.B., 1956. The effect of feeding mineral protein and carbohydrate supplements to growing beef cattle in Mashonaland. Rhod. agric. J. 53 : 969-981.

Richards, J.A., 1965. Effects of fertilizers and management on three promising tropical grasses in Jamaica. Exp. Agric. 1 : 281-288.

Richards, J.A., 1970. Productivity of tropical pastures in the Carribbean. Proc. 11th Int. Grassld. Congr., Surfers Paradise, Australia. A49-A56.

Richards, P.V.M., 1970. Principal Research Officer, Weed Research Unit, Henderson Research Station, Dept. of Research and Specialist Services, Min. of Agric., Rhodesia. Personal communication.

Robertson, W.R., 1970. A comparison of the crop margin possible from maize and from fertilized summer pastures. Rhod. agric. J. 67 : 150-153.

Rodel, M.G.W. & Boultwood, J.N., 1967. Recent pasture research at Henderson Research Station. Rhod. agric. J. 64 : 16-20.

Rodel, M.G.W., 1968a. Effects of minor elements and a nematocide on yields of cotton on granite sandveld soil. Rhod. agric. J. 65 : 101-102.

Rodel, M.G.W., 1968b. Sheep on Star grass. Rhod. agric. J. 65 : 58.

Rodel, M.G.W., 1969. Effect of boron on yield of cotton in a drought year. Rhod. agric. J. 66 : 24-25.

Rodel, M.G.W. & Hopley, J.D.H., 1969. Henderson Research Station, Dept. of Research and Specialist Services, Min. of Agric., Rhodesia. Unpublished data.

Rodel, M.G.W. & Hopley, J.D.H., 1970. Investigations into systems of farming suitable for Tribal Trust Land. Rhod. agric. J., Bull. 2624.

Rodel, M.G.W. & Boultwood, J.N., 1971. Herbage yields of thirty grasses fertilized heavily with nitrogen. Proc. Grassld. Soc. Sth. Afr. 6 : 129-134.

Rodel, M.G.W., 1971. Neonatal goitre and skeletal deformities in autumn born lambs on Star grass pastures. Rhod. agric. J. 68 : 109-110.

Rodel, M.G.W., 1972. Effects of different grasses on the incidence of neonatal goitre and skeletal deformities in autumn born lambs. Rhod. agric. J. 69 : 59-60.

Rodel, M.G.W. & Shepherd, J.A., 1972. Methyl bromide soil fumigation : effect on grass yields. Proc. Grassld. Soc. Sth. Afr. 7 : 117-121.

Romyn, A.E., 1931. The possibilities of cultivated pastures. Rhod. agric. J. 28 : 1125-1129.

Romyn, A.E., 1943. Problems in pasture research in Southern Rhodesia. Rhod. agric. J. 40 : 300-307.

Romyn, A.E., 1947. Annual Report of the Secretary, Department of Agriculture and Lands, Rhod. agric. J. 44 : 348-381.

Rowland, J.W., 1953. The place of leys in Southern Rhodesia agriculture. Rhod. agric. J. 50 : 368-374.

Ruane, J.B. & Raftery, T.F., 1964. An investigation into the merits of intensive rotational grazing. J. Brit. Grassld. Soc. 19 : 376-380.

Rudert, C.P., 1976. Mineral supplementation of ruminants grazing Star grass pastures. Rhod. agric. J. 72 : 113-114.

Sawer, E.R., 1905. Forage and pasture plants. Rhod. agric. J. 3 : 249-258.

Sawer, E.R., 1906. Forage and pasture plants. Rhod. agric. J. 4 : 494-501.

Scarsbrook, C.E., 1970. Regression of nitrogen uptake on nitrogen added from four sources applied to grass. Agron. J. 62 : 618-620.

Shepherd, J.A., 1971. Senior Nematologist, Tobacco Research Board of Rhodesia. Personal communication.

Shepherd, J.A., 1972. Senior Nematologist, Tobacco Research Board of Rhodesia. Personal communication.

Smith, D., 1969. Determination of carbohydrates. Wisconsin Agricultural Experiment Station Research Report. 41 : 1-11.

Stapf, O., 1913. Elephant grass - a new fodder plant. Rhod. agric. J. 10 : 362-268.

Staples, R.R., 1948. The investigation of the grassland problems of Southern Rhodesia. Rhod. agric. J. 45 : 249-254.

Staples, R.R., 1949. Summary of the Annual Report of the Chief Pasture Research Officer for the year ending 31 December 1948. Rhod. agric. J. 46 : 291-295.

Staples, R.R., 1950. Summary of the Annual Report of the Chief Pasture Research Officer for the year ending 31 December 1949. Rhod. agric. J. 47 : 316-320.

Stobbs, T.H., 1969. The effect of grazing management upon pasture productivity in Uganda - rotational grazing and continuous grazing. Trop. agric. Trin. 46 : 293-301.

Stobbs, T.H. & Whitting, J.B., 1970. A note on the performance of cross-bred steers at different stocking rates in Uganda. E. Afr. agric. For. J. 35 : 234-236.

Taerum, R., 1970. Comparative shoot and root growth studies on six grasses in Kenya. E. Afr. agric. For. J. 36 : 94-113.

Thomas, P.E.L., 1963. Maize, cotton and groundnut experiments at Henderson. Rhod. agric. J. 60 : 34-37.

Thompson, J.G., 1965. The soils of Rhodesia and their classification. Rhod. agric. J. Tech. Bull. 6.

Thompson, J.G. & Purves, W.D., 1979. Soils map of Zimbabwe Rhodesia. Surveyor,General, Zimbabwe Rhodesia.

Timson, S.D., 1937. Establishing Rhodes grass. Rhod. agric. J. 36 : 840-841.

Timson, S.D., 1938. Improved pastures, Rhod. agric. J. 35 : 807-828.

Timson, S.D., 1943. Prussic acid content of the Giant Star grasses (Cynodon plectostachyum) and Kavirondo sorghum. Rhod. agric. J. 40 : 371-373.

du Toit, A.A., 1965. Report on a soil survey of Henderson Research Station. Branch of Chemistry and Soil Science, Dept. of Research and Specialist Services, Min. of Agric., Rhodesia.

Vincent, V. & Thomas, R.G., 1960. An agricultural survey of Southern Rhodesia. Part 1. Agro-ecological survey. Min. of Agric., Govt. Printer, Rhodesia.

Vincent, V. & Thomas, R.G., 1961. An agricultural survey of Southern Rhodesia. Part 2. Agro-economic survey. Min. of agric., Govt. Printer, Rhodesia.

Visser, J.H., 1966. Fertilization of the veld. Proc. Grassld.Soc. Sth. Afr. 1 : 41-48.

Walters, J.A.T., 1912. Paspalum. Rhod. agric. J. 10 : 75-80.

Walters, J.A.T., 1913a. Elephant grass or Napier's Fodder. Rhod. agric. J. 10 : 833-836.

Walters, J.A.T., 1913b. New crops for Rhodesia - results of experiments. Rhod. agric. J. 10 : 879-883.

Walters, J.A.T., 1914. New crops for Rhodesia - results of experiments at the Botanical Experiment Station, Salisbury, 1913-14. Rhod. agric. J. 11 : 902-908.

Walters, J.A.T., 1915. New crops for Rhodesia - results of experiments at the Botanical Experiment Station, Salisbury, 1914-15. Rhod. agric. J. 12 : 508-514.

Walters, J.A.T., 1916. Crops unsuitable to Southern Rhodesian conditions. Rhod. agric. J. 13 : 378-383.

Walters, J.A.T., 1917. New crops for Rhodesia. Rhod. agric. J. 14 : 327-331.

Walters, J.A.T., 1918. New crops for Rhodesia - a report on experiments conducted at the Agricultural Experiment Station, Salisbury, 1917-18. Rhod. agric. J. 15 : 327-331.

Walters, J.A.T., 1931. Grass pastures. Rhod. agric. J. 28 : 126-127.

Ward, H.K. & Cleghorn, W.B., 1964. The effects of ring-barking trees in Brachystegia woodland on the yield of veld grasses. Rhod. agric. J. 61 : 98-105.

Weinmann, H., 1947. Determination of total available carbohydrates in plants. Plant Physio. 22 : 279-290.

Weinmann, H., 1948. Seasonal growth and changes in chemical composition of the herbage on Marandellas sandveld. Rhod. agric. J. 45 : 119-131.

Weinmann, H. & Goldsmith, E.P., 1948. Underground reserves of Cynodon dactylon Pers. Better turf through research. African Explosives and Chemical Industries and the S. African Turf Fund, Johannesburg. 56-75.

Weinmann, H., 1950. Productivity and nutritive value of Star grass pastures. Rhod. agric. J. 47 : 435-454.

Weinmann, H., 1961. Total available carbohydrates in grasses and legumes. Review article, Herb. Abs. 31 : 4.

Weinmann, H., 1964. Response of grasses to fertilizers in Southern Rhodesia. Rhod. agric. J. Tech. Bull. 2.

Weinmann, H., 1972. Agricultural research and development in Southern Rhodesia under the rule of the British South Africa Company 1890-1923. Occasional Paper 4, University of Rhodesia.

Wells, J.D., 1977. Pedologist, Chemistry and Soil Research Institute, Dept. of Research and Specialist Services, Min. of Agric., Rhodesia. Unpublished data.

West, O. & Rattray, J.M., 1947. Research programme on veld and pasture management in Southern Rhodesia. Imp. Bur. Past. Fld. Crops, Bull. 38 : 5-22.

West, O., 1947. Bush encroachment in relation to veld management. Rhod. agric. J. 44 : 488-497.

West, O., 1948. Programme and progress report of the Central Veld and Pasture Station for Matabeleland to December 31, 1947. Rhod. agric. J. 45 : 366-390.

West, O., 1952. Promising new grasses for seeded pastures in Southern Rhodesia. Rhod. agric. J. 49 : 89-95.

West, O., 1954. Improvements in the techniques and design of veld management experiments. S. Afr. J. Sci. 9 : 222-227.

West, O., 1956. Pasture improvement in the higher rainfall regions of Southern Rhodesia. Rhod. agric. J. 53 : 439-452.

West, O., 1958. Bush encroachment, veld burning and grazing management. Rhod. agric. J. 55 : 407-425.

West, O., 1965. Fire in vegetation and its use in pasture management with special reference to tropical and sub-tropical Africa. Commonwealth Bur. Past. Fld. Crops, England. Mimeo. Publ.

West, O., 1969. Fire : its effect on the ecology of vegetation in Rhodesia and its application in grazing management. Proc. Veld Mgmt. Conf., Dept. of Conservation and Extension, Bulawayo, Rhodesia. 135-148.

Whitney, A.S. & Green, R.E., 1969. Pangola grass performance under different levels of nitrogen fertilization in Hawaii. Agron. J. 61 : 577-581.

Whitney, A.S., 1974. Growth of Kikuyu grass (Pennisetum clandestinum) under clipping. 1. Effects of nitrogen fertilization, cutting interval, and season on yields and forage characteristics. Agron. J. 66 : 281-287.

Wild, H. & Grandvaux Barbosa, L.A., 1967. Vegetation map and supplement to the vegetation map of the Flora Zambesiaca area. M.O. Collins, Salisbury, Rhodesia.

Williams, F.R., 1953. Annual Report for 1951-52 of the Melsetter Pasture Research Sub-station, Department of Research and Specialist Services, Min. of Agric., Rhodesia.

Wilson, J.H., 1969. Bush control by basal injection of Tordon 22K. Proc. Veld Mgmt. Conf., Dept. of Conservation and Extension, Bulawayo, Rhodesia. 184-187.

Young, T.W., 1954. An incubation method for collecting migratory endo-parasitic nematodes. Plant Dis. Reptr. 38 : 794-795.

APPENDIX 1. Monthly and yearly totals of rainfall in mm recorded at Henderson Research Station between 1963-64 and 1974-75.

Month	Year												12-year mean
	1963-64	1964-65	1965-66	1966-67	1967-68	1968-69	1969-70	1970-71	1971-72	1972-73	1973-74	1974-75	
October	47	16	24	15	14	1	78	4	32	18	30	11	24
November	50	70	127	65	64	130	18	247	225	116	241	117	123
December	134	309	95	120	73	204	378	133	85	101	320	208	180
January	190	267	105	167	104	274	92	263	209	177	134	151	178
February	163	96	278	156	80	66	47	162	116	27	319	251	147
March	15	69	81	263	30	116	18	30	134	83	188	73	92
April	1	1	78	18	28	47	76	26	76	46	17	58	39
May	1	1	22	21	2	8	-	76	5	-	17	-	13
June	-	-	2	17	1	-	-	-	-	-	4	1	2
July	-	-	-	-	-	-	-	-	2	-	29	29	5
August	6	-	3	1	-	5	-	-	-	-	-	-	1
September	-	6	1	13	-	-	-	-	17	-	15	15	6
Totals	607	835	816	856	396	851	707	941	901	568	1314	914	810

APPENDIX 2

ANALYSIS OF VARIANCE TABLES

Standard statistical abbreviations are used in the tables. Significant effects are indicated as follows :-

* $P < 0,05$
** $P < 0,01$
*** $P < 0,001$

APPENDIX 2.1

Analysis of variance of the annual and four-year mean herbage yields in kg dry matter per ha of thirty grasses fertilized with 450 kg N, 90 kg P_2O_5 and 65 kg K_2O per ha, annually. (Reference Table 6).

1965-67

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	1,4547	0,7273			
Grasses	29	946,5423	32,6394	9,27	2,69	***
Error	58	204,2586	3,5217			
Total	89	1152,2556				

1967-68

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	9,9945	4,9972			
Grasses	29	988,9253	34,1009	8,17	2,69	***
Error	58	241,9062	4,1718			
Total	89	1240,8260				

1968-69

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	1,5287	0,7644			
Grasses	29	903,3087	31,1486	13,16	2,69	***
Error	58	137,2930	2,3671			
Total	89	1042,1304				

1969-70

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	33,7544	16,8772			
Grasses	29	1578,0318	54,4149	9,24	2,69	***
Error	58	341,6873	5,8912			
Total	89	1953,4735				

Three-year means

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	7,3924	3,6962			
Grasses	29	795,8487	27,4431	14,13	2,69	***
Error	58	112,6469	1,9422			
Total	89	915,8880				

APPENDIX 2.2

Analysis of variance of the effects of applying 450 kg N per ha in various split dressings with or without 22,4 tonnes of kraal manure per ha on herbage yields of Giant Rhodes grass in kg dry matter per ha. (Reference Table 8).

1965-66

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	1,7653	0,8827			
Method (M)	5	231,3756	46,2751	26,7920	6,19	***
Kraal Manure(K)	1	25,7324	25,7324	14,8983	14,38	***
M x K	5	5,6086	1,1217			
Error	22	37,9989	1,7272			
Total	35	302,4808				

1966-67

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	1,7221	0,8611			
Method (M)	5	17,8257	3,5651	3,3378	2,66	*
Kraal Manure (K)	1	19,4984	19,4984	18,2552	14,38	***
M x K	5	6,0489	1,2098			
Error	22	23,4980	1,0681			
Total	35	68,5931				

APPENDIX 2.3

Analysis of variance of the effect of applying 450 kg N per ha in various split dressings with or without 22,4 tonnes kraal manure per ha during the growing season of 1965-66 on herbage yields in kg dry matter per ha of Giant Rhodes grass regrowth obtained in the 1966 dry season. (Reference Table 9).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	3,1438	1,5719	9,9424	9,61	***
Method (M)	5	27,4401	5,4860	34,7122	6,19	***
Kraal Manure (K)	1	0,6316	0,6316	3,9949	4,30	
M x K	5	5,1333	1,0267	6,4940	6,19	***
Error	22	3,4791	0,1581			
Total	35	39,8279				

APPENDIX 2.4

Analysis of variance of the effects of applied nitrogen (N) on the herbage yields in kg dry matter per ha of four grasses (G) in 1967-68 grown in a sandy soil derived from granite. (Reference Figure 6).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	0,0617	0,0309			
N,,	1	101,0882	101,0882	163,89	13,29	***
N,,,	1	16,5130	16,5130	26,77	13,29	***
N	1	1,4855	1,4855			
G,	3	31,6949	10,2316	16,59	7,05	***
N,, x G	3	7,0364	2,3455	3,80	2,92	*
N,,, x G	3	3,8536	1,2845			
N x G	3	4,3638	1,4546			
Error	30	18,5046	0,6168			
Total	47	184,6017				

APPENDIX 2.5

Analysis of variance of the effects of applied nitrogen (N) on the herbage yields in kg dry matter per ha of four grasses (G) in 1967-68 grown in a silty clay soil. (Reference Figure 7).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	1,4442	0,7221			
N,,	1	59,2620	59,2620	51,22	13,29	***
N,,,	1	6,4096	6,4096	5,54	4,17	*
N	1	0,7517	0,7517			
G,	3	190,4832	63,4944	54,88	7,05	***
N,, x G	3	54,9298	18,3099	15,83	7,05	***
N,,, x G	3	11,5115	3,8372	3,32	2,92	*
N x G	3	1,2147	0,4049			
Error	30	34,7078	1,1569			
Total	47	360,7145				

APPENDIX 2.6

Analysis of variance of the effects of applied nitrogen (N) on the herbage yields in kg dry matter per ha of four grasses (G) in 1968-69 grown in sandy soil derived from granite. (Reference Figure 6).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	16,7537	8,3769			
N,,	1	239,5416	239,5416	74,13	13,29	***
N,,,	1	28,6354	28,6354	8,86	7,56	**
N	1	9,3181	9,3181			
G,	3	28,3700	9,4567			
N,, x G	3	15,4699	5,1570			
N,,,x G	3	6,8348	2,2783			
N x G	3	12,4187	4,1396			
Error	30	96,9445	3,2315			
Total	47	454,2867				

APPENDIX 2.7

Analysis of variance of the effects of applied nitrogen (N) on the herbage yields in kg dry matter per ha of four grasses (G) in 1968-69 grown in a silty clay soil. (Reference Figure 7).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	4,7279	2,3640			
N,,	1	603,6019	603,6019	332,36	13,29	***
N,,,	1	88,0968	88,0968	48,51	13,29	***
N	1	0,2787	0,2787			
G,	3	260,5351	86,8450	47,82	7,05	***
N,, x G	3	62,5322	20,8441	11,48	7,05	***
N,,,x G	3	26,7906	8,9302	4,92	4,51	**
N x G	3	10,2987	3,4329			
Error	30	54,4826	1,8161			
Total	47	1111,3445				

APPENDIX 2.8

Analysis of variance of the effects of applied nitrogen (N) on the herbage yields in kg dry matter per ha of four grasses (G) in 1969-70 grown in a sandy soil derived from granite. (Reference Figure 6).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	1,3826	0,6913			
N'	1	129,2607	129,2607	75,57	13,29	***
N''	1	21,7554	21,7554	12,72	7,56	**
N'''	1	1,2756	1,2756			
G	3	30,7711	10,2570	6,00	4,51	**
N' x G	3	22,7512	7,5837	4,43	2,92	*
N'' x G	3	4,9399	1,6466			
N'''x G	3	1,5019	0,5006			
Error	30	51,3146	1,7105			
Total	47	264,9530				

APPENDIX 2.9

Analysis of variance of the effects of applied nitrogen (N) on the herbage yields in kg dry matter per ha of four grasses (G) in 1969-70 grown in a silty clay soil. (Reference Figure 7).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	1,1748	0,5874			
N'	1	601,8197	601,8197	163,43	13,29	***
N''	1	49,7942	49,7942	13,52	13,29	***
N'''	1	10,6082	10,6082			
G	3	114,2846	38,0949	10,34	7,05	***
N' x G	3	25,5102	8,5034			
N'' x G	3	1,5410	0,5137			
N'''x G	3	9,0754	3,0251			
Error	30	110,4763	3,6825			
Total	47	924,2844				

APPENDIX 2.10

Analysis of variance of the effects of applied nitrogen (N) on the three-year mean herbage yields in kg dry matter per ha of four grasses (G) grown in a sandy soil derived from granite. (Reference Figure 6).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	2,1706	1,0853			
N'	1	141,1383	141,1383	125,4563	13,29	***
N''	1	20,5127	20,5127	18,2335	13,29	***
N'''	1	3,0923	3,0923			
G	3	34,6679	11,5560	10,2720	7,05	***
N' x G	3	11,3324	3,7775	3,3578	2,92	*
N'' x G	3	0,4053	0,1351			
N'''x G	3	3,8453	1,2818			
Error	30	33,7502	1,1250			
Total	47	250,9150				

APPENDIX 2.11

Analysis of variance of the effects of applied nitrogen (N) on the three-year mean herbage yields in kg dry matter per ha of four grasses (G) grown in a silty clay soil. (Reference Figure 7).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	3,0697	1,5349			
N'	1	366,2181	366,2181	210,8580	13,29	***
N''	1	34,4477	34,4477	19,8340	13,29	***
N'''	1	4,6745	4,6745	2,6914		
G	3	119,2698	39,7566	22,8907	7,05	***
N' x G	3	31,4151	10,4717	6,0293	4,51	**
N'' x G	3	3,3536	1,1179			
N'''x G	3	7,1805	2,3935			
Error	30	52,1026	1,7368			
Total	47	621,7316				

APPENDIX 2.12

Analysis of variance of the effects of soils (S) on the three-year mean herbage yields of four grasses (G) grown in a sandy soil derived from granite and in a silty clay soil and to which various amounts of nitrogen (N) were applied. (Reference Figures 8 and 9).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
S	1	43,7576	43,7576	33,40	21,20	**
S x Rep	4	5,2401	1,3100			
N	3	535,1700	178,3900	124,67	6,17	***
G	3	70,1071	23,3690	16,33	6,17	***
N x G	9	27,0880	3,0098	2,10	2,10	*
S x N	3	34,9111	11,6370	8,13	6,17	***
S x G	3	83,8314	27,9438	19,53	6,17	***
S x N x G	9	30,4495	3,3833	2,36	2,10	*
S x N x G x Rep	60	85,8537	1,4309			
Total	95	916,4085				

APPENDIX 2.13

Analysis of variance of the effects of applied nitrogen (N) on the three-year mean crude protein content as a percentage of dry matter of four grasses (G) grown in a sandy soil derived from granite. (Reference Figure 10).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	1,57	0,79			
N'	1	340,36	340,36	250,26	13,29	***
N''	1	5,87	5,87	4.31	4,17	*
N'''	1	0,99	0,99			
G	3	145,06	48,36	35.56	7,05	***
N' x G	3	4,42	1,47			
N'' x G	3	15,03	5,01	3,68	2,92	*
N'''x G	3	2,81	0,94			
Error	30	40,68	1,36			
Total	47	556,81				

APPENDIX 2.14

Analysis of variance of the effects of applied nitrogen (N) on the three-year mean crude protein content as a percentage of dry matter of four grasses (G) grown in a silty clay soil. (Reference Figure 10).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	0,29	0,15			
N'	1	369,62	369,62	206,53	13,29	***
N''	1	5,08	5,08			
N'''	1	0,68	0,68			
G	3	15,29	5,10			
N' x G	3	49,70	16,57	9,26	7,05	***
N'' x G	3	12,56	4,19			
N'''x G	3	3,88	1,29			
Error	30	53,69	1,79			
Total	47	510,79				

APPENDIX 2.15

Analysis of variance of the effects of sulphur (S), boron (B), zinc (Z) and magnesium (Mg) on the herbage yields of Star grass cv. No. 2 in kg dry matter per ha during 1967-68. (Reference Table 10).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	1,5278	0,7639			
S	1	0,5483	0,5483			
B	1	0,8631	0,8631			
Zn	1	0,2309	0,2309			
Mg	1	0,0023	0,0023			
SB	1	0,0590	0,0590			
SZn	1	0,0688	0,0688			
SMg	1	0,1172	0,1172			
BZn	1	0,2204	0,2204			
BMg	1	0,5502	0,5502			
ZnMg	1	0,1368	0,1368			
SBZn	1	0,0614	0,0614			
SBMg	1	0,4064	0,4064			
SZnMg	1	0,4365	0,4365			
SBZnMg	1	0,1320	0,1320			
Error	31	9,9641	9,9641			
Total	47	15,3252				

APPENDIX 2.16

Analysis of variance of the effects of sulphur (S), boron (B), zinc (Z) and magnesium (Mg) on the herbage yields of Star grass cv. No. 2 in kg dry matter per ha during 1968-69. (Reference Table 10).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	1,9340	0,9670			
S	1	13,6100	13,6100	8,2690	7,56	**
B	1	1,3147	1,3147			
Zn	1	0,8847	0,8847			
Mg	1	1,0802	1,0802			
SB	1	5,3226	5,3226			
SZn	1	0,5102	0,5102			
SMg	1	5,6065	5,6065			
BZn	1	0,2448	0,2448			
BMg	1	0,3292	0,3292			
ZnMg	1	0,0679	0,0679			
SBZn	1	0,0041	0,0041			
SBMg	1	0,0782	0,0782			
SZnMg	1	0,1399	0,1399			
SBZnMg	1	0,0638	0,0638			
Error	31	51,0225	1,6459			
Total	47	82,2133				

APPENDIX 2.17

Test of treatments x places interactions of the mean yields of dry herbage in $\frac{1}{2,2046}$ kg per plot in 1970-71 from grasses grown in unfumigated soil and in soil fumigated with methyl bromide in 1970. (Reference Table 11) (Cochran and Cox, 1950).

Grasses	Soil not fumigated	Soil fumigated	T_j
Ermelo Love	11,52	5,85	96,88
Sabi Panicum	9,38	10,38	110,84
Paraguay Paspalum	8,47	10,58	106,95
Wintergreen Paspalum	7,93	9,01	95,04
Star cv. No. 2	10,13	14,97	141,10
Giant Rhodes	13,47	11,74	141,15
Victoria Falls Panicum	8,20	13,34	121,16
Bushman Mine Panicum	9,25	16,64	145,74
W_i	5,52	5,69	11,21 = W
Total (P_i)	78,35	92,51	
W_i P_i	432,49	526,38	958,87 = G
S.S. (S_i)	792,18	1151,85	

Correction term $C = \frac{G^2}{tW} = \frac{(958,87)^2}{(8)(11,21)} =$ 10252,36

Total $\sum(W_i S_i) - C = (5,52)(792,18) + (5,69)(1151,86) - C =$ 674,55

Places $\frac{1}{8}\sum(W_i P_i^2) - C = \frac{1}{8}$ (82581,00) $- C$ = 70,27

Treatments $\sum \frac{T_j^2}{W} - C$ = 264,55

Treatments x Places = 674,55 - 70,27 - 264,55 = 339,73 = I

$\chi^2 = \frac{(n-4)(n-2)}{n(n+t-3)}$ I with $\frac{(P-1)(t-1)(n-4)}{(n+t-3)}$ d.f.

$\chi^2 =$ 153,25 with 3,68 d.f.

3 d.f. $\chi^2 =$ 16,27

4 d.f. $\chi^2 =$ 18,47

APPENDIX 2.18

Test of treatments x places interactions of the mean yields of dry herbage in $\frac{1}{2,2046}$ kg per plot in 1971-72 from grasses grown in unfumigated soil and in soil fumigated with methyl bromide in 1970. (Reference Table 11) (Cochran and Cox, 1950).

Grasses	Soil not fumigated	Soil fumigated	T_j
Ermelo Love	7,17	10,30	98,69
Sabi Panicum	5,28	3,55	41,33
Paraguay Paspalum	11,56	12,58	124,71
Wintergreen Paspalum	7,94	6,70	71,84
Star cv. No. 2	7,60	11,06	106,12
Giant Rhodes	3,93	2,74	31,46
Victoria Falls Panicum	4,86	12,37	102,85
Bushman Mine Panicum	7,86	9,68	92,62
W_i	3,04	7,12	10,16 = W
Total (P_i)	56,20	70,08	
W_iP_i	170,85	498,97	669,82 = G
S.S. (S_i)	434,56	722,57	

Correction term $C = \frac{G^2}{tW} = \frac{(669,82)^2}{(8)(10,16)} =$ 5519,91

Total $\sum(W_iS_i) - C = (3,04)(434,57) + (7,12)(722,57) - C =$ 945,88

Places $\frac{1}{8}\sum(W_iP_i^2) - C = \frac{1}{8}(44618,56) - C$ = 57,41

Treatments $\sum \frac{T_j^2}{W} - C$ = 740,55

Treatments x Places = 945,88 - 57,41 - 740,55 = 147,92 = I

$\chi^2 = \frac{(n-4)(n-2)}{n(n+t-3)}$ I with $\frac{(P-1)(t-1)(n-4)}{n+t-3}$ d.f.

χ^2 = 66,73 with 3,68 d.f.

3 d.f. χ^2 = 16,27

4 d.f. χ^2 = 18,47

APPENDIX 2.19

Analysis of variance of the effects of cutting three grasses (G) at early anthesis on their herbage yields during 1971-72. (Reference Figure 15).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	0,0114	0,0057			
G	2	1,4900	0,7450	44,88	18,00	**
Error	4	0,0663	0,0166			
Total	8	1,5677				

APPENDIX 2.20

Analysis of variance of the effects of cutting three grasses (G) at early anthesis on the crude protein content of their herbage. (Reference Figure 15).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	3,61	1,81			
G	2	1,02	0,51			
Error	4	6,10	1,53			
Total	8	10,73				

APPENDIX 2.21

Analysis of variance of the effects of cutting three grasses (G) at early anthesis on their root and stem base masses. (Reference Figure 15).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	269	135			
G	2	1387	694	9,13	6,94	*
Error	4	302	76			
Total	8	1958				

APPENDIX 2.22

Analysis of variance of the effects of cutting three grasses (G) at early anthesis on the crude protein content of roots and stem bases. (Reference Figure 15).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	0,95	0,48			
G	2	0,00	0,00			
Error	4	2,06	0,52			
Total	8	3,01				

APPENDIX 2.23

Analysis of variance of the effects of cutting three grasses (G) at early anthesis on the total available carbohydrates (TAC) in their roots and stem bases. (Reference Figure 15).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	0,80	0,40			
G	2	51,73	25,87	117,59	61,25	***
Error	4	0,87	0,22			
Total	8	53,40				

APPENDIX 2.24

Analysis of variance of the effects of cutting three grasses (G) at three-weekly intervals on their herbage yields during 1971-72. (Reference Figure 16).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	0,01	0,005			
G	2	0,45	0,225			
Error	4	0,28	0,070			
Total	8	0,74				

APPENDIX 2.25

Analysis of variance of the effects of cutting three grasses (G) at three-weekly intervals on the crude protein content of the herbage. (Reference Figure 16).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	1,17	0,59			
G	2	61,52	30,76	256,33	61,25	***
Error	4	0,46	0,12			
Total	8	63,15				

APPENDIX 2.26

Analysis of variance of the effects of cutting three grasses (G) at three-weekly intervals on their root and stem base masses. (Reference Figure 16).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	226	113			
G	2	2600	1300	56,52	18,00	**
Error	4	93	23			
Total	8	2919				

APPENDIX 2.27

Analysis of variance of the effects of cutting three grasses (G) at three-weekly intervals on the crude protein content of roots and stem bases. (Reference Figure 16).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	1,29	0,65			
G	2	3,30	1,65			
Error	4	1,73	0,43			
Total	8	6,32				

APPENDIX 2.28

Analysis of variance of the effects of cutting three grasses (G) at three-weekly intervals on the total available carbohydrates (TAC) of roots and stem bases. (Reference Figure 16).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	0,24	0,12			
G	2	87,96	43,98	73,30	61,25	***
Error	4	2,41	0,60			
Total	8	90,61				

APPENDIX 2.29

Analysis of variance of the mean effects of applied nitrogen on the herbage yields of Star grass grazed on a set-stocked basis each growing season by sheep. (Reference Figure 17).

1968-69

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	1316,76	658,38			
N'	1	43142,46	43142,46	35,76	35,51	***
N''	1	5281,45	5281,45			
N'''	1	2909,22	2909,22			
Error	6	7238,07	1206,35			
Total	11	59887,96				

1969-70

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	370,34	185,17			
N'	1	11377,64	11377,64	21,41	13,74	**
N''	1	5369,92	5369,92	10,10	5,99	*
N'''	1	10,29	10,29			
Error	6	3189,03	531,51			
Total	11	20317,22				

1970-71

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	1335,88	667,94			
N'	1	16673,34	16673,34	55,07	35,51	***
N''	1	1252,56	1252,56			
N'''	1	192,96	192,96			
Error	6	1816,45	302,74			
Total	11	21271,19				

APPENDIX 2.29 (Continued)

Analysis of variance of the mean effects of applied nitrogen on the herbage yields of Star grass grazed on a set-stocked basis each growing season by sheep. (Reference Figure 17).

1971-72

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	23,54	11,77			
N'	1	35147,60	35147,60	94,82	35,51	***
N''	1	8618,34	8618,34	23,25	13,74	**
N'''	1	160,49	160,49			
Error	6	2224,00	370,67			
Total	11	46173,97				

1972-73

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	248,84	124,42			
N'	1	74356,19	74356,19	41,86	35,51	***
N''	1	18334,08	18334,08	10,32	5,99	*
N'''	1	100,24	100,24			
Error	6	10658,62	10658,62			
Total	11	103697,97				

Four-year means (1969-70 to 1972-73)

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	17,86	8,93			
N'	1	20664,71	20664,71	64,20	35,51	***
N''	1	4095,91	4095,91	12,72	5,99	*
N'''	1	113,44	113,44			
Error	6	1931,33	321,89			
Total	11	26823,25				

APPENDIX 2.30

Mean effects of applied nitrogen on herbage yields in kg dry matter per ha of Star grass when rested from grazing for various periods. (Reference Figure 18).

One year's rest after grazing (means of four years)

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	322,91	161,46			
N'	1	28435,97	28435,97	156,53	35,51	***
N''	1	2742,16	2742,16	15,09	13,74	**
N'''	1	44,03	44,03			
Error	6	1090,02	181,67			
Total	11	32635,09				

Two year's rest after grazing (means of three years)

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	542,55	271,28			
N'	1	18002,41	18002,41	107,56	35,51	***
N''	1	1735,21	1735,21	10,37	5,99	*
N'''	1	21,72	21,72			
Error	6	1004,24	169,37			
Total	11	21306,13				

Three year's rest after grazing (means of two years)

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	76,33	38,17			
N'	1	28627,87	28627,87	194,09	35,51	***
N''	1	1316,80	1316,80	8,94	5,99	*
N'''	1	422,41	422,41			
Error	6	884,98	147,50			
Total	11	31330,39				

APPENDIX 2.30 (Continued)

Mean effects of applied nitrogen on herbage yields in kg dry matter per ha of Star grass when rested from grazing for various periods. (Reference Figure 18).

Four year's rest after grazing (one year)

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	1907,48	953,74			
N'	1	40251,71	40251,71	102,80	35,51	***
N''	1	11419,44	11419,44	29,17	13,74	**
N'''	1	79,86	79,86			
Error	6	2349,26	391,54			
Total	11	56007,75				

Mean effect of resting (all years of resting)

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	190,21	95,11			
N'	1	21477,98	21477,98	469,16	35,51	***
N''	1	1996,92	1996,92	43,62	35,51	***
N'''	1	116,20	116,20			
Error	6	274,66	45,78			
Total	11	24055,97				

APPENDIX 2.31

Analysis of variance of the body mass gains in kg per ha of sheep that were set-stocked on Star grass fertilized with various amounts of nitrogen . (Reference Table 18).

1968-69

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	2274	1137			
N'	1	71829	71829	17,11	13,74	**
N''	1	3888	3888			
N'''	1	5762	5762			
Error	6	25188	4198			
Total	11	108941				

1969-70

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	14654	7327			
N'	1	225952	225952	78,03	35,51	***
N''	1	29403	29403			
N'''	1	4	4			
Error	6	173743	28957			
Total	11	443756				

1970-71

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	20024	10012			
N'	1	190970	190970	39,27	35,51	***
N''	1	76960	76960	15,83	13,74	**
N'''	1	10270	10270			
Error	6	29176	4863			
Total	11	327400				

APPENDIX 2.31 (Continued)

Analysis of variance of the body mass gains in kg per ha of sheep that were set-stocked on Star grass fertilized with various amounts of nitrogen. (Reference Table 18).

1971-72

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	68716	34358			
N'	1	1434069	1434069	83,99	35,51	***
N''	1	380920	380920			
N'''	1	23681	23681			
Error	6	102451	17075			
Total	11	2009837				

1972-73

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	6721	3361			
N'	1	112926	112926	14,68	13,74	**
N''	1	1180	1180			
N'''	1	1392	1392			
Error	6	46145	7691			
Total	11	168364				

Means 1970-71 to 1972-73

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	6734	3367			
N'	1	431293	431293	93,62	35,51	***
N''	1	95944	95944			
N'''	1	25	25			
Error	6	27644	4607			
Total	11	561640				

APPENDIX 2.32

Analysis of variance of the body mass gains per steer in kg of steers grazing four grasses (G) at a stocking rate of 9,88 steers per ha and fertilized with 350 kg N and 90 kg P_2O_5 per ha, annually. (Reference Figure 20).

1968-69

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	173,09	86,55			
G	3	1197,26	399,09	2,26		
Error	6	1057,92	176,32			
Total	11	2428,27				

1969-70

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	3,11	1,56			
G	3	3739,39	1246,46	6,45	4,76	*
Error	6	1159,14	192,19			
Total	11	4901,64				

1970-71

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	279,50	139,75			
G	3	1034,04	344,68	6,68	4,76	*
Error	6	309,75	51,63			
Total	11	1623,29				

Three-year means

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	82,89	41,45			
G	3	1045,24	348,41	6,95	4,76	*
Error	6	300,50	50,08			
Total	11	1428,63				

APPENDIX 2.33

Analysis of variance of the body mass gains per ha in kg of steers grazing four grasses (G) at a stocking rate of 9,88 steers per ha and fertilized with 350 kg N and 90 kg P_2O_5 per ha, annually. (Reference Figure 20).

1968-69

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	16899	8450			
G	3	116859	38953	2,26		
Error	6	103290	17215			
Total	11	237048				

1969-70

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	302	151			
G	3	365046	121682	6,45	4,76	*
Error	6	113165	18861			
Total	11	478513				

1970-71

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	27292	13646			
G	3	100931	33644	6,68	4,76	*
Error	6	30222	5037			
Total	11	158445				

Three-year means

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	8104	4052			
G	3	101860	33953	6,95	4,76	*
Error	6	29319	4887			
Total	11	139283				

APPENDIX 2.34

Analysis of variance of the effects of four stocking rates (R) on the mean body mass gains in kg per steer of steers grazing three grasses (G) fertilized with 350 kg N and 90 kg P_2O_5 per ha, annually. (Reference Figure 21).

1968-69

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	244,79	122,40			
G	2	978,85	489,43	5,12	3,44	*
R'	1	6220,28	6220,28	65,03	14,38	***
R''	1	199,86	199,86			
R'''	1	0,10	0,10			
G x R'	2	540,01	270,01			
G x R''	2	36,68	18,34			
G x R'''	2	114,70	57,35			
Error	22	2104,39	95,65			
Total	35	10439,66				

1969-70

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	78,77	39,39			
G	2	1823,67	911,84	4,69	3,44	*
R'	1	19424,72	19424,72	99,92	14,38	***
R''	1	74,27	74,27			
R'''	1	4,36	4,36			
G x R'	2	453,43	226,72			
G x R''	2	339,14	169,57			
G x R'''	2	225,31	112,66			
Error	22	4276,83	194,40			
Total	35	26700,50				

APPENDIX 2.34 (Continued)

Analysis of variance of the effects of four stocking rates (R) on the mean body mass gains in kg per steer of steers grazing three grasses (G) fertilized with 350 kg N and 90 kg P_2O_5 per ha, annually. (Reference Figure 21).

1970-71

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	156,05	78,03			
G	2	1372,09	686,05	5,79	5,72	**
R'	1	14028,43	14028,43	118,37	14,38	***
R''	1	202,64	202,64			
R'''	1	446,34	446,34			
G x R'	2	80,72	40,36			
G x R''	2	11,43	5,72			
G x R'''	2	450,18	225,09			
Error	22	2607,28	118,51			
Total	35	19355,16				

Three-year means

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	3,57	1,78			
G	2	51,05	25,53			
R'	1	12597,33	12597,33	171,28	14,38	***
R''	1	150,73	150,73			
R'''	1	38,87	38,87			
G x R'	2	35,95	17,98			
G x R''	2	53,45	26,73			
G x R'''	2	87,15	43,58			
Error	22	1618,04	73,55			
Total	35	14636,14				

APPENDIX 2.35

Analysis of variance of the effects of four stocking rates (R) on the mean body mass gains in kg per ha of steers grazing three grasses (G) fertilized with 350 kg N and 90 kg P_2O_5 per ha, annually. (Reference Figure 22).

1968-69

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replication	2	34890	17445			
G	2	135223	67612	4,73	3,44	*
R'	1	284919	284919	19,93	14,38	***
R''	1	291	291			
R'''	1	359	359			
G x R'	2	61772	30886			
G x R''	2	10340	5170			
G x R'''	2	19209	9605			
Error	22	314487	14295			
Total	35	861490				

1969-70

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	17345	8673			
G	2	276164	138082	3,63	3,44	*
R'	1	1344727	1344727	35,32	14,38	***
R''	1	37893	37893			
R'''	1	202	202			
G x R'	2	21130	10565			
G x R''	2	39838	19919			
G x R'''	2	36737	18369			
Error	22	837647	38075			
Total	35	2611683				

APPENDIX 2.35 (Continued)

Analysis of variance of the effects of four stocking rates (R) on the mean body mass gains in kg per ha of steers grazing three grasses (G) fertilized with 350 kg N and 90 kg P_2O_5 per ha, annually. (Reference Figure 22).

1970-71

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	30670	15335			
G	2	229677	114839	5,08	3,44	*
R'	1	402105	402105	17,79	14,38	***
R''	1	1106	1106			
R'''	1	96592	96592			
G x R'	2	1457	729			
G x R''	2	1831	916			
G x R'''	2	82127	41064			
Error	22	497318	22605			
Total	35	1342883				

Three-year means

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	1340	670			
G	2	8027	4014			
R'	1	479055	479055	43,30	14,38	***
R''	1	4011	4011			
R'''	1	8792	8792			
G x R'	2	3838	1919			
G x R''	2	4450	2225			
G x R'''	2	10729	5365			
Error	22	243377	11063			
Total	35	763619				

APPENDIX 2.36

Analysis of variance of the mean basal cover as a percentage of total pasture area of four grasses (G) grazed at a stocking rate of 9,88 steers per ha and fertilized with 350 kg N and 90 kg P_2O_5 annually. (Reference Table 25).

1969

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	1,18	0,59			
G	3	44,16	14,72	4,97	4,76	*
Error	6	17,73	2,96			
Total	11	63,07				

1970

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	7,29	3,65	8,90	5,14	*
G	3	75,86	25,29	61,68	25,70	***
Error	6	2,48	0,41			
Total	11	85,63				

1971

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	8,00	4,00			
G	3	119,85	39,95	10,35	9,78	**
Error	6	23,13	3,86			
Total	11	150,98				

Three-year means

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	1,21	0,66			
G	3	76,32	25,44	13,75	9,78	**
Error	6	11,11	1,85			
Total	11	88,64				

APPENDIX 2.37

Analysis of variance of the mean basal cover as a percentage of total pasture area and of three grasses (G) grazed at four stocking rates (R) and fertilized with 350 kg N and 90 kg P_2O_5 per ha, annually. (Reference Figure 24).

1969

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	6,96	3,48			
G	2	1,46	0,73			
R'	1	2,41	2,41			
R''	1	3,24	3,24			
R'''	1	3,25	3,25			
G x R'	2	19,51	9,76	3,94	3,44	*
G x R''	2	9,26	4,63			
G x R'''	2	0,47	0,24			
Error	22	54,62	2,48			
Total	35	101,18				

1970

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	24,61	12,31	4,75	3,44	*
G	2	17,73	8,87			
R'	1	0,85	0,85			
R''	1	0,11	0,11			
R'''	1	0,06	0,06			
G x R'	2	15,65	7,83			
G x R''	2	4,95	2,48			
G x R'''	2	3,70	1,85			
Error	22	56,99	2,59			
Total	35	124,65				

APPENDIX 2.37 (Continued)

Analysis of variance of the mean basal cover as a percentage of total pasture area of three grasses grazed at four stocking rates and fertilized annually with 350 kg N and 90 kg P_2O_5 per ha. (Reference Figure 24).

1971

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	18,63	9,32			
G	2	197,44	98,72	20,74	9,61	***
R'	1	3,70	3,70			
R''	1	1,21	1,21			
R'''	1	8,19	8,19			
G x R'	2	12,96	6,48			
G x R''	2	2,81	1,41			
G x R'''	2	21,22	10,61			
Error	22	104,76	4,76			
Total	35	370,92				

Three-year means

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	1,70	0,85			
G	2	30,58	15,29	6,34	5,72	**
R'	1	0,72	0,72			
R''	1	1,16	1,16			
R'''	1	0,08	0,08			
G x R'	2	12,67	6,34			
G x R''	2	1,66	0,83			
G x R'''	2	5,22	2,61			
Error	22	53,00	2,41			
Total	35	106,79				

APPENDIX 2.38

Analysis of variance of the density of oven-dried soil at 7,62 and 22,86 cm below soil surface under four grasses (G) fertilized with 350 kg N and 90 kg P_2O_5 per ha, annually and grazed at a stocking rate of 9,88 steers per ha. (Reference Table 26).

7,62 cm depth

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	0,0292	0,0146			
G	3	0,0023	0,0008			
Error	6	0,0181	0,0030			
Total	11	0,0496				

22,86 cm depth

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	0,0218	0,0109	7.79	5,14	*
G	3	0,0029	0,0010			
Error	6	0,0086	0,0014			
Total	11	0,0333				

APPENDIX 2.39

Analysis of variance of the density of oven-dried soil at 7,62 and 22,86 cm below soil surface under three grasses (G) fertilized with 350 kg N and 90 kg P_2O_5 annually, and grazed at four stocking rates (R). (Reference Table 27).

7,62 cm depth

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	0,12700	0,06350	29,81	9,61	***
G	2	0,00400	0,00200			
R'	1	0,00344	0,00344			
R''	1	0,00080	0,00080			
R'''	1	0,00002	0,00002			
G x R'	2	0,00000	0,00000			
G x R''	2	0,00430	0,00215			
G x R'''	2	0,00150	0,00075			
Error	22	0,04700	0,00213			
Total	35	0,18806				

22,86 cm depth

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	0,04915	0,02458	18,62	9,61	***
G	2	0,00673	0,00337			
R'	1	0,00464	0,00464			
R''	1	0,00107	0,00107			
R'''	1	0,00051	0,00051			
G x R'	2	0,00136	0,00068			
G x R''	2	0,00537	0,00269			
G x R'''	2	0,00033	0,00017			
Error	22	0,02902	0,00132			
Total	35	0,09818				

APPENDIX 2.40

Analysis of variance of the mean time in minutes for 100 ml water to infiltrate the soil under four grasses (G) fertilized with 350 kg N and 90 kg P_2O_5 per ha annually, and grazed at a stocking rate of 9,88 steers per ha. (Reference Table 28).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	1095,52	547,76			
G	3	1583,69	527,90			
Error	6	5615,56	935,93			
Total	11	8294,77				

APPENDIX 2.41

Analysis of variance of the mean time in minutes for 100 ml water to infiltrate the soil under three grasses (G) fertilized with 350 kg N and 90 kg P_2O_5 per ha annually, and grazed at four stocking rates (R). (Reference Table 29).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	212,37	106,19			
G	2	1062,79	531,40			
R'	1	163,59	163,59			
R''	1	155,25	155,25			
R'''	1	430,59	430,59			
G x R'	2	2379,44	1189,72			
G x R''	2	2771,48	1385,74			
G x R'''	2	349,49	174,80			
Error	22	18739,50	851,80			
Total	35	26264,50				

APPENDIX 2.42

Analysis of variance of the specific soil resistance (S.S.R.) in kg per cm^2 to a disc plough used to plough under four grasses (G) fertilized with 350 kg N and 90 kg P_2O_5 per ha, annually and grazed at a stocking rate of 9,88 steers per ha. (Reference Table 30).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	4,79	2,40			
G	3	17,67	5,89	9,98	9,78	**
Error	6	3,51	0,59			
Total	11	25,97				

APPENDIX 2.43

Analysis of variance of the specific soil resistance (S.S.R.) in kg per cm^2 to a disc plough used to plough under three grasses (G) fertilized with 350 kg N and 90 kg P_2O_5 per ha, annually and grazed at four stocking rates (R). (Reference Figure 25).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	27,733	13,867	18,22	9,61	***
G	2	4,698	2,349			
R'	1	1,402	1,402			
R''	1	0,065	0,065			
R'''	1	0,991	0,991			
G x R'	2	4,598	2,299			
G x R''	2	10,179	5,090	6,69	5,72	**
G x R'''	2	5,523	2,762	3,63	3,44	*
Error	22	16,747	0,761			
Total	35	71,936				

APPENDIX 2.44

Analysis of variance of the effects of applied nitrogen (N) and the height at which grazing of Star grass commenced (GH) on herbage yields in kg dry matter per ha during the 1970-71 and 1971-72 growing seasons. (Reference Figure 35).

1970-71

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
N	2	37,56	18,78			
GH	2	152,28	76,14	25,13	18,00	**
NXGH(Error a)	4	12,12	3,03			
Main plots	8	201,96				
N'	1	12,34	12,34			
N''	1	25,22	25,22			
GH'	1	149,86	149,86	47,57	34,12	**
GH''	1	2,43	2,43			
N' x GH'	1	2,68	2,68			
NXGH other (Error b)	3	9,46	3,15			
Sub-plots	16	403,95				

1971-72

Source of Variation	d.f.	S.S.	M.S.	F	V.R.	Significant Effects
N	2	53,11	26,55			
GH	2	572,09	286,04	20,06	18.00	**
NXGH (Error a)	4	57,03	14,26			
Main plots	8	682,23				
N'	1	48,29	48,29			
N''	1	4,82	4,82			
GH'	1	559,24	559,24	90,64	34,12	**
GH''	1	12,85	12,85			
N' X GH'	1	38,51	38,51			
NXGH other (Error b)	3	18,51	6,17			
Sub-plots	16	1364,45				

APPENDIX 2.45

Analysis of variance of the effects of applied nitrogen (N) on the herbage yields of Star grass in kg dry matter per ha grazed whenever growth reached a height of 10 cm above ground level. (Reference Figure 38).

1972-73

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	1	2775	2775			
N'	1	13517550	13517550	25,70	10,13	*
N''	1	177906	177906			
N'''	1	3875685	3875685			
Error	3	1578078	526026			
Total	7	19151994				

1973-74

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	1	5				
N'	1	1568279	1568279	12,20	10,13	*
N''	1	200503	200503			
N'''	1	7524782	7524782	58,54	34,12	**
Error	3	385606	128535			
Total	7	9679175				

Two-year mean

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	1	613	613			
N'	1	6074643	6074643	22,75	10,13	*
N''	1	189113	189113			
N'''	1	5547270	5547270	20,77	10,13	*
Error	3	801063	267021			
Total	7	12612702				

APPENDIX 2.46

Analysis of variance of the effect of height of stubble left after simulated rotational grazing on regrowth of Star grass in 1972-73 and on the regrowth and components of that regrowth and of the stubble left after grazing in 1974-75, all in kg dry matter per ha. (Reference Figure 39).

1972-73

Total herbage

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	1	2658672	2658672			
Stubble height	2	9384122	4692061	22,39	19,00	*
Error	2	419073	209537			
Total	5	12461867				

1974-75

Total herbage (T)

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	1	93500	93500			
Stubble height	2	75455733	37727867	48,42	19,00	*
Error	2	1558302	779151			
Total	5	77107535				

Green leaf (G)

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	1	171365	171365			
Stubble height	2	8742240	4371120	52,30	19,00	*
Error	2	167144	83572			
Total	5	9080749				

Dead leaf (D)

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	1	3700	3700			
Stubble height	2	146371	73186			
Error	2	7926	3963			
Total	5	157997				

Stem (S)

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	1	2242	2242			
Stubble height	2	29397730	14698865	39,58		*
Error	2	742785	371393			
Total	5	30142757				

APPENDIX 2.46 (Continued)

Analysis of variance of the effect of height of stubble (S) left after simulated rotational grazing on regrowth of Star grass in 1972-73 and on the regrowth and components of that regrowth and of the stubble left after grazing in 1974-75, all in kg dry matter per ha. (Reference Figure 39).

1974-75

Total herbage in stubble (T)

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	1	9082	9082			
Stubble height	2	11538960	5769480	70,92	19,00	*
Error	2	162703	81352			
Total	5	11710745				

Green leaf (G)

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	1	2774	2774			
Stubble height	2	490184	245092	192,2	99,00	**
Error	2	2550	1275			
Total	5	495508				

Dead leaf (D)

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	1	3902	3902			
Stubble height	2	58283	29142	24,22	19,00	*
Error	2	2406	1203			
Total	5	64591				

Stem (S)

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	1	46465	46465			
Stubble height	2	6062150	3031075	240,52	99,00	**
Error	2	25203	12602			
Total	5	6133818				

APPENDIX 2.47

Analysis of variance of the effects of applied nitrogen (N) and of mowing (M) on the basal covers of Star (S) and Rats Tail (R) grasses expressed as a percentage of total pasture area. (Reference Table 35).

Star grass

1973

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	264	132			
N	3	64	21			
Error (a)	6	155	26			
Main plots	11	483				
M	1	9	9			
M x N	3	99	33			
Error (b)	8	115	14			
Sub-plots	23	706				

1974

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	384	192			
N	3	70	23			
Error (a)	6	506	84			
Main plots	11	960				
M	1	67	67			
M x N	3	104	35			
Error (b)	8	511	64			
Sub-plots	23	1642				

1975

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	543	272			
N	3	603	201			
Error (a)	6	1174	196			
Main plots	11	2320				
M	1	704	704	27.08	25.42	***
M x N	3	196	65			
Error (b)	8	210	26			
Sub-plots	23	3430				

APPENDIX 2.47(Continued)

Analysis of variance of the effects of applied nitrogen (N) and of mowing (M) on the basal covers of Star (S) and Rats Tail (R) grasses expressed as a percentage of total pasture area. (Reference Table 35).

Star grass

Three-year means

Source of Variation	d.f.	S.S.	M.S.	F	V.R.	Significant Effects
Replications	2	227	114			
N	3	149	50			
Error (a)	6	187	31			
Main plots	11	563				
M	1	117	117	7.31	5.32	*
M x N	3	62	21			
Error (b)	8	128	16			
Sub-plots	23	870				

Rats Tail

1973

Source of Variation	d.f.	S.S.	M.S.	F	V.R.	Significant Effects
Replications	2	16	8			
N	3	772	257			
Error (a)	6	722	120			
Main plots	11	1510				
M	1	165	165			
M x N	3	119	40			
Error (b)	8	364	46			
Sub-plots	23	2158				

1974

Source of Variation	d.f.	S.S.	M.S.	F	V.R.	Significant Effects
Replications	2	289	145			
N'	1	2058	2058	35.48	13.74	**
N''	1	198	198			
N'''	1	13	13			
Error (a)	6	347	58			
Main plots	11	2905				
M	1	35	35			
M x N	3	38	13			
Error (b)	8	210	26			
Sub-plots	23	3188				

APPENDIX 2.47 (Continued)

Analysis of variance of the effects of applied nitrogen (N) and of mowing (M) on the basal cover of Star (S) and Rats Tail (R) grasses expressed as a percentage of total pasture area. (Reference Table 33).

Rats Tail

1975

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	87	44			
N'	1	7915	7915	46,83	35,51	***
N''	1	1317	1317	7,79	5,99	*
N'''	1	0	0			
Error (a)	6	1011	169			
Main plots	11	10330				
M	1	425	425			
M x N	3	268	89			
Error (b)	8	1423	178			
Sub-plots	23	12446				

Three-year means

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	57	29			
N'	1	2623	2623	100,88	35,51	***
N''	1	532	532	20,46	13,74	**
N'''	1	0	0			
Error (a)	6	154	26			
Main plots	11	3366				
M	1	22	22			
M x N	3	9	3			
Error (b)	8	168	21			
Sub-plots	23	3565				

APPENDIX 2.48

Analysis of variance of the effects of applying nitrogen (N) to maize in 1971-72 grown after four grasses (G) that were heavily fertilized and grazed at a stocking rate of 9,88 steers per ha for the previous three growing seasons. (Reference Table 36).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	265,69	132,85	13,95		
G	3	194,63	64,88	6,82	4,31	**
N	4	20,39	5,10			
N x G	12	82,42	6,87			
Error	47	447,31	9,52			
Total	59	1 010,44				

APPENDIX 2.49

Analysis of variance of the effects of applying nitrogen (N) to maize in 1971-72 grown after three grasses (G) that were heavily fertilized and intensively grazed at different stocking rates (R) for the previous three growing seasons. (Reference Table 37).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	748,22	374,11	10,14	9.61	***
R'	1	1,56	1,56			
R''	1	1,40	1,40			
R'''	1	95,10	95,10			
G	2	86,85	43,43			
G x R'	2	93,12	46,56			
G x R''	2	143,56	71,78			
G x R'''	2	67,72	33,86			
Error (a)	22	812,02	36,91			
Total Main Plots	35	2049,55				
N'	1	7,72	7,72			
N''	1	2,09	2,09			
N'''	1	2,16	2,16			
N''''	1	1,89	1,89			
N' R'	1	0,73	0,73			
N' R''	1	7,10	7,10			
N' R'''	1	7,37	7,37			
N'' R'	1	0,00	0,00			
N'' R''	1	10,52	10,52			
N'' R'''	1	13,60	13,60			
N''' R'	1	20,56	20,56			
N''' R''	1	63,97	63,97	11,11	6,85	**
N''' R'''	1	8,70	8,70			
N''' R'	1	25,23	25,23	4,38	3,92	*
N''' R''	1	0,38	0,38			
N'''' R'''	1	4,97	4,97			
G x N'	2	4,10	2,05			
G x N''	2	18,59	9,30			
G x N'''	2	14,82	7,41			
G x N''''	2	2,70	1,35			
Error (b)	120	691,14	5,76			
Total Sub-Plots	179	2957,89				

APPENDIX 2.50

Analysis of variance of the effects of applying different amounts of nitrogen (N), removing or ploughing under maize stover (S) annually, on maize grain yield where maize was grown on the same land for six successive years. (Reference Table 38).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	450,85	225,43	11,50	10,39	***
S	1	159,99	159,99	8,16	4,41	*
N'	1	0,31	0,31			
N''	1	3,21	3,21			
N'''	1	0,05	0,05			
N''''	1	4,79	4,79			
N x S	4	175,47	43,87			
Error	18	352,77	19,60			
Total	29	1147,44				

APPENDIX 2.51

Analysis of variance of the changes in percentage basal cover of the herbaceous plants between 1961 and 1975 with various grazing intensities (G) and burning treatments (B). (Reference Table 39).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	0,5079	0,2540			
Control vs rest	1	7,4401	7,4401	8,74	8,28	**
G	2	4,4428	2,2214			
B	2	0,7763	0,3882			
G x B	4	1,0939	0,2735			
Error	18	15,3223	0,8512			
Total	29	29,5833				

APPENDIX 2.52

Analysis of variance of the percentage changes in numbers of trees present in 1975 as compared with 1961 with different grazing intensity (G) and burning (B) treatments. (Reference Table 41).

Brachystegia boehmii

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	6633,6	3316,8	4,06	3,55	*
Control vs rest	1	8156,5	8156,5	9,99	8,28	**
B	2	7798,7	3899,4	4,78	3,55	*
G	2	511,6	255,8			
B x G	4	1418,0	354,5			
Error	18	14694,4	816,4			
Total	29	39212,8				

Julbernardia globiflora

Replications	2	1993,4	996,7			
Control vs rest	1	28768,0	28768,0	59,44	15,38	***
B	2	14692,7	7346,4	15,18	10,39	***
G	2	4422,9	2211,5	4,57	3,55	*
B x G	4	3017,1	754,3			
Error	18	8712,6	484,0			
Total	29	61606,7				

Brachystegia spiciformis

Replications	2	5787,8	2893,9			
Control vs rest	1	1596,6	1596,6			
B	2	21831,4	10915,7	8,28	6,01	**
G	2	700,3	350,2			
B x G	4	278,6	69,7			
Error	18	23734,5	1318,6			
Total	29	53929,2				

APPENDIX 2.52 Continued

Analysis of variance of the percentage changes in numbers of trees present in 1975 as compared with 1961 with different grazing intensity (G) and burning (B) treatments. (Reference Table 41).

All tree species

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	3766,5	1883,3			
Control vs rest	1	25365,5	25365,5	27,63	15,38	***
B	2	7012,8	3506,4	3,82	3,55	*
G	2	2461,5	1230,8			
B x G	4	1256,9	314,2			
Error	18	16522,2	917,9			
Total	29	56385,4				

APPENDIX 2.53

Analysis of variance of the effects of complete protection and of various grazing intensity (G) and burning (B) treatments on the 15-year mean annual herbage yield of veld grasses in kg dry matter per ha. (Reference Table 43).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	1585666,4	792833,2			
Control vs rest	1	114162,3	114162,3			
B	2	935366,3	467683,2			
G	2	1585988,7	792994,4			
B x G	4	1021663,0	255415,8			
Error	18	5949896,5	330549,8			
Total	29	11192743,2				

APPENDIX 2.54

Analysis of variance of the effects of various grazing intensities (G) and burning (B) treatments on veld on the 15-year mean body mass changes in kg of Africander-type cows. (Reference Table 44).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Replications	2	2540,6	1270,3	4,29	3,63	*
G	2	68,1	34,1			
B	2	42,4	21,2			
G x B	4	1309,2	327,3			
Error	16	4734,6	295,9			
Total	26	8694,9				

APPENDIX 2.55

Analysis of variance of the carcass mass gains per steer in kg of steers grazing at different stocking rates (R) on Star grass pastures fertilized with 25 kg N per steer per ha and 90 kg P_2O_5 per ha during the 1974-75 growing season. (Reference Figure 40).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Regression for R	1	1209,758	1209,758	14,78		
Regression R^2/R	1	306,324	306,324			
Lack of fit	1	89,946	89,946			
Error (steers in R)	76	6307,324	82,99			
Total	79	7913,352				

APPENDIX 2.56

Analysis of variance of the carcass mass gains per ha in kg of steers grazing at different stocking rates (R) on Star grass pastures fertilized with 25 kg N per steer per ha and 90 kg P_2O_5 per ha during the 1974-75 growing season. (Reference Figure 41).

Source of Variation	d.f.	S.S.	M.S.	F.	V.R.	Significant Effects
Regression for R	1	68 957	68 857			
Regression R^2/R	1	120 498	120 498	5,70	4.99	*
Lack of fit	1	14 675	14 675			
Error (steers in R)	76	1606 705	21 141			
Total	79	1810 735				