INFLUENCE OF LIVESTOCK GRAZING WITHIN PIOSPHERES UNDER FREE RANGE AND CONTROLLED CONDITIONS IN BOTSWANA

By

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ABSTRACT

The study was conducted in the Eastern Kalahari sandveld of Botswana on a shrub savanna vegetation type dominated by Terminalia sericea / Boscia albitrunca / Grewia flava and Dichrostachys cinerea woodland. It was initiated in an attempt to determine the impact of livestock grazing within piospheres on soil nutrients, range condition and the influence of season on forage quality and diet composition of livestock. The study was centered around the water points and conducted on both free range grazing and controlled conditions.

Measurements on soil and vegetation attributes were recorded at particular points along the transects from the water point. Vegetation and livestock diets were measured seasonally over a period of two years.

Chemical analyses of soil revealed the low background fertility of the Kalahari sandveld. The impact of dung and urine on soil chemistry was localized in the area immediate to the vicinity of the water point. Phosphorus, pH and cation exchange capacity were the most responsive attributes to variation along the transect from the water point. High livestock units carried at any particular borehole had an influence on the level of soil nutrient status. Management plans should aim at a more even spread of nutrients by improving the distribution of water points.

The zonation of vegetation along the transect from water point reflected the type of management, indicating different class of range condition which can be used in range evaluation and planning. Heavy grazing pressure and trampling in the vicinity of the water point kills sensitive perennial grasses resulting in a zone dominated by annual plants. High amount of available biomass were recorded during summer and autumn and low biomass occurred in spring. The 3 – paddock system produced less biomass compared to other systems, while biomass of palatable species was favored by the 9 – paddock system. Forage utilization was higher following drought years, when grazing pressure was concentrated on reduced forage availability. Utilization of forage was greatest in spring and lowest in summer. Utilization along the transect from water did not taper off until after 4000m from the water point in the free range grazing situation suggesting that forage availability was limiting factor, while in the controlled conditions the influence of grazing tapered off at 1200m. Piosphere size as determined by the distance livestock can travel was greater in the free range grazing management area than in the controlled management conditions.

Canopy volumes and leaf dry mass values reflect quantitative variations in the contribution of relatively small number of woody species. In general, both leaf volume and leaf mass decrease with the increase in distance from water due to the reduced plant density. Grewia flava and D. cinerea contributed substantially to the total leaf dry mass within the height below 2m. Leaf dry mass above 2m was largely contributed by Acacia gerrardii, T. sericea and B. albitrunca. Woody species diversity increased with the increase in distance from the water point. High density of G. flava was concentrated to the immediate vicinity of the water points, while species such as Bauhinia petersiana and Croton gratissimus occurred only at further distances from water. There was no clear pattern in the density distribution of D. cinerea along the transect from the water point.

Plants exhibit variations in the concentration of nutrients between species and season. High levels of crude protein, phosphorus and low crude fibre content occurred in summer for most species and the opposite was observed during winter or spring. Crude protein and phosphorus during dry periods were believed to be the limiting nutrients in maintaining nutritional quality in grazing animals. Mature forage generally is deficient, and may require supplementation of crude protein or phosphorus. Crude protein, phosphorus and crude fibre were not influenced by the grazing systems. The nutrient enrichment through cattle dung and urine in the vicinity of the water point was reflected in the forage nutrient content.

The micro – histological technique proved to be a useful tool for estimating the botanical composition of livestock diets. The technique, however, under-estimates the forbs in the diet of livestock. Diets of cattle were dominated by grasses all year round with a high proportion of woody plants occurred during the spring when available herbaceous biomass was low. Diet of goats was 72% and 82% browse in summer and spring, respectively. Competition for herbaceous plants was high between cattle and sheep. Seasonal species diversity was high in summer and lowest in spring. Goats are more diverse in their diets compared to cattle or sheep which have a strong similarity in their diets.

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CHAPTER 1

INFLUENCE OF LIVESTOCK GRAZING WITHIN PIOSPHERES UNDER FREE RANGE AND CONTROLLED CONDITIONS IN BOTSWANA

Introduction and Review of Techniques

1.1 Introduction

Livestock production is extremely important in Botswana’s national economy (contributes 4% of the total exports) and remains a priority enterprise in most of the rural economy where 55% of the population derive their income mainly from agriculture because of climatic, soil and vegetation limitations. The climate of Botswana is predominantly semi – arid to arid (Pike 1971), with rainfall confined to the months of October through March. The amount ranges from 250mm in the south – west to over 700mm in the extreme north – west. The high frequency of prolonged dry spells during critical growth periods and extreme localization of storms all combine in various ways to make dry land agriculture and range management a hazardous undertaking.

The soils are predominantly sandy soils of the Kalahari in the central and western zone, and the heavier textured soils of the Molopo catchments in the eastern part of the country. The sub – desert soils form the most extensive group (84%) and includes most of the soils of the Aeolian origin (Bawden & Stobbs 1963). These soils have been described as unproductive, but respond very well to phosphorus, nitrogen and manure (Bawden & Stobbs 1963; Van der Merwe 1949).

The vegetation of the Kalahari area are mainly occupied by T. sericea woodland and low shrubs of G. flava, D. cinerea and B. petersiana. In some areas Acacia erioloba is the dominant woodland. The vegetation of the alluvial and basic complex of the Molopo catchments consist of mainly Acacia mixed woodland. These include a number of local dominants associated with specific conditions. These soils have by far the highest production potential. However, overgrazing in these areas results in bush encroachment. Mopane woodland is associated with high clay soils with a high sodium content and occur extensively on calcrete soils or sand underlain by calcrete (FAO 1990).

There are two types of livestock production system, namely the communal and the commercial production systems. Eighty two percent of the national herd is under communal management systems (unfenced grazing land) and 18% is under commercial management systems (fenced grazing land) (Central Statistics Office 1986). The communal grazing rangeland is thus of major importance in the livestock industry as a whole.

Livestock production in the communal grazing areas is characterized by the integration of grazers (cattle and sheep) and browsers (goats). This has generally been reported to promote more effective utilization of both browse and herbaceous plants (Stuart – Hill & Tainton 1988). It has been assumed that the relative grazing or browsing pressure exerted by livestock affect the competitive balance between the herbaceous and woody plants, and that balance in turn affects the most profitable stocking rate for both browsing and grazing animals (Teague *et al.* 1981; Stuart – Hill & Tainton 1988). Communal grazing systems in Botswana are often based around a central water source (borehole, wells or temporal water pans) around which livestock graze. As livestock numbers have increased over time, a zone of degradation developed around the water source and livestock were forced to travel further searching for better grazing. The concentration of livestock around the water point is a norm and knowledge of soil nutrient distribution, through dung or urine is very important if not essential.

Because of the paucity of information on these facets it is necessary to investigate under both communal and commercial systems the seasonal diets of livestock and the influence of animal concentration around the water points, on range condition and soil nutrient distribution. Knowledge of livestock feeding habits and preferences is also essential for designing effective grazing systems and formulating economical supplementation programs.

Information from such a study would benefit the range users with respect to the competition for different plant species between animals. Such information would also provide a scientific basis for allocating different animal species to specific vegetation types to achieve better and more efficient range utilization or to use the animal to manipulate the vegetation structure and composition. With the development of the new agricultural policy in the livestock sector, this information would also aid in the fencing and water distribution decisions at the existing cattle posts in the communal grazing areas.

1.2 Hypotheses

The main thrust of the investigation is based on the hypotheses that:

- increased concentration of excreta near water points improves the fertility status of the soil and hence potential productivity and nutritive value of forage plants in those areas and hence their relative acceptability.

- frequency or intensity of grazing (correlated with distance from water point) may make species more acceptable because of vegetative and leafy growth with few stems.

- animal species differ in their plant species preference spectrum and that these spectrums may overlap to a greater or lesser extent at different times of the year.

- preference does vary with distance from the water point and that these preferences may be affected by; a) composition of material on offer; b) physiological maturity of material; c) grazing pressure and stocking density.

1.3 Objectives

The objectives of this research are:

1. To compare forage preferences (for different plant species) of cattle, sheep and goats in different seasons and relate this to forage availability and density.
2. To determine the influence of livestock concentration on both vegetation and soil fertility status in the vicinity of the water point.
3. To determine the forage quality through the seasons and to relate this to forage preference.

1.4 A review of techniques used in the study of grazing behaviour of ungulates

The composition of diets selected by domestic ruminants has long been of interest to range and wildlife ecologists (Storr 1961; Van Dyne & Torell 1964). The influence of species selected by ruminants on the dynamics of grassland communities has long been observed and is implicit in the increaser - decreaser classification of species (Weaver & Clements 1935; Dyksterhuis 1949). Information on the preferences of large free roaming herbivores is an important tool in resource management (Hansen & Martin 1973; Scotcher 1979; Holechek *et al.* 1982; McInnis *et al.*1983). Such information can be used in the assessment of nutrient intake of animals and evaluation of forage competition between herbivores.

The most commonly used techniques for estimating diet composition of large ruminants include:, forage utilization, direct observation and microhistological identification of plant material in oesophageal,gut or dung samples. The latter examines plant residues recovered from oesophageal fistulas, stomach or rumen contents and the feaces. Each of these techniques has its own advantages and disadvantages. This has heated the controversy as to which is the most useful in determining the diet of large herbivores (Storr 1961; Stewart 1967; Holechek *et al.*1982; McInnis *et al.*1983).

1.4.1 Forage utilization technique

The forage utilization method is reported to be one of the oldest approaches used to evaluate the diet of grazing animals (Holechek *et al.* 1982). The advantages of this approach include speed and the fact it provides information on where and to what extent the range is being used. When a forage species was used and how often a species was used are, however, questions this method will not answer, unless surveys are repeated at frequent intervals (Daines 1976). The greatest disadvantage with any utilization method is that large losses of plant parts from trampling, weathering, and animals other than those of interest can occur and these can confound the results. Smith & Shandruk (1979) observed that utilization is difficult to detect when grazing is light and when more than one herbivore is present it may not be possible to separate their effects. There are also limited opportunities of observing wild ungulates. However, the use of tamed animals (Cooper & Owen - Smith 1985) can minimize these difficulties but they provide limited and possible unrepresentative samples (Krueger *et al.* 1974; Smith & Shandruk 1979). Studies comparing utilization data with fistula samples were observed to lack agreement (Laycock *et al.* 1972; McInnis 1977). Roos *et al.* (1973) however, demonstrated agreement of data obtained from the wheel point method, as a measure of species utilization, and that of oesophageal fistula samples.

1.4.2 Direct observation technique

This method is known for its simplicity. Minor equipment requirement and ease of use are its major advantages. Difficulties in plant species identification and quantification of how much of a plant was consumed are, however, important problems with the procedure (Pieper 1978). Quantitative information has, however, been obtained from bite - counts and grazing time approaches (Ahmed & Bonham 1982). The time spent grazing each species is quantified and assumed to be proportional to the preference for that species. Wild animals are, however, often difficult to locate and approach closely for accurate observation with the direct observation method. These problems may be reduced by using tame animals (Cooper 1982; Cooper & Owen - Smith 1985), but only one animal can be observed at a time. Krueger *et al.* (1974) mentioned that diet selection is a complex behavioral act that is influenced by several factors such as physiological condition, degree of hunger, topography, other animals present and past grazing experience, all of which influence which, and how much of, plant species is consumed.

1.4.3 Oesophageal fistula technique

The use of oesophageal fistula has been restricted to domestic animals because an easily manageable animal, amenable to frequent handling is essential (Vavra *et al.* 1978). The technique is reported to be the most accurate (Cook 1964; Van Dyne & Torell 1964). However, the following disadvantages associated with the use of the technique have been identified: a) associated surgery; b) fistulated animals are grazed for short time and c) incomplete collection. Other disadvantages associated with the technique, as outlined by Holechek *et al.* (1982), include contamination by rumen contents, high cost and low sampling precision for individual species in the diet.

1.4.4 Faecal technique

The faecal technique is increasingly advocated, to avoid the disadvantages of other methods, for determining the diet of free - ranging ruminants. This method depends on the identification of indigestible cutinized fragments of leaves persisting in the faeces (Hercus 1960; Storr 1961; Stewart 1967; Sparks & Malecheck 1968; Liversidge 1970; Scotcher 1979). Faecal samples can be obtained without intensive animal observation, disturbance of the animal, dense vegetation or topographical hindrances. It allows sampling under natural conditions of any number of animals; the faeces themselves are representative of food selected at different times and over different parts of the animal range (Hansen & Martin 1973; Scotcher 1979; Holecheck *et al.* 1982).

The greatest limitations of the technique are that overall accuracy is a problem (Stewart 1967; Stewart & Stewart 1970; Scotcher 1979; Holechek *et al.*1982); the time required to train technicians and variation in accuracy between technicians (Holechek & Gross 1982). Hansen & Martin (1973) indicated that even if the discerniability of plant fragments is changed by digestion, the magnitude is not generally great enough to destroy the identifying characteristics. Studies by Storr (1961) and Williams (1969) have shown that only a few plant species could not be found in the faeces after they have gone through the digestive tract of a herbivore. The epidermal tissues of forbs were not as easily found in cattle and sheep faeces (Free *et al.* 1970) or in that of the grey rhebuck (Ferreira & Bigalke 1987). During the growing season the faecal analysis method tends to under - estimate the forbs and overestimate the grasses (Vavra *et al.* 1978) in the diet when compared to fistula technique. However, in winter the two methods were found to be comparable. Samples from oesophageas, rumen and faeces of sheep were compared to the actual diet in a study by McInnis (1977). Faecal samples were lower in the composition of forbs (with respect to the contribution) than the actual diet as well as the oesophageal and rumen samples. Not all studies have shown the under estimation of forbs in the actual diet. Hansen & Martin (1973) reported good agreement between composition of ingested and faecal material. Johnson & Pearson (1981) reported high similarity between oesophageal fistula and faecal samples from cattle though there was a tendency for forbs to be under estimated. Most scientists mention that differential digestion of plant species has little or no influence on the proportion of identifiable plant fragments (Free *et al.* 1970; Todd & Hansen 1973; Anthony & Smith 1974;

Dearden *et al.* 1975; Alipayo *et al.*1992). Sanders *et al.* (1980) cautioned that a method for determining grazing animal diet should: a) allow free animal movement and completely natural selection of all available plants regardless of the size of the area, b) allow for diet selection regardless of the terrain c) be equally useful for both domestic and wild animal d) should require minimum animal care and be relatively objective and e) allow identification of each individual plant species consumed. Omphile (1997) indicated that these requirements, laid down by Sanders *et al.* (1980), rule out the use of conventional approaches to diet selection, such as direct observation, forage utilization or oesophageal techniques. Hence, the advocated faecal procedure, which meets the conditions outlined by Sanders *et al.* (1980).

1.5 Forage Availability

Diet composition data alone are not sufficient to explaining the reason for observed diet differences between animal species, or switching of diet through the seasons. A knowledge of the reason why herbivores select the species that they eat is necessary for an understanding of the forage needs of range animals and the underlying basis of composition interaction among them (Hanley 1982). Information on herbage availability and quality is therefore, also essential.

Vegetation analysis is necessary for determining stocking rates; determining changes in range condition and determining the responses to many other treatments (Pieper 1978; Stuart - Hill 1985). There are many techniques available for measuring vegetation condition. Some of these include measuring production, cover, density, abundance and composition of herbage. Each has its advantages and disadvantages and the correct choice depends on the individual situation. The most widely used methods for estimating herbage availability include: a) clipping method, b) indirect method and c) weight estimate methods.

In most parts of Southern Africa primary production is limited to one growing season per year and herbage availability changes throughout the year, mostly through herbivory after its peak production.

1.5.1 Clipping Method

This is the most extensively used method in experimental work where forage production and /or availability is the dependable variable. Although the method is considered the most accurate, it has many drawbacks for administrators, researchers or ranchers, is time consuming and costly. Quadrats or plots of various sizes and shapes have been used for clipping studies depending on the nature of the vegetation being sampled. One important consideration in choosing quadrat size and shape is the perimeter - area ratio (Mueller-Dombis & Ellenberg 1974). A major source is the boundary error, deciding what is inside the quadrate and what is outside; this error increases as the perimeter increases.

1.5.2 Indirect Methods

Since direct clipping of vegetation has many drawback, many indirect methods have been suggested. If some easily measured variable were closely related to production, then once the relationship was established, only the easy measurement needs to be made. Jordaan *et al.* (1991) observed that tuft volumes were highly related to herbage yield and woody plants canopy volumes (Smit 1989) were found to be related to browse yield. The height - weight method seems to be a reliable indirect method for determining utilization of perennial grasses (Cook & Stubbendieck 1986). The problem with the procedure is the construction of height - weight tables which is a tedious work and should be done with consideration of the growth forms of plant species resulting from different sites and climate.

The disc meter has been used as a rapid, and non – destructive method for making accurate estimates of herbage yield (Bransby *et al.* 1977; Bransby & Tainton 1977). The problem associated with this technique is the change in phenological growth stage in pure stands of sward and changes in species composition in mixed swards, which might affect the regression relationship (Bransby *et al.* 1977). The meter should be calibrated frequently to ensure reliable estimates throughout the season. Many indirect methods, when compared with the clipping technique, may be relatively inaccurate owing to operator or environmental factors (Bransby *et al.* 1977; Pieper 1978). Probably the most used indirect method is that of relating rainfall to vegetation production because of high correlation between herbage yield and rainfall (Barnes & McNeill 1978; Field 1978; Pieper *et al.* 1971; Pumphrey 1980). The disadvantage of this method is that several years of data are needed with a wide spread in rainfall data, and data from one site may not be applicable to another site (Pieper *et al.* 1971).

1.5.3 Estimation Methods

Nearly all estimation methods use clipping for comparisons with the estimates. Such estimates may range from an ocular estimate of a whole paddock to an estimate on a small quadrat by species. The double sample method was devised by Pechanec & Pickford (1937) to provide an easy, rapid method for determining range production (Tadmor *et al.* 1975; Ahmed & Bonham 1982). During the use of the method frequent checks (clippings) are made to serve as an adjustment for the estimator. This approach increases accuracy of the estimates (Cook & Stebbendieck 1986; Pieper 1978). The method has been used extensively (Tadmor *et al.* 1975; Barnes *et al.* 1982). The regressions obtained locally range between 0.87 to 0.97. The major advantage of the double sampling procedure is the increased size of sample that may be realized.

1.6 Herbage quality

In the semi - arid environments of Southern Africa the herbivore community often consists of several species of grazers and browsers utilizing a large diversity of plant species. Bouttom *et al.* (1988) mentioned that the abundance of plant species might create a false impression that food sources for animals are plentiful. In some conservation areas, McNaughton (1988) suggested that limited supplies of food, and /or mineral deficiencies in food items, regulate the herbivore population. Food quality is influenced by the concentration of nutrients and by the balance between nutrients required for nutritional sufficiency (O’Reagain & Mentis 1988; Georgiadis & McNaughton 1990) and inhibitory chemicals (Cooper & Owen - Smith 1985). It is known that variations in nutrient content occur between, and within, plant species and that herbivores select their food to obtain a nutritionally balanced diet (Owen - Smith & Novellie 1982; Hardy & Mentis 1986; O’Reagain & Mentis 1988; McNaughton 1988). Some grass species are characterized by high levels of a particular element (APRU 1977), and no single species can accumulate high levels of all nutrients (Georgiadis & McNaughton 1990). The variation in individual mineral concentrations, found among plant species may explain the observation that herbivores tend to diversify their diets (Bouttom *et al.* 1988). Each plant species shows a highly distinctive element profile, distinctions that are maintained between sites and over time. McNaughton (1988) noted that species composition at a given site is of fundamental importance in determining the availability of element to herbivores. He also mentioned that as herbivore activity can radically change species composition, it affect the nutritional content of their diet.

Many studies have reported a high concentration of nitrogen, phosphorus and other nutrients and low concentration of fibre soon after growth resumes at the on set of the rainy season (APRU 1977; Hardy & Mentis 1986; O'Reagain & Mentis 1988). Plant species selection by animals has been shown to be positively associated with the content of protein, potassium and phosphorus but negatively correlated to fibre content (Heady 1964). However, attempts to predict dietary selection on these bases in sheep (Westoby 1974), kudu (Owen - Smith & Novellie 1982), goats and impala (Cooper & Owen - Smith 1985) have been unsuccessful. The latter proponents demonstrated that plant secondary metabolites (tannins) are important determinants of dietary selection among browsers. However, Stebbins (1981) and Coughenour (1985) suggested that plant secondary chemicals in grasses play a relatively insignificant role in the diet selected by grazers. Plant structure, percentage leaf, tuft diameter, leaf canopy and tensile strength of leaves has been found to influence diet selection (Theron & Booysen 1966; Gammon & Roberts 1978; O'Reagain & Mentis 1988).

The mineral content of forages is generally a reliable index of the ability of forages to meet the mineral requirements of animals. In wildlife studies it was observed that the spatial distribution of wild animals was a result of mineral content of forages; particularly phosphorus, sodium and magnesium(McNaughton 1988). Pienaar *et al.*(1993) mentioned that it is possible to predict the performance of grazing animals given a certain level of available forage of particular quality in any livestock management enterprise.

1.7 Structure of the Thesis

The goal and specific purposes of this thesis have been stated in the subsequent sections. It is hoped this thesis will prove useful not only as a thesis but also as a reference for livestock graziers, range technicians / or scientists and land administrators responsible for livestock water point (boreholes) allocation. This thesis is divided into four parts. The first part (chapter 1) serves as an introduction to give the reader the background information on livestock production systems in Botswana and those factors limiting production. The chapter also overviews the most frequently applied techniques when sampling vegetation and livestock diets. Part two (chapter 2) presents the characteristics (climatic, soils, and livestock units) and experimental design of the study area. Part three (chapter 3) focuses on the soil texture and nutrition and has been written to reflect the changes in the concepts of animal as agents in redistributing soil nutrients through their dung and urine. The final part (chapters 4 –8) deals with vegetation available biomass, its quality and utilization by livestock. The interrelationships between soil – plant – animal are indicated to facilitate an understanding of what plants do, how this influences animals, how animals can utilize and manipulate plants.

The order of chapters reflect my own bias about the sequence of topics in general range management. In developing what I have found to be an effective topic sequence, I have also attempted to make chapters sufficiently independent so that their order of presentation can be easily modified.

CHAPTER 2

STUDY AREA

2.1 Location and description

The trial was located at Makhi Ranch and the adjacent communal grazing area in Botswana (approximately 26.10’ degrees South and 23.40’ degrees East at an elevation of 1200m). The area is broadly described as a rolling flat country with dunes, wide plain depressions and pans (Weare & Yalala 1971). The soils are classified as Ferralic arenosols (FAO 1990). These are described as deep to very deep, well to somewhat excessively drained. The texture is fine sand to loamy fine sand and run – off is non – existent.

In general, the region consists of sandveld vegetation type (Weare & Yalala 1971; FAO 1991) of the Northern Kalahari tree and bush savanna (Fig. 2.1). The main tree species are T. sericea, Acacia fleckii, A. luederitzii, and Lochocarpus nelsii. Low growing shrubs, between taller trees, which often contribute significantly to canopy cover, include G. flava, G. retirnevis, B. petersiana, D. cinerea Mudulea sericea and Rhus ternunavis. The grass component has a low basal cover and consists mainly of Stipagrostis uniplumis, Eragrostis lehmanniana, Schmidtia pappophoroides, Anthephora pubescens (perennials) and Urochloa trichorpus, Aristida congesta and Megaloprotachne albescense (annuals). Various families of forbs are also found.

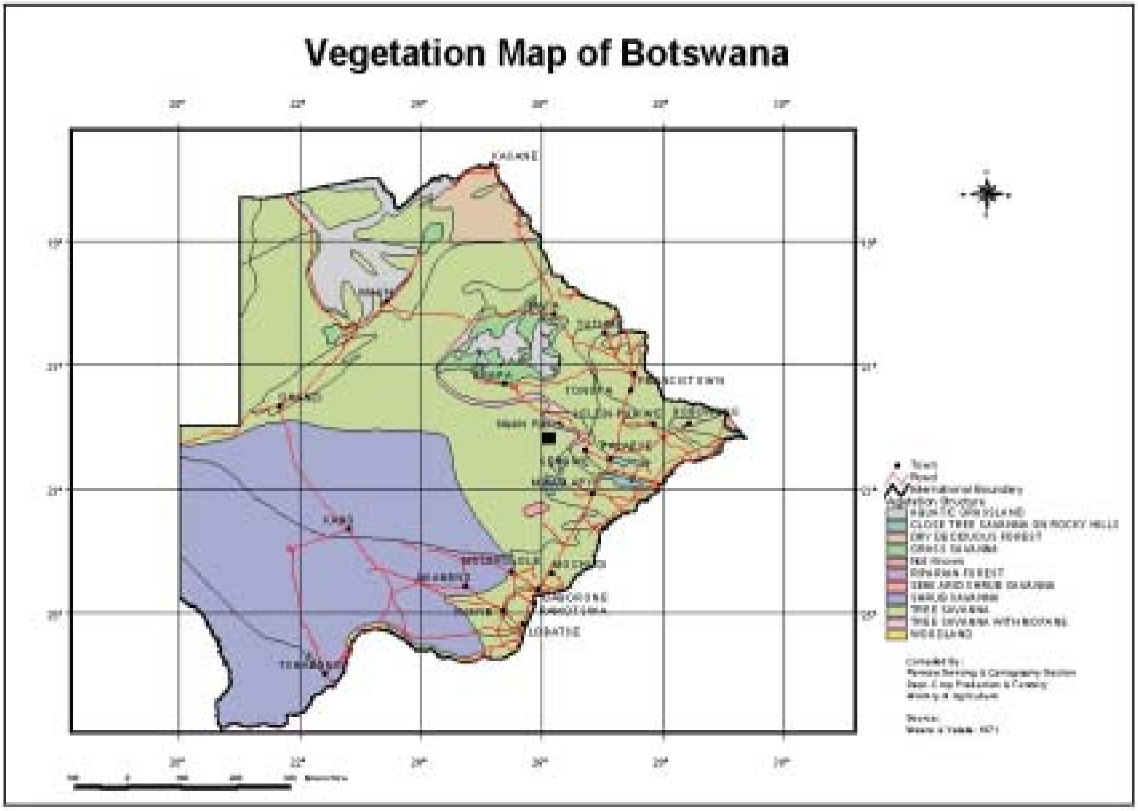

Fig. 2.1. **Vegetation Map of Botswana**

The mean monthly maximum temperatures range from 32 degrees centigrade in December and January to 23 degrees centigrade in June to July (measured at Serowe Weather Station). The corresponding minima are 18 and 4 degrees centigrade, respectively. Rainfall is erratic in total and distribution, with an annual long – term mean (1925 – 1998) of 451mm. Total annual rainfall during the study period (recorded at Makhi ranch) was 553 and 284mm for the 1996/97 and 1997/98 rainy seasons, respectively (Fig.2.2). Total rainfall for 1996/97 and 1997/98 was 22.6% and 20.8% above and below the long – term mean, respectively.

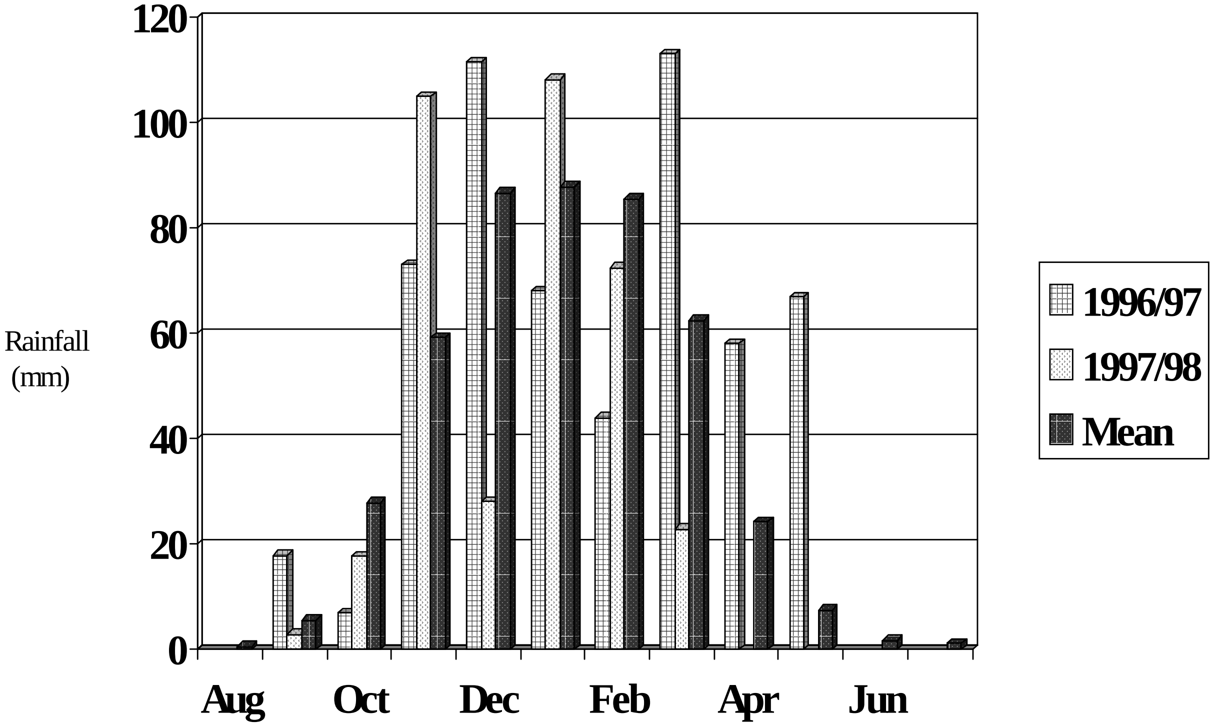

Fig. 2.2 Long-term (1925-1998) and study period monthly rainfall at Makhi Ranch

2.2 Experimental Design

The trial was conducted in two different grazing management systems; namely the communal grazing system (free range grazing – unfenced conditions) and the commercial ranching system (controlled grazing - fenced conditions). Figure 2.3 shows the location of the three boreholes where the study was undertaken, namely Makhi ranch in the controlled grazing conditions, Motshwagole and Masaane, both in the free range grazing area.

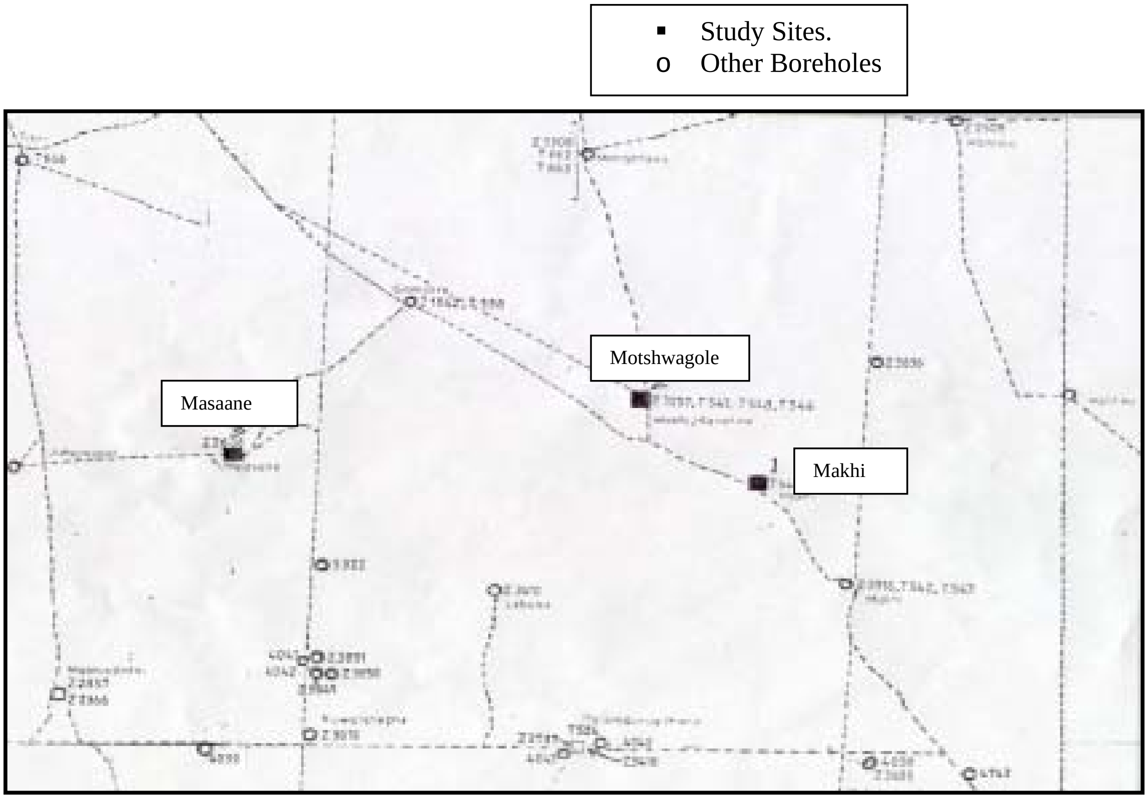

Fig. 2.3. **Map of study area showing distribution of boreholes**

The Makhi borehole had been under traditional unfenced cattle – post management for many years and it was converted into a ranch in 1980. On the ranch the trial made use of a wagon – wheel layout. A 2340 hectare hexagon was constructed with dividing fences radiating out from the central water hub (Fig. 2.4). Each radiating fence was 2.5 km from the hub to the perimeter fence. The trial incorporated three grazing systems that were replicated twice. These systems were as follows:

System 1.	Continuous grazing – where a paddock was grazed continuously throughout the year.
System 2.	3 – paddock rotational grazing – where a paddock was grazed for one month and rested for two months.
System 3.	9 – paddock rotational grazing – where a paddock was grazed for 4 days and rested for 32 days.

Continuous grazing = 4 & 17
3 – paddock grazing = 1, 2, 3, 14, 15 & 16
9 – paddock grazing = 5 – 13 & 18 -26

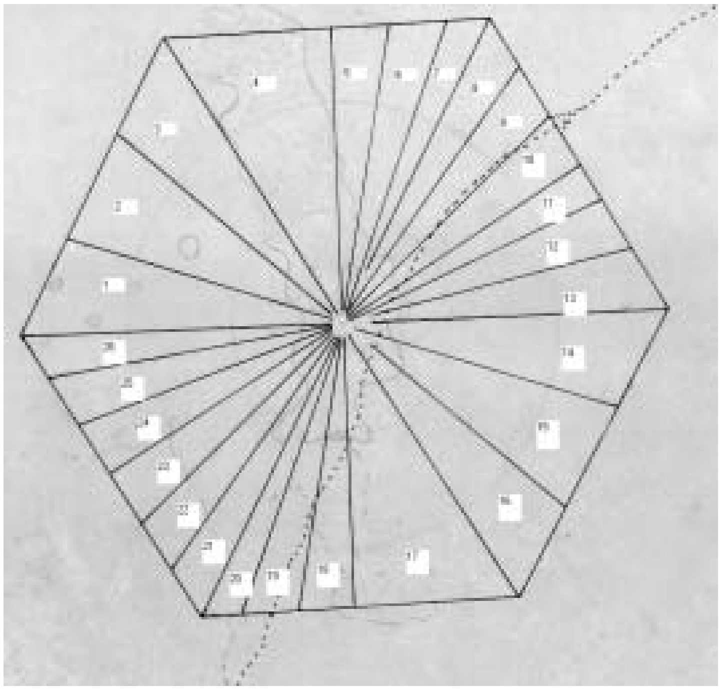

Fig. 2.4 Layout of the Makhi ranch

There were, therefore, a total of 26 paddocks in this trial. Unreplicated non – grazing exclosures in each treatment were used as controls. Vegetation and soil data were collected in 14 paddocks (2,6 and 6 paddocks of the continuous grazing, 3 – paddock grazing system and 9 – paddock grazing system, respectively). The trial was stocked with one and two years old Tswana – type steers at 12ha per livestock unit. Mature steers were replaced annually.

2.3 Livestock units and grazing area

In the free range grazing area, both Motshwagole and Masaane cattle posts were chosen to investigate the influence of livestock concentration around water point on soil and vegetation condition. Data were collected on three transects radiating from each borehole. The standard grazing area in the communal grazing land of the sandveld is 6400 ha per borehole (8 x 8 km). However, old boreholes (drilled before the country attained its independence) may be less than 8 x 8km and in such cases livestock from neighbouring boreholes may overlap their grazing before returning to their cattle – posts. The livestock type utilizing the range around these boreholes include cattle, sheep, goats and a few donkeys.

Numbers of livestock utilizing each borehole was considered to be of great importance to any attempt to relate variation in soil and vegetation variables measured. Table 2.1 shows the borehole name, date of drilling and numbers of livestock units.

Table 2.1 Livestock units and date of drilling each borehole in the study area

Borehole name	Drilling date	Livestock units	Stocking rate (ha / livestock unit)
Makhi	1954	217.44 (since 1980)	11.0
Masaane	1973	547.04 (5 years mean)	unknown*
Motshwagole	1957	379.23 (5 years mean)	unknown

*Animals in the free range grazing area (unfenced). Animals from each water point may overlap their range of grazing making difficult to estimate the stocking rate.

Livestock numbers for both Masaane and Motshwagole Boreholes were obtained from the veterinary office records in at Serowe. These figures were based on counts made by veterinary staff following the vaccination of livestock in the field. Although these statistics may be under – estimates, due to the impossibility of collection and vaccination of all cattle dispersed over the open free range grazing at any one time, they present the most accurate assessment of livestock numbers available. Records for the past five years only for the cattle posts in the free – range grazing could be obtained.

2.4 Plant species occurring in the area

The major herbaceous and woody plant species plus the miscellaneous species class (miscellaneous grasses and forbs) found in the study area are shown in Table 2.2. Grasses in the miscellaneous class included Aristida congesta, Aristida graciliflora, Eragrostis pallens, Pogonanrthria squarrosa, and Melinus repens. Forbs in the miscellaneous class included several families or genera.

Table 2.2 List of herbaceous and woody plant species and miscellaneous species class found in the study area

Code	**Grasses**	**Code**	**Woody plants**
D. aeg	Dactylotinium aegyptiun	A.fle	Acacia fleckii
D. era	Digitaria eriantha	A.ger	Acacia gerrardii
E. leh	Eragrostis lehmanniana	B. alb	Boscia albitrunca
E. rig	Eragrostis rigidior	B. pet	Bauhinia petersiana
E. afr	Eleusine africana	C. gra	Croton gratissimus
M. alb	Megaloprotachne albescens	D. cin	Dichrostachys cinerea
P. max	Panicam maximum	G. fla	Grewia flava
S. pap	Schmidtia pappophoroides	G. ret	Grewia retinervis
S. uni	Stipagrostis uniplumis	M. ser	Mudulea sericea
U. tri	Urochloa trichopus	R. bra	Rhigozum bravispinosum
Miscellaneous grasses		T. ser	Terminalia sericea
Code	**Forbs**	Com	Commiphora pyracantoides
A. thu	Amaranthus thumbergi*i*	O. plu	Ochna plucra
C. bie	Cassia beiscensis	P. afr	Peltophorum africanum
I. dal	Idingofera daleoides	R. ten	Rhus tenunervis
T. ter	Tribulus terrestris	Z. muc	Ziziphus mucronata
Miscellaneous forbs			

Miscellaneous grasses included: A. con = Aristida congesta, A. gra = A. graciliflora, E. pal = Eragrostis pallens, P. pat = Perotis patens, P. squ = Pogonarthria squarrosa, M. rep = Melinis repens

CHAPTER 3

Influence of livestock concentration at water points on the distribution of soil nutrients along the distance from water point

3.1 Introduction

Soils, along with climate, are indicated as the primary agents in plant selection through evolutionary change (Brady 1974; Barbour *et al.* 1980). In general, finer textured soils are reported to have greater porosity than sandy soils (Brady 1974; Siderius 1972). Water moves into and drains out of sandy soils with much greater ease than finer textured soils, which means that sandy soils are more permeable than fine textured soils.

A sandy soil carries less organic matter than finer textured soil. This is probably because of the lower moisture content and greater oxidation occurring in lighter soil (Brady 1974). On the other hand the clay fraction acts as soil nutrient storage and improves the water holding capacity. Clay particles and colloidal organic matter within the soil are negatively charged on their surfaces. Brady (1974) reported that the capacity of these particles to provide the primary soil nutrient storage results from a) the negative charge on the particles and b) their very large surface to volume ratio. Cation exchange capacity is a measure of the number of negatively charged sites on soil particles that attract exchangeable cations, that is, positively charge ions that can be replaced by other such ions in the soil. The factors that strongly influence the cation exchange capacity of a soil are the type of clay content and the humus content.

Typically soils exhibit pH values that range from 4 - 8, although certain soils may have higher or lower values. A pH of less than 6.6 is considered an acid soil. Nutrients are both brought from subsoil by plants and then deposited with litter on the surface. Grasses tend to use more bases, and grasslands often prevent the soil pH dropping (Barbour *et al.* 1980). The effect of soil pH on nutrient availability is of particular importance. The availability of nutrients such as nitrogen and phosphorus and the leacheability, or solubility, of nutrients such as potassium or phosphorus is strongly influenced by soil pH. A pH of 6.5 to 7.5 is best for phosphorus availability, and to most nutrients needed for plant growth.

Plant tissue is the primary source not only of food for the various soil organisms but of organic matter, which is essential for soil formation. Organic matter has been indicated

(Brady 1974) to have a great influence on soil properties such as;

a) soil colour,
b) structure, plasticity and water holding capacity,
c) cation adsorption capacity and
d) the availability of nutrients.

Kalahari sands generally form poorly structured and infertile soils with poor moisture retaining capacity (McKay 1968). The few reconnaissance studies undertaken in Western Kalahari (Bergstrom & Skarpe 1985; DHV 1980), Southern Kalahari (Buckley *et al*. 1967; Leistener 1967; Blair Rain & Yalala 1972) and Eastern Kalahari (Perkins 1991; Siderius 1972), all indicate slight to moderate acidic soils, deficient in all essential plant nutrients, especially phosphorus. These soils have a lower organic carbon content than those in the North (DHV 1980). In general these results match with the environmental history which was dominated by aelion process (Leistener 1967), and a negligible rate of soil formation due to the removal of organic matter by wind and termite activity. Significant silt – clay fractions are generally confined to inter – dune depressions, dry river valleys and pans.

Grazing animals may, however, change the distribution pattern of nutrients. Many of the plant nutrients consumed by grazing animals return to the soil through dung or urine, but not necessarily at the same place where they were eaten. There are areas of concentration around which faecal deposits and urination spots are found. For livestock these areas are around water points, bedding grounds and areas of level topography or where preferred plants are growing (Lange 1969; Hyder 1969). Hilder (1966) found that about one third of sheep faeces were deposited on only five to seven percent of the pasture. This material contains large amounts of nitrogen, phosphorus, etc. Estimates vary, but it has been estimated that 80 – 95% of nutrients eaten by range animals are excreted and returned in soil.

Knowledge of soil characteristics is essential to the range manager. This is because soil is the primary factor determining the potential for forage production of an area within a given climate (Barbour *et al*. 1980). The objective of this research was to determine the influence of livestock concentration at water points on the distribution of soil nutrients through dung and urine deposits along the transect from the water point.

3.2 Methods and material

Nutrient content of the soil was determined from soil samples taken from both the traditional cattle posts of the free range grazing area and from the livestock controlled condition (ranch). In the communal grazing area, two cattle posts were chosen for investigation. Soil samples were taken at nine locations along a transect radiating from the water point. Samples were taken at distances of 0, 150, 300, 500, 700, 1000, 1500, 2500 and 4000 metres away from the borehole. These locations were replicated three times at each cattle post. The zero (0) location is near the water trough where animals concentrate or rest after drinking water. On the traditional cattle posts conditions, livestock kraals or abandoned old kraals are found within the vicinity of the cattle post, which makes the area look more like a sacrifice area.

In the livestock controlled condition (ranch), soil samples were also taken along three transects for each grazing system (see treatment design). The treatments were replicated twice. Samples were taken at distances of 0, 150, 300, 600, 950, 1500, and 2450 metres away from the water point.

Samples were taken from the upper 10cm. Three individual samples from each location were collected and bulked together. Each soil was analysed for pH, phosphorus, calcium, magnesium, sodium, cation exchange capacity, organic carbon and some samples were also analysed for particle size.

This investigation was conducted to provide base information for further research. As such, analyses using the general linear model was used for all variables (pH, phosphorus, calcium, magnesium, potassium, sodium and organic carbon). The protected Fisher's Least Significant Difference was used to separate the means of the main effects (Steel & Torrie 1980)

3.3 RESULTS

3.3.1 Soil particle size

Average particle size in soils for both the Makhi ranch and adjacent free range grazing area revealed that fine sand or very fine sand composed of 51.59 and 15.18% respectively (Table 1). Medium sand was 24.45% while coarse sand was 5.45% and silt counted for only 3.11%. The soil did not contain any clay.

Table 3.1. Particle size in soil in the Makhi area

Very fine sand	15.18%
Fine sand	51.59%
Medium sand	24.45%
Coarse sand	5.45%
Very coarse sand	0.03%
Fine silt	3.11%
Silt	0.13%
Clay	0

3.3.2 Variation in soil nutrients along the transect from water in controlled grazing conditions – Makhi Ranch

Table 3.2 illustrates the variation of soil nutrient status measured along transects at increasing distance away from the water point at Makhi ranch. The results reveal the general infertility and acidic nature of the Kalahari sands. Even in tabulated form, the results illustrate impact of livestock around the water point on soil nutrient status. This is, however, localised and generally confined to the first 0 - 150m zone. Concentration of soil nutrients was higher ($P < 0.05$) at the first location (0m) than subsequent locations. Strikingly, values from the table illustrate how large impacts occur mainly at the first location and to a lesser extent out to 150m zone. Beyond 300m soil nutrients decrease to an almost constant level up to the furthest location of what may be considered the background nutrient status to be found in the Kalahari sandveld. All the variables measured appeared to be responsive to the variation at the 0 - 150m from the water point. All soil nutrients appeared to be consistently low at all but the 0 and 150m distance, where the input of dung and urine typically resulted in high values.

Dung, with a large number of cations or phosphates locked up in the organic matter, clearly had a profound influence on soil nutrients.

Table 3.2. Variation in soil nutrient status along transects away from the water point in controlled grazing conditions.

					Exchangeable Cations (c mo+/kg)			
Dist. (m)	pH ($CaCl_2$)	P (ppm)	OC (%)	:CEC (c mo+/kg)	Mg	K	Ca	Na
0	6.34^a	41.59^a	0.68^a	6.09^a	1.23^a	1.41^a	2.80^a	0.38^a
150	4.59^b	20.21^a	0.20^{bc}	5.15^a	0.84^{ab}	0.35^b	1.55^b	0.14^a
300	4.51^b	13.42^b	0.24^b	3.33^b	0.70^b	0.29^b	1.31^b	0.09^a
600	4.34^b	11.29^b	0.18^c	2.75^b	0.57^b	0.17^c	1.06^b	0.11^a
950	4.24^{bc}	11.08^b	0.17^c	2.46^b	0.44^b	0.17^c	1.04^b	0.11^a
1500	4.34^b	9.01^c	0.21^{bc}	2.80^b	0.54^b	0.18^c	1.01^b	0.11^a
2450	4.07^{bc}	8.50^c	0.20^{bc}	2.63^b	0.43^b	0.15^c	0.66^c	0.09^a

Means in each column followed by the same superscript are not significantly ($P > 0.05$) different between distances

Key to soil nutrients: pH = Acidity, P = phosphate, OC = organic carbon, Ca = calcium, Mg = magnesium, K = potassium, Na = sodium and CEC = cation exchange capacity and Dist = distance.

3.3.3 Variation of soil nutrients between the grazing systems at Makhi ranch

Mean variation in soil nutrient status between the grazing treatments at Makhi ranch is illustrated in Table 3.3. The continuous grazing system tended to be higher ($P < 0.05$) in pH, phosphorus, calcium and cation exchange capacity than the other grazing systems while sodium, magnesium, potassium and organic carbon showed no differences between the treatments. The 3 – paddock, 9 – paddock and non - grazing systems showed no difference in soil nutrient status. However, the magnitude of difference for all minerals between the treatments was very small.

Table 3.3. Mean variation in soil nutrients at each grazing system in controlled conditions - Makhi ranch

					Exchangeable Cations_(c mo+/kg)			
Treatment	pH ($CaCl_2$)	P (ppm)	OC (%)	CEC (c mo+/kg)	Mg	K	Ca	Na
1- Pd grazing	4.69^{a}	17.25^{a}	0.28^{a}	3.81^{a}	0.69^{a}	0.33^{a}	1.48^{a}	0.13^{a}
3 - Pd grazing	4.44^{b}	11.61^{a}	0.24^{a}	3.08^{a}	0.56^{a}	0.31^{a}	1.01^{c}	0.15^{a}
9 - Pd grazing	4.54^{ab}	14.91^{a}	0.28^{a}	2.96^{b}	0.65^{a}	0.33^{a}	1.27^{b}	0.11^{a}
Non - grazing	4.52^{ab}	13.66^{a}	0.24^{a}	3.70^{a}	0.63^{a}	0.29^{a}	1.18^{b}	0.12^{a}
Mean	4.52	14.59	0.27	3.28	0.66	0.32	1.24	0.13

Means in each column followed by the same superscript are not significantly (P>0.05) different between distances

3.3.4 Variation in soil nutrients in free – range grazing

Variations in the soil nutrient status along the transect away from the water point at Masaane and Motshwagole cattle posts on the free – range grazing are illustrated in Tables 3.4 and 3.5. The trend of soil nutrient along the transect away from the water point is the same for the two cattle posts and also follow that found on the Makhi grazing trial, namely that of decreasing nutrient status with increasing distance from the water point. The two cattle posts appeared to have the same level of all soil nutrients except for phosphorus and pH despite the borehole age or the stocking rate practiced at the borehole (Chapter 2). Phosphorus levels were marginally higher at the Masaane cattle post than at the Motshwagole cattle post while pH was higher at the Motshwagole cattle post. Phosphorus and cation exchange capacity were the most variable attributes along the transect from water points for both cattle posts.

Table 3.4. Mean soil nutrient status along the transect from the water point at Motshwagole cattle post.

					Exchangeable Cations (c mo+/kg)			
Dist. (m)	pH (CaCl$_2$)	P (ppm)	OC (%)	CEC (c mo+/kg)	Mg	K	Ca	Na
0	6.63^{a}	21.89^{a}	0.36^{a}	5.20^{a}	1.16^{a}	0.60^{a}	2.58^{a}	0.21^{a}
150	5.91^{a}	15.01^{b}	0.33^{a}	3.89^{b}	0.84^{b}	0.31^{b}	2.30^{a}	0.08^{a}
300	5.74^{ab}	13.69^{bc}	0.22^{b}	3.24^{bc}	0.62^{bc}	0.16^{b}	1.70^{b}	0.08^{a}
500	5.08^{bc}	12.38^{bc}	0.28^{ab}	3.43^{bc}	0.77^{b}	0.22^{b}	1.22^{b}	0.12^{a}
700	5.13^{bc}	9.05^{c}	0 $.30^{ab}$	3.05^{c}	0.87^{b}	0.20^{b}	0.94^{bc}	0.11^{a}
1000	5.21^{bc}	9.51^{c}	0.27^{ab}	2.64^{c}	0.68^{bc}	0.20^{b}	0.60^{bc}	0.08^{a}
1500	5.16^{bc}	10.32^{bc}	0.22^{b}	3.13^{c}	0.62^{bc}	0.20^{b}	0.57^{c}	0.09^{a}
2500	4.42^{c}	8.14^{cd}	0.24^{b}	2.85^{c}	0.46^{c}	0.17^{b}	0.64^{bc}	0.08^{a}
4000	4.24^{c}	7.31^{d}	0.23^{b}	2.44^{c}	0.38^{c}	0.13^{b}	0.48^{c}	0.11^{a}
Mean	.5.28	14.29	0.20	2.05	0.71	0.23	1.17	0.16

Means in each column followed by the same superscript are not significantly (P> 0.05) different between distances

Table 3.5. Mean soil nutrient status along the transect away from the water point at Masaane cattle post.

					Exchangeable Cations (c mo+/kg)			
Dist. (m)	pH (CaCl$_2$)	P (ppm)	OC (%)	CEC (c mo+/kg)	Mg	K	Ca	Na
0	5.84^{a}	21.64^{a}	0.28^{a}	3.76^{a}	0.73^{a}	0.42^{a}	2.36^{a}	0.28^{a}
150	5.78^{a}	15.99^{ab}	0.28^{a}	3.25^{a}	0.59^{a}	0.30^{ab}	1.35^{ab}	0.21^{a}
300	5.26^{ab}	14.41^{b}	0.21^{b}	3.17^{a}	0.60^{a}	0.20^{b}	1.30^{b}	0.13^{a}
500	4.47^{b}	12.74^{abc}	0.26^{ab}	2.13^{b}	0.55^{ab}	0.18^{b}	0.96^{b}	0.13^{a}
700	4.21^{b}	12.25^{c}	0.16^{b}	2.07^{b}	0.51^{b}	0.18^{b}	0.89^{b}	0.14^{a}
1000	5.02^{ab}	12.34^{c}	0.16^{b}	1.36^{b}	0.54^{b}	0.20^{b}	0.68^{b}	0.15^{a}
1500	4.69^{b}	12.17^{c}	0.18^{b}	1.54^{b}	0.59^{ab}	0.19^{b}	0.96^{b}	0.15^{a}
2500	4.44^{b}	12.22^{c}	0.17^{b}	1.57^{b}	0.39^{b}	0.16^{b}	0.67^{b}	0.15^{a}
4000	4.47^{b}	12.32^{c}	0.17^{b}	1.44^{b}	0.48^{b}	0.18^{b}	0.67^{b}	0.15^{a}
Mean	4.95	16.03	0.27	3.20	0.67	0.33	1.54	0.16

Means in each column followed by the same superscript are not significantly (P> 0.05) different between distances

Table 3.6 presents a comparison of soil nutrient status measured at two cattle posts in the free range grazing studied. Results between the cattle posts reveal a higher ($P < 0.05$) content of organic carbon, cation exchange capacity and phosphorus at Masaane cattle post. The high livestock units carried at the latter cattle post (Chapter 2) might probably account for the higher soil nutrient measured. The other soil nutrients were similar at both sites. Phosphorus and cation exchange capacity were the most variable soil nutrients observed between the cattle posts. However, the values at the Motshwagole cattle post tended to be lower than the mean of the two sites.

Table 3.6 Mean variation in soil nutrients at two cattle posts in the free -range grazing conditions.

Cattlle post	pH (CaCl$_2$)	P (ppm)	OC (%)	CEC (c mo+/kg)	Exhangeable Cations (c mo+/kg) Mg	K	Ca	Na
Motshwagole	5.28^a	14.29^b	0.20^b	2.05^b	0.71^a	0.23^a	1.17^a	0.16^a
Masaane	4.95^a	16.03^a	0.27^a	3.20^a	0.67^a	0.33^a	1.54^a	0.16^a
Mean	4.94	14.04	0.24	3.07	0.66	0.27	1.28	0.16

Means in each column followed by the same superscript are no significantly ($P > 0.05$) different between distances

3.4 DISCUSSION

Over large areas of the Kalahari soils are deficient in soil nutrients making those localities that are rich in nutrients important to grazing animals. The enrichment of soil, occurring within the immediate vicinity of the water points is due, theoretically to the input of dung and urine coincident with the daily animal concentration around the water point and is the result of the centripetal movement of nutrients from the area over which animal graze. These data are concurrent with those found elsewhere (Tolsma *et al.* 1987a; Ernst & Tolsma 1989; Perkins 1991). However, Perkins (1991) reported a zone of 25 – 50m having more concentrated nutrients compared to the 0 – 150m zones reported in this study. The variation might have been attributed by the borehole age or stocking rate fluctuation experienced on each borehole. However, reduction in livestock units at a particular borehole is likely to weaken the link between herbivore impact and length of exploitation. A large amount of cations or phosphates remain locked up in the organic matter, and clearly has a profound influence on soil nutrients. As a result, phosphorus and to a lesser extent cation exchange capacity showed the higher variation with distance from water point and between cattle posts.

There were no differences in soil nutrient status between the two cattle posts of the free – range grazing except for organic carbon, cation exchange capacity and phosphorus. However, the Masaane cattle post tended to have higher values in nutrient content than the Motshwagole. These differences can be interpreted in terms of animal population at each cattle post or the time the borehole had existed (Chapter 2). Livestock units were higher at Masaane cattle post and might have influenced high soil nutrient status despite the late date of drilling the borehole. Makhi and Motshwagole boreholes were drilled at an earlier date but tended to be lower in soil nutrient status probably due to lower stocking rates. High soil nutrient status observed at the continuous grazing system might have been contributed by the landform within the ranch as one replication of the continuous system had more bottomland grey soil colour and was characterized by bigger trees of Acacia gerradii.

3.5 CONCLUSION

The generally homogeneous nature of the Kalahari soils is notable in terms of the silt - clay content and a mean sand grain size in the fine sand fraction along all the transects from water points and confirms the extensive literature on characteristic of the Kalahari sandveld.

Chemical analyses revealed the low background fertility of the Kalahari sand with significant variation only being registered around the water points. The impact of dung and urine on soil chemistry is localised to the area immediately around the water point (0 –150m). Phosphorus and to a lesser extent cation exchange capacity were the most responsive attributes to variation along the transect from the water point.

However, phosphorus and cations in particular, give a clear proof to the general infertility of the Kalahari sands with low values at and beyond 300m from the water point.

High stocking rates applied at any particular borehole had an influence on the level of the soil nutrient status. Thus an early step in any management plans directed at conserving the soil resource should aim to ensure a more even spread of nutrient recycling. In this respect it is also important to ensure that access to water should not be a limiting factor.

CHAPTER 4

Influence of livestock grazing on the distribution and production of woody plants within a piosphere

4.1 Introduction

Woody plants are an important component of semi - arid rangelands throughout the world. These plants are generally well adapted to persist and spread in these regions under natural and man- induced perturbations including overgrazing and drought. The ecological status of woody plants in semi – arid grass / shrub rangeland has been outlined by Pratchatt 1978, Teague *et al.* 1981, Walker *et al.* 1981; Stuart – Hill *et al.* 1983; Stuart Hill 1985; Smit 1989 and Smit & Rethman 2000. Seeds of many shrub species are capable of being passed through the digestive tract of animals intact, with improved chances of germination and survival when deposited in faeces. In many cases the shrub component provides palatable and nutritious forage to animals, but more often the woody species become undesirable from a livestock management point of view because of excessive densities.

The measurement of browse species production presents additional problems, not encountered with the herbaceous species. Some of the basic problems which make practical sampling difficult, as indicated by Rutherford (1979), are that browse: a) is often not easily distinguishable in a uniform way in the field b) it consist of a very large number of small discrete parts c) its three dimensional distribution on a plant is often highly varied and d) spatial distribution of woody plants can be highly heterogeneous. Browse species are often large, have indeterminate growth, and are difficult to harvest (Cook & Stubbendieck, 1986). Rutherford (1979) mentioned that techniques specifically aimed at the determination of browse production rates were not as standardized as those for herbaceous vegetation production. Several scientists have developed regression equations expressing the relationship between twig length and diameter with twig weight (Lyon 1970; Halls & Harlow 1971; Dean *et al.* 1981). While these methods provide a means of estimating twig weight, they do not provide an estimate of the browse available per unit area (Cook & Stubbendieck

1986). It would be necessary to extrapolate these data to an individual plant and to an area basis. Canopy volumes of individual plant species on an area basis have been used to predict browse availability (Teague *et al*. 1981; Smit 1989; Smit 1996) as have indices derived from canopy and trunk diameters (Hobson & de Ridder 1991). The indirect measure of canopy volumes appears more practical than the twig lengths and diameter measurements, or hand harvest of leaves to determine the production of browse, as applied by Aucamp *et al*. (1984)

Monitoring of woody plants aims at measuring the number of plants by species, plant size and vertical distribution of live canopy. These parameters are used to determine the potential productivity of available browsable material and competitive influence of the woody plants on grass productivity (Teague *et al*. 1981; Aucamp *et al*. 1983; Stuart - Hill *et al*. 1987; Smit 1989). High bush densities cause a significant reduction in the grazing capacity of the range. Aucamp *et al*. (1983) found that at densities of Acacia karroo of 1000, 1500 and 2000 tree equivalents per hectare, the grazing capacity of the range can be expected to be 90, 67 and 32% of its potential, respectively. Du Toit (1968; 1972) indicated that the annual production of grass material was reduced by approximately 40 - 50 percent in range encroached with bush.

Because of the complexity of most plant communities, no single criterion will usually serve as the basis for the determination of range rating of any forage type or site (Humphrey 1962). Many factors affect plant production or growth. Species composition and plant density have been used extensively as criterion of forage site condition. Plant composition is a relatively stable and reliable criterion in perennial range, although it is a less sensitive in range condition (Fourie *et al.* 1984). Density data are commonly used to describe tree communities, but are often inadequate to quantify biomass accurately.

Woody plant composition determines, to some extent, those animal species which can best utilize the vegetation since each species shows preference for certain kinds and parts of plants (Kelly (1977). In some cases the shrub component provides palatable and nutritious forage to animals but the woody species often becomes undesirable from a livestock management point of view, because of their excessive density. The conversion of savanna to mature thickets generally reduces herbaceous forage production and livestock accessibility to the forage

(Teague *et al* 1983; Stuart-Hill *et al.* (1983). The objective of this study was directed towards answering questions regarding browse production and density, as influenced by livestock concentrations and grazing around water points.

4.2 Material and Methods

Available browse was determined by measuring the spatial volume of the tree canopies and the relationship to the true leave volume and true tree leaf mass (Smit 1989). This procedure follows three quantitative descriptive units which describe the status of the woody plant community in terms of potential water use, value of tree as a food for browsers and sub-habitat suitable for grass - tree associations. These descriptive units were described as follows:

a) Browse Tree Equivalent (BTE) - defined as the leaf mass equivalent of a 1.5m single stemmed tree.

b) Evapotranspiration Tree Equivalent (ETTE) - defined as a leaf volume equivalent of a 1.5m single stemmed tree.

(c) Canopied sub - habitat Index (CSI) - defined as the canopy spread area of those trees in the transect under which associated grasses, such as Panicum maximum, are likely to occur, expressed as a percentage of total transect area.

A belt transect of 5m x 50m was laid out within the 50m x 50m plot (where herbaceous biomass was studied) at each location along the main transect. On the ranch (fenced / controlled) plots were located at 0, 600, 1200 and 2400m from the water point. On the traditional cattle posts (uncontrolled / free range grazing) plots were located at 0, 500, 1500 and 4000m from the water point. The spatial volume of each separate tree canopy was determined by measurements taken within each belt transect. Measurements included: a) height of a tree, b) height of maximum canopy diameter, c) height of first leaves or potential bearing leaf stems, d) maximum canopy diameter and diameter at 1.5m, and e) base diameter of foliage at height c.

4.3 Statistical Analysis

A biomass estimate from the canopy volume model compiled by Professor Smit (Smit 1996) from University of Orange Free State was used to analyse the woody plant data. The model estimates are based on the relationship between spatial canopy volume of the tree's leaf volume and true leaf mass. The model also calculates single tree density data on a species basis and canopy spread index. The technique follows a regression analysis using standard statistical least squares regression analysis. It incorporates a number of regression equations for specific tree species, as well as a number of general regression equations. General regression equations are used for tree species for which specific regression equations do not presently exist. These values were also calculated per hectare. Only two plant species recorded at Makhi area were incorporated in the general regression model. The estimated leaf volume and leaf mass were calculated for each tree individually by substituting the tree's spatial volumes into a regression equations obtained from harvested leaves. The regression equation simulates the relationship between spatial tree volume and actual leaf mass. Two equations, one for the leaf dry weight and one for the leaf volume were derived for each plant species (Smit 1996). Smit (1996) indicated that by calculating the canopy volume below any specified maximum browse height, an estimate of browse potential within the reach of a browser is possible.

4.4 RESULTS

4.4.1 Density of woody plants in controlled grazing conditions – Makhi ranch

Variations in woody plant density (plant / ha), leaf volumes and subdivision of canopy spread index height strata of individual species for each distance along the transect from water point under controlled grazing conditions (Makhi ranch) is illustrated in Table 4.1. The mean densities were 1502, 1673, 1456 and 1575 plants / ha at 0, 600, 1200 and 2400 metres from water, respectively. Plant density was highest at 600m away from the water point and was lower at 1200m and in the immediate vicinity of the water point.

Sixteen plant species were recorded in the immediate vicinity of the water point and these increased to eighteen at the furthest distance from water. Woody vegetation in the Makhi area was dominated by low shrubs, which included D. cinerea, G. flava, B. petersiana and M. sericea, and taller trees including B. albitrunca P. africanum and T. sericea. The density of A. gerradii increased with the decreasing distance from the water point (Table 4.1). Distribution of individual plant species along the transect radiating from the water point showed that D. cinerea, and G. flava were prominent in the vicinity of the water point (first distance from the water point). Although D. cinerea seemed to be well distributed throughout the area, its density was more pronounced at the 600m distance away from the water point. Bauhinia petersiana did not occur in the vicinity immediate to the water point. Grewia flava, B. albitrunca and D. lycioides occurred in high densities at the first distance from water while that of C. gratissimus, B. petersiana and T. sericea followed the opposite trend. High densities of M. sericea occurred at two mid – points of the transect from the water point.

Table 4.1. Individual plant species density (P/ha), leaf volume (LVol cm^3) and subdivision of canopy spread index (CSI %) height strata for each distance from the water point in controlled grazing conditions

Plant spp	**Distance from water (m)**															
	0				600				1200				2400			
	P / ha	LVol.	CSI2	CSI4	P / ha	LVol.	CSI2	SCI4	P / ha	LVol.	CSI2	SCI4	P / ha	LVol.	CSI2	CSI4
A. flei					40	74	0 .7		73	154	2.3		13	4		
A. ger	267	1792	31.5	19.6	160	442	6.2	1.8	13	104	1.8					
B. alb	147	139	3.2		120	85	1.4		63	24	0.2		73	66	1.2	
B. pet					33	2.0			233	27			440	56		
Com	7	3			33	1.5			13	4			7	4		
C. gra	13	4			133	26			167	48			167	37		
D. cin	207	280	3.4		460	257	0.9		333	229	0.7		280	362	5.1	
D. lyc	120	4			7	2			13	1.0			27	3		
E. rhy	27	12	0.1		40	6			20	3.0			20	18		
G. bic	13	19	0.3		20	3							7			
G. fla	340	177	1.0		207	203			93	76			47	106	1.2	
G. ret	7	3	1.7		40	55	0.4		40	60	0.5		27	17	.2	
M. ser	120	13			173	18			167	27			73	10		
M. sen	7	5							7	3						
O. pul					7	1.1			13	2			53	2		
P. afr	7	6			27	47			67	450	8.9	4.0	47	147	2.7	1.8
T. ser					53	50			47	23	3		67	324	5.5	0.6
R. bav	120	7.4	1.5		67	15			80	37			187	97	0 .6	
R. ten	80	107	1.7		40	11			7	1.0			33	51		
Z. muc	20	20	.6		13	9			7	8.0			7	93	2.7	
Total	**1502**	**2590**	**45**	**19.6**	**1673**	**1319**	**9.6**	**1.8**	**1456**	**1291**	**17.4**	**4.0**	**1575**	**1397**	**19.2**	**2.4**

CSI2 = canopy spread index based on trees with minimum height of 2m. CSI4 = canopy spread index based on trees with minimum height of 4m

Key to species: A. fle = Acacia fleckii, A. ger = A. gerrardii, B. alb = Boscia albitrunca, B. pet = Bauhinia petersiana, B. foe = B. foetida, Com = Commiphora spp, C. gra = Croton gratissimus, D.cin = Dichrostachys cinerea, D. lys = Diospyros lycioides, E. rhy = Erhytia rigidior; G.bic = Grewia bicolar, G. fla = G. flava, G. ret = G. retinervis, M. sen = Maytinus senegalensis, M. ser = Mudulia sericea, O. pul = Ochna pulchra, P. afr = Peltophorum africanum, T. ser = Terminelia sericea, R.bra = Rhigozum revispinosum, R. ten = Rhus tenunervis, X. ame = Ximenia americana, and Z. muc = Ziziphus mucronata

4.4.2 Leaf volume and canopy spread index in controlled grazing conditions

Table 4.1 presents the estimates of leaf volumes and subdivision of canopy spread index distribution for each distance along the transect from water. Despite the low plant density occurring in the immediate vicinity of the water point, leaf volume was higher (2590cm^3) at this point than at other distances, which tended not to be much different. Leaf volume was dominated by A. gerrardii in the first two distances from water while G. flava and D. cinerea were in the second order of dominance. High leaf volumes for P. africanum and T. sericea occurred towards the end of the transect from water.

Canopy spread index provided by trees in both height strata (between $\geq$2.0 - $\leq$4.0m and >4.0m) were largest (45% and 19.6%, respectively) at the first distance from water (Table 4.1). In this context, canopy spread index is defined as canopy spread area of those trees in the transect under which associated grasses like P. maximum are most likely to occur, expressed as percentage of the total transect (Smit 1996). Acacia gerrardii and P. africanum were the only species that provided canopy spread index above 4.0m height stratum. Canopy spread index of P. africanum in height stratum above 4.0m, occurred at 1800 to 2400m from water, covering an area of 4% and 1.8%, respectively. Canopy spread index of D. cinerea in height stratum between $\geq$2.0 - $\leq$4.0m was found at 2400m point from the water point. Terminalia sericea provided a canopy spread index of 5.5% in the height stratum above 2m at the furthest distance from the water. The impact of livestock grazing probably did not suppress the height of these plants, especially D. cinerea at the furthest distance from the water.

4.4.3 Leaf dry mass in controlled grazing conditions

Estimates of leaf dry mass per hectare, for each distance along the transect from water, with subdivision into specified strata are presented in Fig. 4.1. Total leaf dry mass was 1226, 567, 572 and 579 kg/ha at distances 0, 600, 1200, and 2400m from water point, respectively. In the immediate vicinity of the water point more than twice the leaf mass was recorded than at other distances. Most of the leaf dry mass at the first point was distributed between the 2 – 4 m height strata. However, with the exception of the first distance from water, the height stratum below 1.5m contributed greater leaf dry mass than the other two strata above 1.5m.

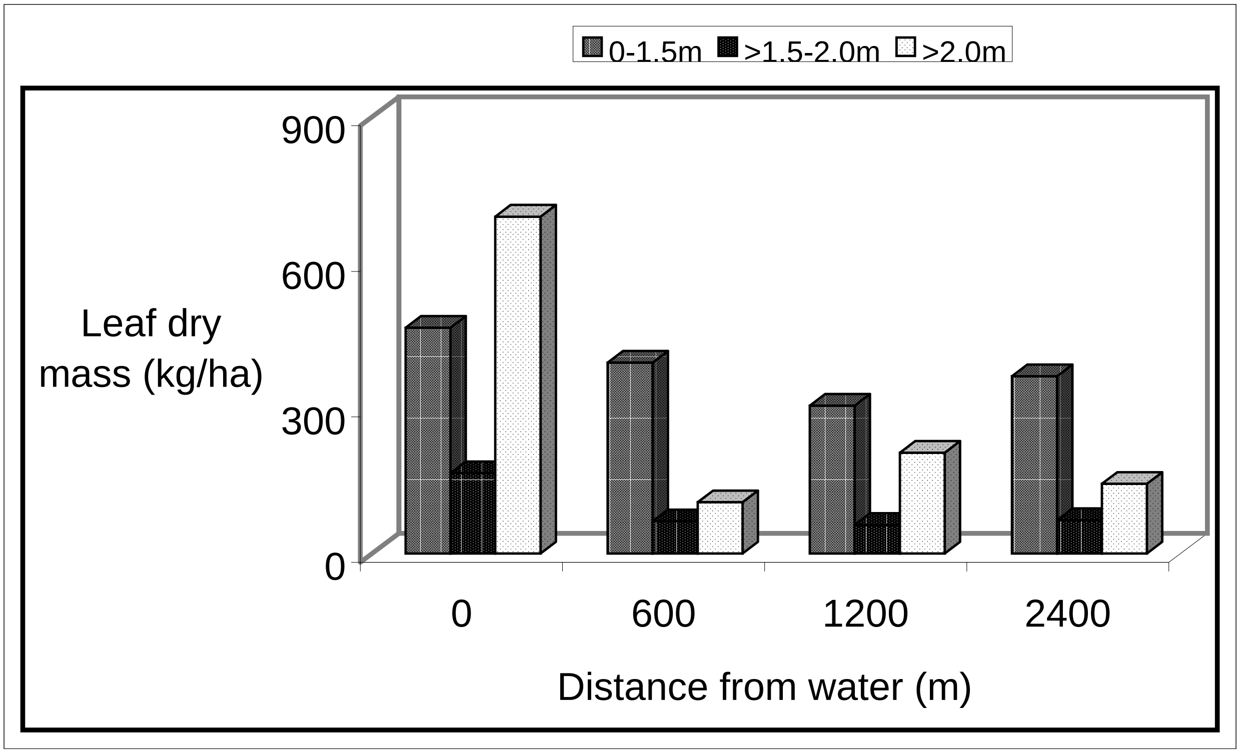

Fig. 4.1. Estimates of total leaf dry mass (kg/ha) at peak biomass of woody plants with subdivision into height strata for each distance from water at Makhi ranch

Total leaf dry mass at Makhi ranch was dominated by A. gerrardii, A. fleckii, D. cinerea and G. flava (Fig. 4.2). Most of the leaf dry mass was distributed below the 2m height strata and was largely contributed by D. cinerea and G. flava, while above the 2m height strata the major contributors were A. gerrardii, A. fleckii, T. sericea and P. africanum. Plant species such as B. petersiana, M. sericea, C. gratissmus and R.. tenuinervis had their leaf mass distributed below 1.5m.

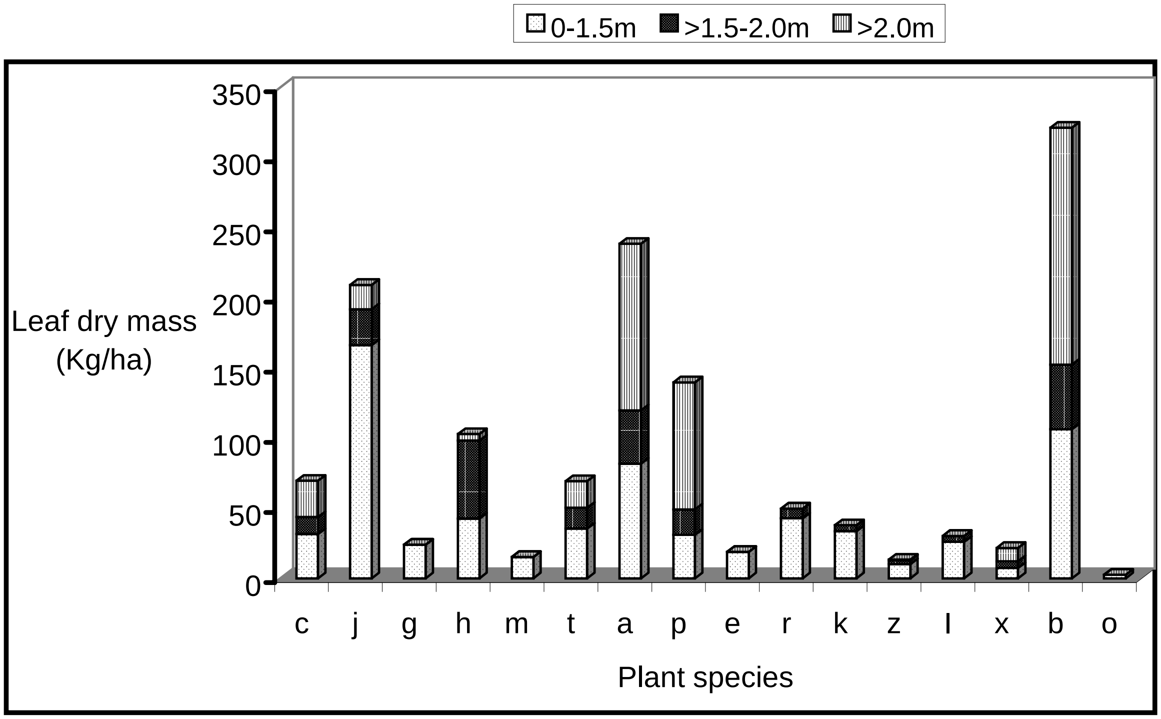

Fig. 4.2. Estimates of leaf dry mass (kg/ha) at peak biomass with subdivision into height strata of individual woody plant species in controlled grazing conditions

Key to species: a = Acacia fleckii, b = Acacia gerrardii, c = Boscia albitrunca, d = Boscia foetida, e = Bauhinia petersiana, f = Commiphora pyracanthoides, g = Croton gratissimus, h = Grewia flava, I = Grewia retinervis, j = Dichrostachys cineria, k = Rhus tenuinervis, m = Mudulea sericea, o = Ochna pulchra, p = Peltophorum africanum, r = Rhigozum brevispinosum, t = Terminalia sericea, x = Ximenia americana and z = Ziziphus mucronata.

4.4.4 Density of woody plants at Masaane cattle post – free range grazing

The density of woody plants at the Masaane cattle post which, is located in the free – range grazing area, was 1920 plants / ha in the vicinity of the water point and this thinned out to 1600 plants / ha at 4000m from the water point (Table 4.2). Six plant species were encountered in the vicinity of the water point while species richness increased to thirteen plant species at 4000m from the water point. The first distance was heavily populated with G. flava (1760 plants/ha) and the density of this species decreased with the increasing distance from water. In contrast, the density of D. cinerea was 380 plants/ha at 4000m point while only 20 plants/ha occurred at first distance from the water point, wile at Makhi ranch, density of this species was highest at the mid – points from water. Croton gratissimus and B. petersiana were not found near the water point but became prominent at the 500m point and beyond, where scattered populations of T. sericea were also found. Unlike at the Makhi ranch, density of B. albitrunca was lower at the first distance and remained constant for the subsequent distances (Table 4.2).

Table 4.2. Individual plant species density (P/ha), leaf volume (LVol cm^3) and subdivision of canopy spread index (CSI %) height strata along the distance from water point at Masaane cattle post.

Plant Species	**Distance from water (m)**															
	0				500				1500				4000			
	P / ha	LVol.	CSI2	CSI4	P / ha	LVol.	CSI2	CSI4	P / ha	LVol.	CSI2	CSI4	P / ha	LVol.	CSI2	CSI4
A. flei	20	11			20	57	1.0									
A.ger									20	3.5						
B. alb	20	6			80	145	3.2		80	253	4.2	4.1	80	239	5.5	
B. pet					140	12			20	3			200	10		
Com					40	17	0.8						220	121		
C. gra					220	182	1.5		800	209			260	136		
D. cin	20				100	78			80	43			380	202	1.0	
G. fla	1760	2058	2.7		320	479	0.6		80	182	2.2		220	201		
G. ret					180	45			1120	188			20	42		
M. ser	20	3											20	2		
M. sen													20	1		
O. pul					20	1							80	20		
P. afr					60	450	7.1	3.5								
T. ser					60	45	0.8		80	253	4.9		80	71		
R. bra	40	17											20	1		
X. ame													20	2		
Totals	**1920**	**2195**	**2.7**	**-**	**1840**	**1563**	**15**	**3.5**	**1700**	**1105**	**12.7**	**4.1**	**1600**	**045**	**6.7**	**-**

CSI2 = canopy spread index based on trees with minimum height of 2m. CSI2 = canopy spread index based on trees with minimum height of 4m

Key to species: A. fle = Acacia fleckii, A. ger = A. gerrardii, B. alb = Boscia albitrunca, B. pet = Bauhinia petersiana, B. foe = B. foetida, Com = commiphora spp, C. gra = Croton gratissimus, D.cin = Dichrostachys cinerea, D. lys = Diospyros lycioides, E. rhy = Erhytia rigidior; G.bic = Grewia bicolar, G. fla = G. flava, G. ret = G. retinervis, M. sen = Maytinus senegalensis, M. ser = Mudulia sericea, O. pul = Ochna pulchra, P. afr = Peltophorum africanum, T. ser = Terminelia sericea, R.bra = Rhigozum brevispinosum, R. ten = Rhus tenunervis, X. ame = Ximenia americana, and Z. muc = Ziziphus mucronata

4.4.5 Leaf volume and canopy spread index at Masaane cattle post – free range grazing

Estimates of leaf volume and subdivision of canopy spread index for each distance from the water point of individual plant species at the Masaane cattle post are presented in Table 4.2. Leaf volume was 2195, 1563, 1105 and 1045 cm^3 at distances 0, 500, 1500 and 4000m from the water, respectively. Leaf volume decreased with the increase in distance from water. Most of the leaf volume across the transects was dominated by G. flava, B. albitrunca and to a lesser extent by T. sericea and C. gratissimus. Grewia flava contributed most of the leaf volume at the first distance from the water point while the leaf volume of B. albitrunca tended to increase with the increase in distance from water.

Canopy spread index from trees between ≥2.0 - ≤4.0m height stratum was 2.7, 15, 12.7 and 6.7% at distances 0, 500, 1500 and 4000m from water, respectively (Table 4.2). Larger areas were covered at 500 and 1500m points than the first or last distances. Canopy spread index provided by trees higher than 4.0m stratum was 3.5% and 4.1% at 500 and 1500m points from the water, respectively. Unlike at the Makhi ranch, trees of greater than 4m were non – existent at the first and last distances from water point. Trees contributing to the canopy spread index, at stratum above 4m, included T. sericea and B. albitrunca. Like the Makhi ranch, canopy spread index of D. cinerea, at height stratum between ≥2.0 - ≤4.0m, occurred at 4000m from the water point but the area covered was very small (1%). Livestock browsing was the probable cause of the suppression of D. cinerea at distances less than 4000m. Judging from the small percentage of canopy spread index from trees above 2.0m height strata found along the transect from water, this vegetation type might be classified as a shrub savannah.

4.4.6 Leaf dry mass at Masaane cattle post – free range grazing

Estimates of leaf dry mass per hectare for each distance along the transect from water, with subdivision into specified height strata are presented in Fig. 4.3. Total leaf dry mass at Masaane cattle post was 835, 610, 458 and 436 kg/ha at distances 0, 500, 1500 and 4000m from water point, respectively. Total leaf mass thus tended to decrease with the increase in distance from water point. Leaf dry mass was almost equal at the last two distances from water. Most of the leaf dry mass was distributed below 1.5m height strata. As at the Makhi ranch, the greatest leaf mass occurred at the first distance from water. Leaf mass above 1.5m height strata was very low at the first and last distances.

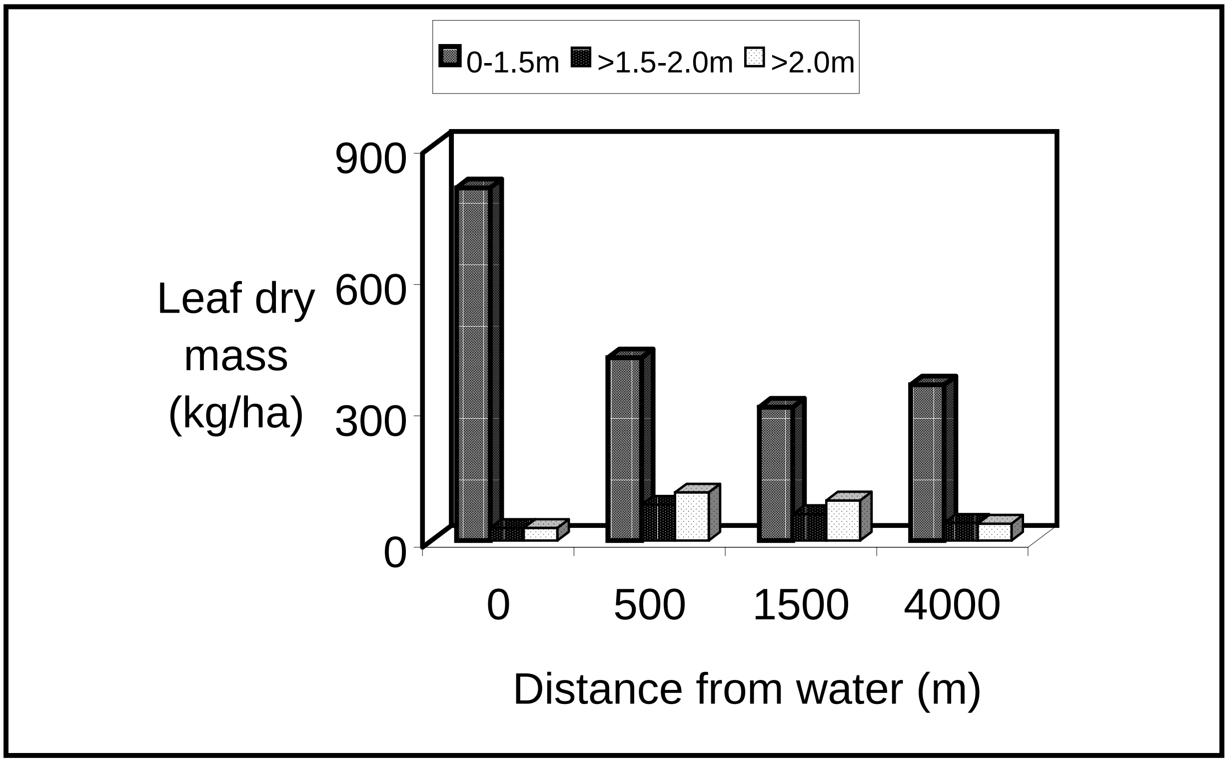

Fig. 4.3. Estimates of total leaf dry mass at peak biomass of woody plants with subdivision into height strata for each distance from water at Masaane cattle post.

Total leaf dry mass at Masaane cattle post was dominated by G. flava, B. albitrunca, C. gratissimus, T. sericea and to a lesser extent, M. sericea and D. cinerea (Fig. 4.4). Most of the leaf dry mass distributed below 1.5m height stratum was made up of G. flava, C. gratissimus, D. cinerea and M. sericea, while the above 2m height strata was dominated by T. sericea and B. albitrunca.

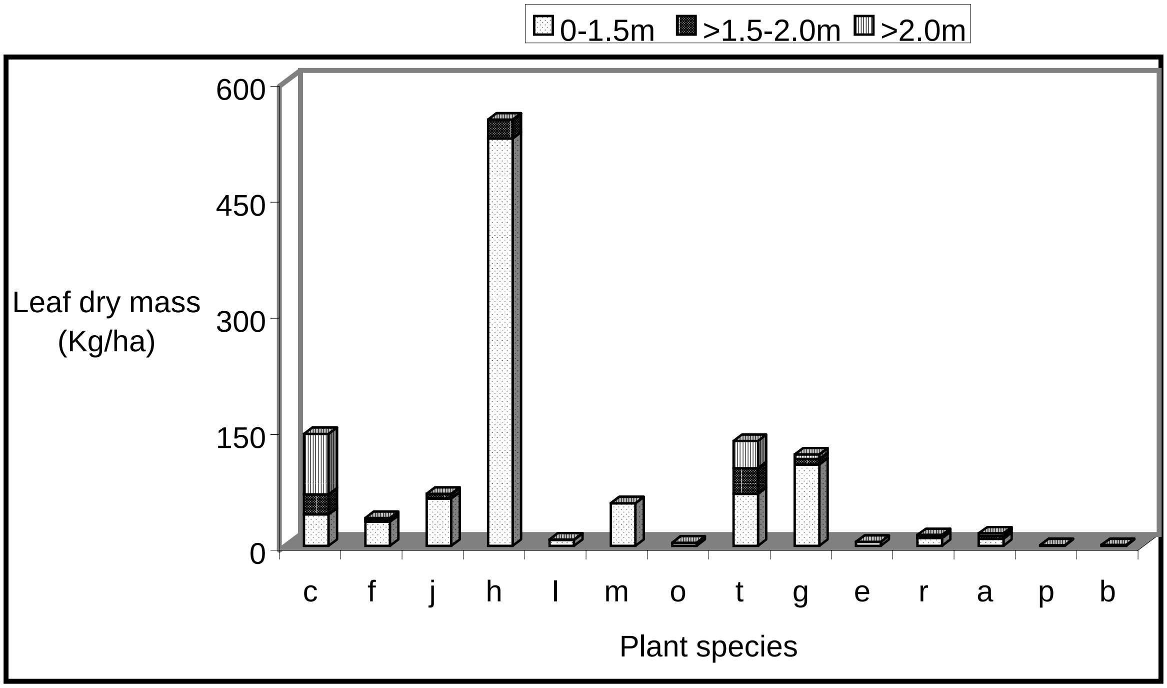

Fig. 4.4. Estimates of leaf dry mass at peak biomass with subdivision into height strata of individual woody plant species at Masaane cattle post.

Key to species: a = A. fleckii, b = A. gerrardii, c = B. albitrunca, d = B. foetida, e = B. petersiana, f = C. pyracanthoides g = C. gratissimus, h = G. flava, I = G. retinervis, j = D. cinerea, k = R. tenuinervis, m = M. sericea, o = O. pulchra, p = P. africanum, r = R. bravispinosum, t = T. sericea, x = X. americana and z = Z. mucronata

4.4 7 Density of woody plants at Motshwagole cattle post – free range grazing

The density of woody plants at the Motshwagole cattle post was lowest at the first two distances compared to the furthest two distances from water (Table 4.3). The furthest (1500m and 4000m) distances had almost the same plant densities. Acacia gerrardii, B. albitrunca and G. flava were the most prominent species in the vicinity of the water point. Five plant species were recorded around the water point and this increased to thirteen species at 1500m from the water point. Grewia flava was more abundant at the first two distances and started to decline at the third distance, where B. petersiana started to occur, again indicating that B. petersiana is a decreaser and G. flava is an inceaser II. Like the Masaane cattle post, a high density of D. cinerea was found at the 4000m and was non – existent at the first point. (Table 4.3).

Table 4.3. Individual plant species density (P/ha), leaf volume (LVol cm^3) and subdivision of canopy spread index (CSI %) height strata along the distance from water point at Motshwagole cattle post

PlantSpecies	**Distance from water (m)**														
	0			500				1500				4000			
	P / ha	LVol.	CSI2	P / ha	LVol.		CSI2	P / ha	LVol.	CSI2	CSI	P / ha	LVol.		CSI2
A. fle	CSI4			CSI4				80	73			CSI			
A. ger												40	49	1.0	
A. mel	200	515	7.9	160	1071		20.5					80	612	13.0	4.7
B. alb	40	28		15.2				80	48						
B. foe	360	92													
B. pet	140	11		80	170	3.0		840	90						
B. afr				40	413	1.5	1.5	20	3			560	56		
Com								180	108						
C. gra								60	15						
D. cin				40	24			80	77			220	75		
G. fla								80	394	5		400	239		
G. ret	320	144		80	27			80	161	1.5		20	63		
M. ser				360	624	2.0		80	22						
P. afr				20	25			20	72	1.1					
T. ser								360	785	5.1					
R. bra				20	1			120	75	0.4					
Total								**1680**	**1880**	**13.4**		300	105		
	1060	**788**	**7.9**	40	21							**1620**	**1199**	**14.0**	**4.7**
				980	**2402**		**26**								
				16.7											

CSI2 = canopy spread index based on trees with minimum height of 2m. CSI4 = canopy spread index based on trees with minimum height of 4m

Key to species: A. fle = Acacia fleckii, A. ger = A. gerrardii, B. alb = Boscia albitrunca, B. pet = Bauhinia petersiana, B. foe = B. foetida, Com = Commiphora spp, C. gra = Croton gratissimus, D.cin = Dichrostachys cinerea, D. lys = Diospyros lycioides, E. rhy = Erhytia rigidior; G.bic = Grewia bicolar, G. fla = G. flava, G. ret = G. retinervis, M. sen = Maytinus senegalensis, M. ser = Mudulia sericea, O. pul = Ochna pulchra, P. afr = Peltophorum africanum, T. ser = Terminelia sericea, R.bra = Rhigozum revispinosum, R. ten = Rhus tenunervis, X. ame = Ximenia americana, and Z. muc = Ziziphus mucronata

4.4.8 Leaf volume and canopy spread index at Motshwagole borehole - free range grazing

Estimates of leaf volume and subdivision for canopy spread index for each distance along the transect from water is presented in Table 4.3. Leaf volume for each distance was 788, 2402, 1880 and 1199 cm^3 at distances 0, 500, 1500 and 4000m from water, respectively. Greatest leaf volume occurred at 500m and lowest at adjacent to the water point. Most of the leaf volumes, regardless the distance, were dominated by A. gerrardii and G. flava.

Canopy spread index provided by trees between $\geq$2.0 - $\leq$4.0m height stratum was 26% at 500m point and larger than at any other point along the transect (Table 4.3). Acacia gerrardii provided 20% of the canopy spread index from trees between $\geq$ 2.0 - $\leq$4.0m height stratum and the remaining 4% was provided by Boscia species and G. flava. Canopy spread index from trees above 4.0m stratum was 16.7% and 4.7% at 500 and 4000m from water, respectively and was almost all contributed by A. gerrardii.

4.4.9 Leaf dry mass at Motshwagole cattle post - Free – range grazing

Unlike Makhi Ranch or the Masaane cattle post, the Motshwagole cattle post had the greatest leaf dry mass at the second and third (500 and 1500m point) distances from water (Fig. 4.5). The point in the immediate vicinity of the water point had almost all the leaf dry mass distributed below 2m height strata. Excepting the first distance from the water point, there was a tendency of a decrease of leaf dry mass with the increase of distance from water. Leaf mass above 2.0m was largest at the 500m point from water. Most of the leaf mass across the distances was distributed below 1.5m height stratum.

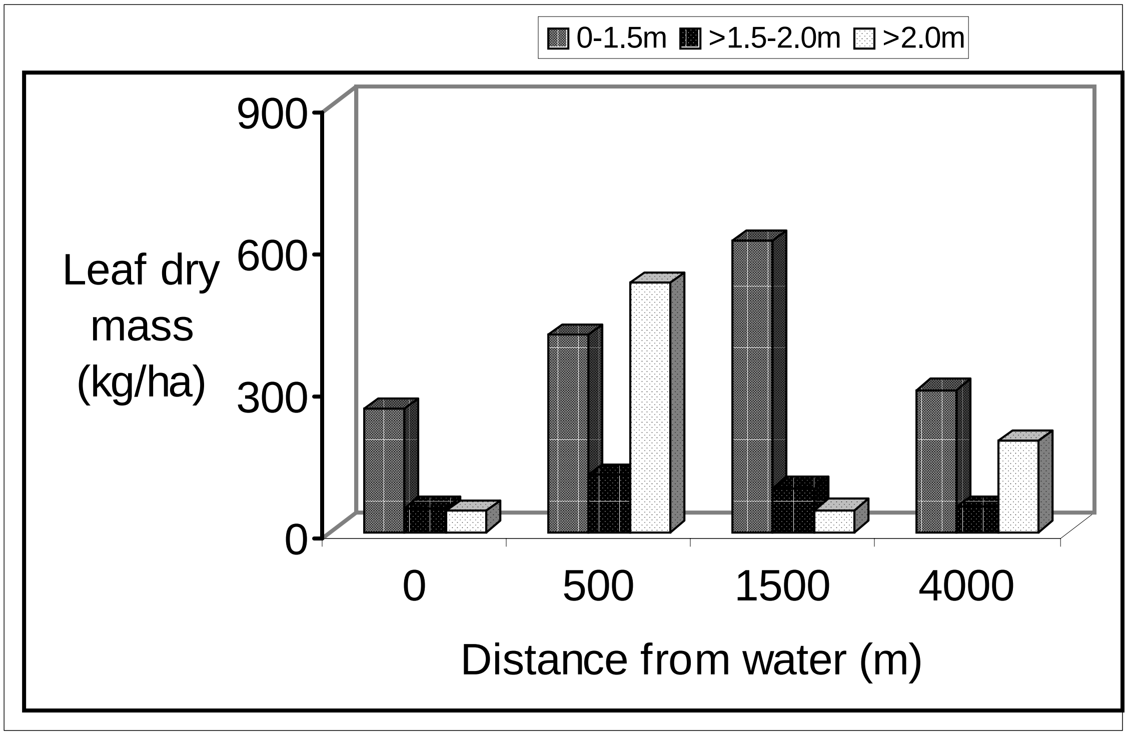

Fig. 4.5. Estimates of total leaf dry mass (kg/ha) at peak biomass of woody plants with subdivision into strata for each distance from water at Motshwagole cattle post.

Total leaf dry mass at the Motshwagole cattle post was dominated by A. gerrardii, A. fleckii, D. cinerea and T. sericea (Fig. 4.6). Grewia flava, D. cinerea and A. fleckii contributed the most leaf dry mass below 1.5 m height stratum, while A. gerrardii, A. fleckii and T. sericea dominated the above 2m height strata.

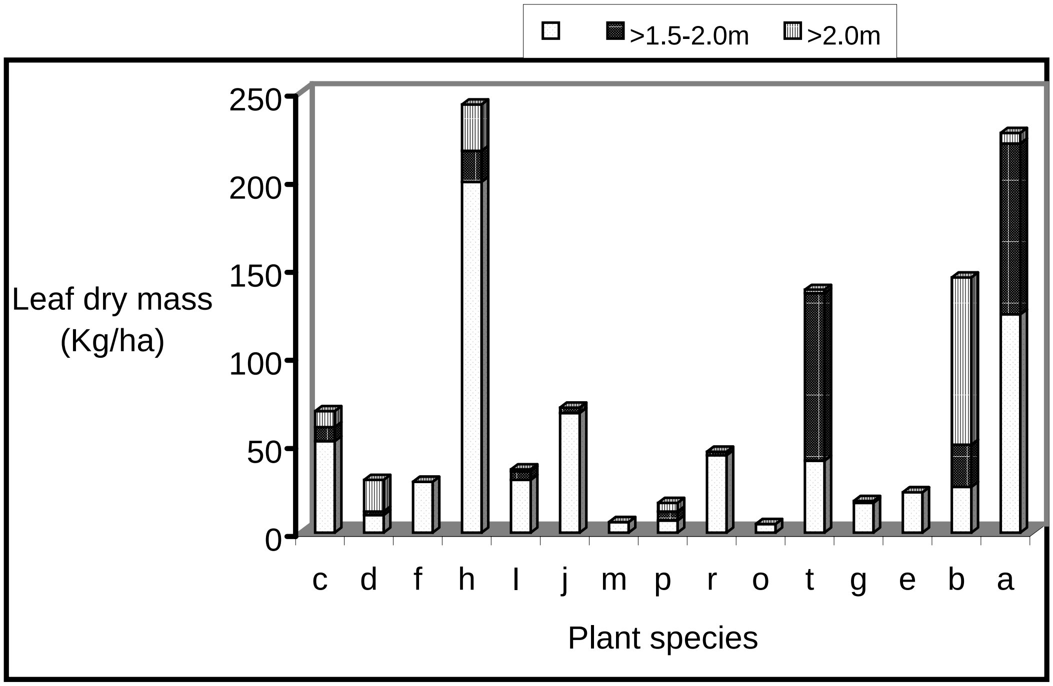

Fig. 4.6. Estimates of leaf dry mass (kg/ha) at peak biomass with subdivision into height strata of individual woody plant species at Motshwagole cattlle post.

Key to species: a = A. fleckii, b = A. gerrardii, c = B. albitrunca, d = B. foetida, e = B. petersiana, f = C. pyracanthoides g = C. gratissimus, h = G. flava, I = G. retinervis, j = D. cinerea, k = R. tenuinervis, m = M. sericea, o = O. pulchra, p = P. africanum, r = R. bravispinosum, t = T. sericea, x = X. americana and z = Z. mucronata

4.5 DISCUSSION

Bush encroachment is a characteristic feature of the sacrificial areas (piospheres) found around the water points in Eastern Kalahari (Perkins 1991). Piospheres in semi – arid environments are the results of livestock dependency on discrete and spatially located water points.

The leaf volumes and leaf dry mass values appear to reflect quantitative variations in the contribution of a relatively small number of woody species. Low growing plant species including B. petersiana, M. sericea etc made less of a contribution to the leaf volume and leaf mass, compared to higher growing plants such as A. gerrardii, D. cinerea, T. sericea, G. flava etc. Both leaf volume and leaf dry mass, with the exception of Motshwagole cattle post, tended to decrease with the increase in distance from water point due to the reduced density and canopy spread index of the plants. Both Motshwagole and Makhi cattle posts were dominated by A. gerrardii with canopy spread index above 2.0m height and large amounts of leaf dry mass at the first or second distances. However, at the Masaane cattle post, the high density of G. flava, associated with large leaf volumes at the first distance from water, provided high leaf dry mass. Grewia flava and D. cinerea, as heavily browsed plant species by both livestock and game (Palgrave 1977), contributed substantially to the total leaf dry mass within the height below 2.0m and their dominance as shrubs was evident from the small amount of leaf mass that was carried above 2.0m height strata. Thus, a large quantity of leaf dry mass is within the browse line of goats as defined by Aucamp (1981) and Sweet & Mphinyane (1986). Leaf dry mass above 2.0m was largely contributed by A. gerrardii, T. sericea and B. albitrunca at all cattle posts.

High plant density occurring immediately after the first distance from water point was reported by Perkins (1991), who indicated a sacrificial zone around the drinking trough up to 200m followed by a high bush density zone. In this study, one borehole (Makhi ranch) had high bush density at the second distance while the Masaane cattle post in the free range grazing was densely populated at the first distance from the water point. Plant densities at Makhi and Masaane cattle posts generally decreased with the increase in distance while that at Motshwagole cattle post tended to increase with increased distance from water. Plant density at the first two distances was lower compared to further distances at Motshwagole cattle post probably due to the age and stocking rate applied (chapter 2). Abandoned old cattle kraals around the borehole provide evidence of pressure exerted on plant density by livestock.

Common to all these data is the lack of any obvious quantitative shift in species composition within piospheres, particularly with respect G. flava and D. cinerea. Differences in species composition between piospheres appear to exist, particularly the contrast between D. cinerea at Makhi ranch and the dense stands of G. flava at Masaane cattle post or the abundance of B.

albitrunca at both Makhi ranch and Motshwagole cattle post occurring around the vicinity of the water point. Both Makhi ranch and Masaane cattle post had high densities of G. flava at the first distance from water. However, differences were that density of D. cinerea were 20 plants / ha and over 200 plants / ha, at Masaane cattle post and Makhi ranch, respectively. Unlike G. flava and D. cinerea, B. petersiana and C. gratissimus were not found at the vicinity of the water point suggesting that the latter are decreaser species and the former are increasers. This may reflect broader scale variations in woody layer that may further accentuate piosphere effect with centripedal movement of seeds through livestock dung deposition likely to occur over time (Kelly 1977). In general, there seemed to be no clear pattern in the density distribution along the transect from the water point particularly for D. cinerea. Boscia albitrunca is not a recognised encroacher on Botswana's rangelands. Its appearance has been explained by the deep regard with which this species is held in Southern African folklore (Palgrave 1977). It might be considered as a remnant of the flora that was in place before the imposition of piospheres. Similarly the occurrence of A. gerradii may be explained by the fact that this species is often used to locate potential borehole sites in sandveld, as its presence may indicate tapable water. This was certainly the case in vicinity of the two boreholes (Makhi ranch and Masaane borehole) and other surrounding boreholes in the area.

4.6 CONCLUSION

The incidence of daily livestock concentrations in the vicinity of water points result in woody vegetation dominated by shrubby plants of less than 2m height due to livestock browsing. Total leaf volume and leaf dry mass values appear to reflect quantitative variation in contribution by a relatively small number of woody species. Within the height stratum below 2.0m G. flava and D. cinerea contributed substantially to the total leaf dry mass. Leaf volume and leaf mass above 2.0m were largely provided by A. gerrardii, T. sericea, and B. albitrunca

High densities of G. flava tended to be confined to the immediate vicinity of water points rather than further distances, while species such as B. petersiana and C. gratissimus occur only at further distances from water. There was no clear pattern in the density distribution of D. cinerea along the transect from the water point.

Plant species diversities increased with the increase in distance from the water point. Makhi ranch and Motshwagole cattle post had higher species diversity than Masaane cattle post.

The dominance of G. flava and D. cinerea as shrubs in this study was evident from the small amount of leaf dry mass that was carried above 2.0m height strata.

CHAPTER 5

The influence of livestock grazing around water points on the primary production of herbaceous plants

5.1 Introduction

The measurement of available phytomass is of great value to the range manager and may be one of the most important vegetation and animal determinations. Phytomass is measured to obtain a quantitative measure of production over time. A single field measurement at maturity in grassland would reflect the accumulated seasonal production. To illustrate changes in phytomass over time, measurements should be taken at the beginning and end of the season or treatment period. Another use of phytomass measurements is the determination of forage utilization by animals (clipping plots before and after grazing). The need for a time and cost effective technique to monitor phytomass production, availability and utilization was emphasized in chapter one.

Water is a major determinant of livestock distribution. Animals graze from a water point to a distance they can afford depending on the availability of forage and their dependency on water. In the early days animals in Botswana used to water from surface source such as pans, rivers and hand dug wells through out the year. These limited water sources resulted in the protection of large areas of rangeland from grazing, except by wildlife, especially in the Kalahari sandveld. The introduction of borehole technology and a financial assistance policy opened the Kalahari rangeland to grazing by livestock. This improved livestock distribution, but increased overgrazing because the stocking densities around the water sources were not sufficiently considered. Changes in rangeland condition around water points have been reported by many authors (Lange 1969; Zumer – Linde 1976; Hanan *et al.* 1991; Perkins 1991; Van Rooyen *et al.* 1994 & Thrash 1998). Lange (1969) used the ‘piosphere’ to describe the pattern of decreasing grazing effects with distance from the water. In the southern Kalahari of Botswana, herbage utilization was affected to a distance of 20km, or more, from the water point (APRU 1985; Skarpe 1983 and Zumer – Linde 1976). It is, therefore, appropriate to estimate the primary production of the vegetation at distances from the water point.

Animals select their diets on the basis of forage availability and quality in addition to their body size, type of digestive system, etc (Owen – Smith 1999). These factors influence the performance of grazing animal in terms of weight gain, reproduction and other parameters. Information on forage availability and quality is, therefore, essential to explain observed livestock diet selection. This study was designed to evaluate the influence of grazing systems and various distances along the transect radiating from water point on the available herbage phytomass at different seasons so as to relate livestock preferences to the relative abundance of plant species. This type of information would be useful in refining adjustment for distances from water in stocking rate determinations, and in decisions regarding location and espacement of water points

5.2 Material and methods

The available herbage phytomass was estimated using a double sample method (Weight estimate method). Samples were taken at five points along the transect radiating from the water point. These points were located at 0, 600, 1200, 1800 and 2400 meters at Makhi ranch (controlled grazing), while in the free range grazing area, these were located at 0, 500, 1500, 2500 and 4000 meters from the water point. The zero (0) point is near the livestock drinking water, where animals concentrate or rest after drinking. A 50m x 50m permanent plot at each point was demarcated in which herbaceous plants was measured. Within each such plot, 20 quadrates of 0.5 x 0.5m were randomly placed to estimate herbage biomass. The first four quadrates were estimated visually and the fifth quadrate was clipped so that the visual estimated weights could be adjusted by a regression technique. Clipping one quadrate in every five provided a ratio of 1:5, which is better than 1:7 ratio recommended for short grass by Ahmed & Bonham (1982). The clipped samples were weighed and bagged by species at clipping time and re - weighed after oven drying. Only the current years growth was collected, by separating the old material from the current growth. Samples were taken at the end of January (summer), the end of April (Autumn), the end of July (winter) and the end of October (spring) over the period of two years.

5.2.1 Statistical Analysis

Descriptive statistics was used to summarize the data according to relevant parameters. The main effects of season, grazing system and distance from water point on available forage phytomass were determined by General Linear Model (SAS 1985). Where differences were significant at the 5% level, Scheffe's test was used to separate the means. All differences discussed in the results or discussion sections are significant at the 5% level unless otherwise noted.

5.3 RESULTS

5.3.1 Seasonal plant species availability in controlled grazing conditions at Makhi Ranch

The variation in the available phytomass of individual herbaceous plant species during each sampling season over two years is illustrated in Table 5.1. There were significant ($P< 0.05$) differences in the amount of herbaceous available phytomass on each plant species between the seasons. The highest phytomass available on all plant species peaked in summer to autumn and was the lowest in spring in both years. Total herbage phytomass on all plant species was higher during the first year (1996/97) than during the second year (1997/98). The lowest phytomass recorded was 257.50 gm^{-2} in the spring of 1997/98 compared to 316.86 gm^{-2} for the same season of the previous year. The amount and distribution of rainfall was the basic cause for these differences. Total rainfall was 553mm and 357.2mm for 1996/97 and 1997/98 growing seasons, respectively (Fig. 2.2). Poor rainfall recorded in February 1997 resulted in lower phytomass availability observed in the autumn of 1996/97. In the 1997/98 growing season, no effective rainfall was measured after February 1998 and this accounted for lower phytomass availability. The phytomass of S. uniplumis and S. pappophoroides, during the summer of 1997/98, was approximately half that of the previous summer. Available phytomass over the experimental period was dominated by S. uniplumis, E. rigidior, D. eriantha, S. pappophoroides and E. lehmanniana.

Table 5.1 Phytomass available (gm^{-2}) on individual plant species, or species groups in each season over two years in controlled grazing - Makhi ranch.

Plant species*	Season of year								
	Summer 1996/97	Autumn 1996/97	Winter 1996/97	Spring 1996/97	Summer 1997/98	Autumn 1997/98	Winter 1997/98	Spring 1997/98	Mean
D. eri	37.42^{ab}	44.16^{a}	38.30^{ab}	31.30^{ab}	33.26^{b}	42.19 ^{a}	41.56^{a}	32.58^{ab}	36.32
E. leh	68.50^{a}	67.16^{ab}	48.86^{bc}	38.00^{c}	38.82^{c}	40.02^{c}	42.02^{c}	37.88^{c}	49.24
E. rig	85.10^{a}	63.78^{ab}	81.14^{a}	69.92^{ab}	66.30^{ab}	74.76^{ab}	57.24^{ab}	49.92^{b}	68.52
S. uni	90.14^{a}	79.34^{a}	71.80^{ab}	61.70^{ab}	41.46^{c}	73.66^{ab}	50.72^{bc}	50.52^{bc}	65.34
S. pap	53.20^{a}	49.18^{ab}	62.52^{a}	44.60^{ab}	25.06^{b}	39.90^{ab}	45.12^{ab}	36.32^{ab}	44.74
P. max	47.00^{a}	23.98^{b}	30.48^{ab}	0^{c}	29.24^{ab}	14.94^{b}	0^{c}	0^{c}	18.20
Misc grass	41.04^{a}	41.32^{a}	34.66^{a}	33.74^{a}	30.48^{a}	33.68^{a}	35.92^{a}	28.32^{a}	34.92
M.alb/U.tri	24.14^{ab}	21.08^{b}	34.10^{a}	21.80^{ab}	21.74^{ab}	19.12^{b}	14.44^{b}	0^{c}	20.04
C.bie/I.dal	33.20^{a}	30.40^{a}	25.20^{a}	15.80^{a}	21.90^{a}	20.6^{a}	13.60^{a}	0^{b}	19.96
D.aeg/E.afr	58.52^{a}	15.50^{a}	5.04^{b}	0^{d}	5.36^{bc}	1.42^{cd}	0^{d}	0^{d}	10.72
A.thu/T.ter	41.20^{a}	25.98^{ab}	0^{c}	0^{c}	18.24^{b}	13.60^{b}	0^{c}	0^{c}	12.36
Misc Forbs	17.40^{a}	14.10^{a}	15.56^{a}	0^{b}	9.86^{a}	14.10^{a}	17.10^{a}	21.96^{a}	14.04
Total	596.86	475.98	447.66	316.86	341.72	387.88	317.72	257.50	

Values in each column followed by a same superscript are not significantly different ($P>0.05$) between seasons

Annual plant species (grasses and forbs), had in general, a high phytomass during summer periods but this declined drastically in winter and spring, resulting in bare ground (Table 5.1). During summer of 1997/98, however, the phytomass of D. aegyptium and E. africana (annual grasses), A. thunbergii and T. terrestris (annual forbs) was significantly ($P<0.05$) lower due to poor rainfall in December 1997. The phytomass of P.maximum was low, or non – existent, during the dry seasons

5.3.2 Plant species available at points along the transect from the water point in controlled grazing conditions

Table 5.2 illustrates the variation in the phytomass availability of individual plant species along the transect from the water point. There were significant ($P<0.05$) differences in the availability of phytomass of each plant species between points. Total herbage phytomass for all plant species at each point was 142.58, 325.0, 360.46, 385.74 and 366.02 gm^{-2} at 0, 600, 1200,1800 and 2400m from the water point, respectively. The point in the immediate vicinity of the water point produced less than half of all other points. Beyond the 600m point the effects of livestock grazing tended to taper off. The increased grazing pressure near the water point was probably the reason for these differences. The furthest point (2400m) had slightly less material than at 1800m. The most probably reason might be that the 2400m location was only 100m from the perimeter fence, where animals tended to rest and to concentrate their grazing immediately after the rest.

Table 5.2. Phytomass availability (gm^{-2}) of individual plant species and species group at each distance from the water point in controlled grazing - Makhi ranch.

Plant species	Distance from water(m)				
	0	600	1200	1800	2400
D. eri	0^{c}	27.90^{b}	38.90^{a}	38.84^{a}	37.96^{a}
E. leh	23.52^{b}	43.32^{a}	46.08^{a}	56.72^{a}	53.12^{a}
E. rig	19.58^{b}	63.02^{a}	77.08^{a}	77.22^{a}	74.84^{a}
S. pap	0^{b}	38.76^{a}	45.10^{a}	49.66^{a}	45.18^{a}
S. uni	0^{b}	69.56^{a}	62.20^{a}	64.12^{a}	60.28^{a}
P. max	29.04^{a}	0^{b}	0^{b}	0^{b}	0^{b}
Misc grasses	3.94^{b}	26.02^{a}	37.40^{a}	37.08^{a}	33.54^{a}
M. alb/U. tri	16.06^{a}	18.16^{a}	19.24^{a}	23.26^{a}	22.82^{a}
C. bie/ I. dal	0^{b}	23.06^{a}	21.24^{a}	24.22^{a}	21.74^{a}
D. aeg/E. afr	5.08^{a}	0.20^{a}	0^{b}	0^{b}	0^{b}
A. thu/T. ter	19.16^{a}	0^{b}	0^{b}	0^{b}	0^{b}
Misc forbs	26.20^{a}	15.22^{a}	13.22^{a}	14.62^{a}	16.54^{a}
Total	142.58	325.0	360.46	385.74	366.02

Values in each column followed by the same superscript are not significantly ($P>0.05$) different between distances

Due to the daily concentration of animals around the water point, certain plant species were limited to such areas. Table 5.2 illustrates that D. aegyptium and E. africana (grasses), T terrestris, and A. thumbergii (forbs) were only found at the 0m (zero) zone but were rare at 600m point or beyond. Such plants tend to be associated with soil disturbance. The occurrence of P. maximum at this location was influenced by the huge tree canopies of A. gerradii, and higher soil nutrients (Chapter 3), occurring in the vicinity of the water point. The occurrence of S. uniplumis, S. pappophoroides, D. eriantha (grasses), C. biensis and I. daleoides (forbs) were observed starting at the 600m point from the water point. Due to its morphological growth form, S. uniplumis, with its growing points raised above ground surface, is sensitive to trampling, while D. eriantha and S. pappophoroides although having their growing points below ground surface were sensitive to grazing pressure (decreaser plants)

Cassia biensis and I. daleoides (perennial forbs) tended to be uniformly distributed at all points along the transect, except the one next to the water point, where phytomass was probably reduced by trampling. Urochloa trichopus and M. albescens (annual grasses) were more or less evenly distributed along the transect from the water point. Phytomass available in the vicinity of the water point was mostly accounted for by annual grasses and forbs and their contribution was largely restricted to the growing seasons.

5.3.3 Plant species availability on different grazing systems at Makhi Ranch

The variation in phytomass of individual plant species as influenced by the system of grazing, is illustrated in Table 5.3. Total phytomass available on all plant species was 399.26, 381.34, 420.63 and 184.27 gm^{-2} for the continuous grazing system, 3 – paddock grazing system, 9 – paddock grazing system and the non – grazing exclosures, respectively. The 3 – paddock system was significantly inferior ($P<0.05$) to the 9 – paddock system and the control which did not differ significantly, from the 1 – paddock system.

There was a significantly ($P< 0.05$) less phytomass of D. eriantha in the continuous and 3 – paddock grazing systems than the non-grazing exclosure or the 9 – paddock grazing treatments. P. maximum was low in the continuous system compared to other two systems. Phytomass availability was dominated by S. uniplumis and E. rigidior in all the treatments. Available phytomass of miscellaneous grasses was almost the same across the treatments.

The non – grazing exclosure had higher phytomass although plant species diversity was surprisingly low compared to other treatments. With the exception of C. biensis and I. daleoides, there were no annual plants found in the non – grazing exclosure.

Table 5.3 Phytomass availability (gm^{-2}) of individual plant species, or species group, at each grazing system in controlled grazing

Plant species	Grazing Systems			
	1 P system	3 – P system	9 – P system	Control
D. eri.	33.50^{bc}	31.76^{c}	41.92^{ab}	47.14^{a}
E. leh	52.74^{a}	42.38^{a}	46.86^{a}	54.06^{a}
E. rig	72.84^{a}	61.92^{ab}	65.06^{a}	37.46^{b}
S. uni	66.68^{a}	63.46^{a}	58.84^{a}	45.60^{a}
S. pap	43.76^{a}	43.92^{a}	47.23^{a}	-
P. max	17.68^{a}	25.28^{a}	33.46^{a}	-
Misc grasses	35.16^{a}	32.10^{a}	36.54^{a}	-
M. alb / U. tri	18.26^{b}	20.34^{ab}	23.96^{a}	-
C. bie / I.dal	20.62^{a}	$24.7o^{a}$	19.38^{a}	11.70^{a}
D. aeg / E. afr	3.44^{a}	3.66^{a}	5.88^{a}	-
A. thu / T. ter	19.06^{a}	18.56^{a}	20.82^{a}	-
Misc Forbs	15.52^{a}	13.26^{a}	20.68^{a}	-
Total	399.26^{ab}	381.34^{b}	420.63^{a}	184.27^{c}

Values in each column followed by the same superscript are not significantly different between the grazing systems

Forage plants regarded as ‘key grazing species’ in terms of quality or amount in this particular sandveld area are D.eriantha, S. pappophoroides and E.lehmanniana. Although the phytomass on the continuous system and the 9 – paddock systems was not significantly different, the available phytomass of quality species was higher in 9 – paddock system than the continuous or the 3 – paddock systems (Table 5.3), thus, placing the 9 – paddock system in superior position.

5.3.4 Availability of phytomass on different plant species in free range grazing areas

Table 5.4 illustrates the variation in available phytomass of individual herbaceous plant species at the two cattle posts in the free range grazing area. A comparison between the available phytomass of total plant species revealed no significant ($P>0.05$) difference between the two cattle posts, hence the data for the two were pooled together for the seasons and along the transect from the water point. However, there were differences in phytomass of few individual species between the two cattle posts. The available phytomass of D. eriantha, S. pappophoroides, and M. albescens / U. trichopus was higher ($P<0.05$) and E. rigidior was lower at Motshwagole cattle post while the phytomass available on D. aegytinum and E. africana was higher at Masaane cattle post.

Table 5.4. Phytomass availability (gm^{-2}) of individual plant species, and species group at two cattle posts in free range grazing.

Plant species	Cattle Post	
	Motshwagole	Masaane
D. eri	47.62^a	34.72^b
E. leh	41.52^a	36.62^a
E. rig	46.80^b	50.54^a
S. uni	67.96^a	71.32^a
S. pap	45.74^a	42.10^a
Misc grasses	48.62^a	28.34^b
M. alb / U. tri	26.86^a	18.26^b
C. bie / I.dal	32.18^a	29.08^a
D.aeg / E. afri	9.98^b	30.24^a
A.thu / T. ter	39.16^a	25.52^a
Misc forbs	23.78^a	21.06^a
Total	430.22	387.8

Values in each column followed by the same superscript are not significantly different ($P>0.05$) between the boreholes

5.3.5 Seasonal availability of phytomass of different plant species in free range grazing area.

The herbage available on individual plant species observed, during sampling seasons over two years, is illustrated in Table 5.5. Comparison of different season revealed differences in the total available phytomass of all species for each season. Significantly ($P<0.05$) low phytomass was evident during Spring 1997/98 and highest ($P<0.05$) phytomass peaked in autumn 1996/97.

The available phytomass of annual grasses and those species growing near the water point, were very low ($P<0.05$) during the summer of 1997/98 because of the dry December experienced in 1997,which resulted in their disappearance during the dry season (winter and spring). Their phytomass diminished starting from autumn due to the physiological nature where leaf senescence occurs followed by death of the plant. Grasses and forbs of the miscellaneous groups were uniformly distributed between the seasons except for the spring 1997/98. Most of the available phytomass was contributed by S. uniplumis, E. rigidior, E. lehmanniana, D. eriantha and S. pappophoroides.

Table 5.5. Phytomass availability (gm^{-2}) of individual plant species, and species group in each season over two years in the free range grazing area.

Plant species	Season of year								
	Summer 1996/97	Autumn 1996/97	Winter 1996/97	Spring 1996/97	Summer 1997/98	Autumn 1997/98	Winter 1997/98	Spring 1997/98	Mean
D.eri	28.06^{bc}	51.86^{ab}	49.90^{ab}	41.46^{abc}	30.88^{bc}	63.34^{a}	24.34^{bc}	19.68^{c}	38.74
E. leh	54.44^{ab}	52.84^{ab}	47.12^{abc}	36.10^{abc}	38.34^{abc}	63.70^{a}	52.14^{ab}	28.08^{bc}	42.34
E. rig	39.26^{a}	55.28^{a}	59.94^{a}	44.74^{a}	33.38^{a}	61.32^{a}	55.62^{a}		47.74
S.uni	56.86^{a}	106.88^{a}	83.90^{a}	55.48^{a}	79.96^{a}	68.66^{a}	50.66^{a}	45.36^{a}	68.34
S.pap	63.28^{ab}	74.78^{a}	69.00^{a}	30.94^{abc}	34.64^{abc}	60.02^{a}	34.66^{bc}	44.20^{a}	48.10
Misc grass	40.90^{a}	54.98^{a}	42.66^{a}	43.18^{a}	38.14^{a}	47.06^{a}	47.06^{a}	23.42^{c}	41.54
M.alb/U.tri	32.36^{ab}	43.54^{a}	19.02^{bc}	0^{d}	24.94^{b}	34.90^{a}	28.16^{ab}	43.60^{a}	20.24
C.bie/I.dal	60.64^{a}	33.08^{ab}	0^{d}	0^{d}	24.80^{bc}	30.58^{ab}	18.58^{b}	0^{d}	21.02
D.aeg/E.afr	32.36^{a}	32.32^{a}	7.56^{b}	0^{c}	17.78^{a}		0^{c}	0^{d}	12.20
A.thu/T.ter	46.44^{a}	26.08^{b}	6.20^{b}	0^{c}	15.46^{b}	7.34^{b}	0^{c}	0^{c}	9.36
Misc.forbs	27.14^{a}	25.70^{a}	17.70^{a}	14.82^{a}	16.44^{a}	6.90^{b}	12.06^{a}	0^{c}	15.84
Total	481.71	557.27	403.0	266.72	354.76	24.60^{a} 468.42	325.28	8.47^{b} 212.81	

Values in each column followed by the same superscript are not significantly different (>0.05) between seasons

5.3.6 Phytomass availability on different plant species along the transects from the water point in free range grazing areas.

The available phytomass on each plant species or group of species, along the transect from the water point is illustrated in Table 5.6. Comparison of the phytomass between the points revealed differences between the distances. Total available phytomass at each point increased with the increase in distance from the water point. The point in the vicinity of the water point was totally dominated by annual plants (grasses and forbs). Available phytomass of perennial plant species only occurred from the 500m zone from water point, and beyond.

Table 5.6 Phytomass availability (gm^{-2}) of plant species and species groups at each point along the transects from water point in the free range grazing area.

Plant species	Distance from water (m)				
	0	500	1000	2500	4000
D. eri	0^{c}	17.14^{b}	15.70^{b}	33.34^{ab}	53.22^{a}
E. leh	0^{c}	16.94^{b}	41.06^{a}	44.12^{a}	50.42^{a}
E. rig	0^{d}	24.12^{c}	50.10^{b}	74.00^{a}	67.42^{ab}
S. uni	0^{b}	0^{b}	68.80^{a}	56.06^{a}	79.86^{a}
S. pap	0^{c}	2.18^{b}	13.46^{a}	43.76^{a}	53.64^{a}
Misc grasses	0^{c}	11.50^{b}	47.86^{a}	36.14^{ab}	37.46^{ab}
M. alb / U. tri	21.08^{abc}	12.30^{c}	15.30^{bc}	25.38^{ab}	33.30^{a}
C. bie / I. dal	0^{b}	29.86^{a}	27.18^{a}	21.90^{a}	30.26^{a}
D. aeg / E.afr	18.86^{a}	16.86^{a}	0^{b}	0^{b}	0^{b}
A. thu / T. ter	26.78^{b}	67.00^{a}	1.530^{c}	0^{d}	0^{d}
Misc forbs	13.42^{a}	19.12^{a}	25.04^{a}	22.72^{a}	41.42^{a}
Total	80.14^{c}	197.90^{b}	280.9^{ab}	357.42^{a}	447.0^{a}

Values in each column followed by the same superscript are not significantly different ($P>0.05$) between the distances

Herbage available in the 0m zone was about one third of that in the 500m zone, which in turn was only about half that in the 4000m zone. Annual forbs (eg. T. terrestris), associated with soil disturbance, were found as far as the 1000m zone or 500m for D. aegytinum / E. africana, a situation which was not observed in the controlled grazing conditions. The occurrence of these species at such distances from the water point suggests that the size of the “sacrifice area” is larger in the cattle posts of the free range grazing area than in the controlled conditions. Stipagrostis uniplumis (perennial grass) occurred starting from the 600m zone and beyond. Comparison of distances between 2500 and 4000m from water point generally showed no significant (P>0.05) difference in the availability of the major grass species although the trend tended not to taper off, suggesting that grazing influence was still present at 4000m (Table 5.6).

5.4 DISCUSSION

The zonation of vegetation along the transect from the water point reflected the type of management, indicating different classes of range condition, which can be used in range evaluation and planning. Heavy grazing pressure and trampling in the vicinity of the water point killed sensitive perennial grass species resulting in a zone dominated by annual plants. A rapid transitional zone occurs beyond this, which is a zone of more or less uniform grazing influence by livestock, where perennial plants dominate.

Differences between the wet and dry season forage availability of the annual grasses and forbs were primarily due to early cessation of growth and ultimately death of plants, which coupled with grazing pressure and physical losses, led to the drastic decline in their availability during spring. In practice, such incidents of forage scarcity need to be remediated by stock reduction or feeding of hay.

Digitaria eriantha is widely recognised as a palatable and desirable grazing species (Drewes 1984). Its abundance indicates that the veld is in good condition (Field 1977) and it has been classified within the decreaser catagory (Field 1977; Thrash 1998). Results from this study confirm that this species is a decreaser and sensitive to trampling in sandveld areas (Table 5.6). Perkins (1991), however, indicated that this species was associated with high grazing pressure and soil disturbance. Certain plant species were found to occur at various distances along the transects, or associated with many other plants (wide range). Such species included E. lehmanniana, U. trichopus and to a lesser extent E. rigidior. Plant species such as A. thunbergii, T. terrestris, (forbs), D. aegyptium and E. africana are associated with soil disturbance and higher soil fertility, hence their occurrence where animal concentrate their dung or urine and soil trampling. The occurrence of P. maximum in the sandveld is of a rare species, and it was totally grazed out in the communal cattle post area. In this study, the amount of phytomass recorded occurred under the tree canopies of A. gerradii, which were found in the vicinity of the water points, where higher soil nutrients were accumulated through dung and urine from animals. Due to the sub – habitat nature of this species, Stuart – Hill (1985); Teague & Smit (1992) and Smit & Rethman (2000) emphasized the fact that herbaceous plants should not be viewed in isolation from the woody vegetation.

Other miscellaneous grasses, which included A. congesta, A. graciliflora, E. pallens, P. squarrosa, M. repens and P. patens, exhibited no definite trend with regard to grazing systems, or different seasons, except that their phytomass declined during spring at the water point due to limited availability of forage. Lack of response to grazing systems, or to season of the year, of these plant species is the result of their poor preference by livestock.

Problems of the impact on rangeland condition near water points are likely to cause soil erosion because of the reduced protection of soil surface during the dry seasons and enhanced bush encroachment because these areas will not burn (Grossman *et al.* 1999). If water points are used by livestock to any extent, an impact on the vegetation is expected, or cannot be avoided. Fusco *et al.* (1995) illustrated in their data that even long term conservative cattle grazing causes a reduction in perennial grass phytomass the closer to the water. What is perhaps more important is the ecological extent of the “sacrifice area” around the water points over time. The main focus should, therefore, concentrate not on preventing the changes around water points, but on controlling the changes such that livestock production can be made sustainable.

Two practical approaches had been mentioned by certain workers that can minimize degradation and enhance the productivity of perennial grasses around the water points. Fusco *et al.* (1995) indicated the adjustment of stocking rate with distance from water. However, in Botswana, data on the influence of travel distance between forage and water on cattle performance are not available. Research is needed to evaluate how travel distance between water and forage affects animal performance, particularly during forage scarce periods. Martin & Ward (1970) found that the yield of perennial grasses, over a period of eight years, doubled when rotational access to water points was practiced compared to continuous grazing.

5.5 CONCLUSION

High grazing pressure and trampling near water points cause sacrifice areas in which perennial herbaceous plants cannot survive. Annual plants grow on bare areas near the water point during growing seasons and their presence is inversely proportional to distance from the water point. Beyond these sacrifice area, the effects taper off rapidly until an upper level is approached (grazing effect diminish).

The sacrifice zone was larger in the free range grazing areas than in the controlled grazing management systems. Over the study period, significantly higher amounts of available phytomass were recorded in summer and autumn with low phytomass available occurring in spring.

Phytomass production of annual plants was more variable than that of the perennials under the variable rainfall conditions.

The 3 – paddock system produced less phytomass compared to the other systems, while phytomass of quality plant species was favoured by the 9 – paddock grazing system. Less utilized plant species were not responsive to either grazing system or season of the year.

In the free range grazing management system, the influence of grazing did not taper off at 4000m from the water point suggesting that animals travel beyond this point, while in the controlled conditions, grazing influence tapered off at 1200m from the water point suggesting that forage availability was more limiting in the free range grazing system.

CHAPTER 6

FORAGE QUALITY AROUND WATER POINTS

6.1 Introduction

Rangeland is the most important source of feed for livestock in Botswana. Livestock production from rangeland resources is variously constrained by both quantity and quality of forage produced and consumed. Identification of nutritional factors that have an influence on the animal production is, therefore, of paramount importance in the livestock industry. Prachett *et al*. (1977) indicated that the crude protein content of forages in Botswana was the single most important factor limiting animal production, whilst digestibility of the dry matter appeared to be another important nutritional factor. Weight changes in range cattle are influenced primarily by nitrogen and digestible dry matter content of the herbage selected. Phosphorus deficiency is also widespread in Botswana's rangelands and grasses rarely contain more than 0.1% phosphorus in the dry matter. A deficiency of phosphorus in cattle is responsible not only for reduced growth rates but also for poor reproductive performance (APRU 1980).

Pienaar *et al*. (1993) mentioned that it is important to be able to predict the performance of the grazing animals given a certain level of available forage of a particular quality in any livestock management program. However, they indicated that methods of feed analysis currently used do not provide data directly related to animal performance when a wide range of forages are used. Any understanding of nutritional constraints on livestock production in an area depends upon the availability of detailed knowledge of the quality of the diet available and any associated seasonal fluctuations. More efficient livestock production can only be achieved when managers are able to match nutritional requirements of their livestock with the quality of forage available. To attain this goal, more information is needed on changes in nutrient content of forages as influenced by stage of maturity and season of the year.

Based on the literature, nitrogen, phosphorus and dry matter digestibility or fibre appear to be the best indicators available to evaluate the nutrient quality of forages in Botswana's rangelands. This study was initiated as part of a multi – factor research effort to quantify the effects of grazing systems and influence of animal concentration at water points on range condition at Makhi ranch and the adjacent cattle posts in the free range grazing area. The specific objectives of this chapter were: a) to characterize the seasonal concentration dynamics of crude protein, phosphorus and fibre in the dominant forages growing around Makhi area. b) to determine the changes in nutritive quality of three forage species growing along the transect from the water point.

6.2 Material and Methods

The nutrient content of herbaceous plant species was estimated from samples obtained from both free range grazing areas and controlled conditions (ranch). In the free range grazing areas, forage samples were collected at two cattle posts. Forage samples were taken at five points along the transect from the water point. These points were located at 0, 500, 1000, 2500 and 4000 metres from the water point. These points were replicated three times on each cattle post. The zero (0m) point was located near the water trough, where animals concentrate or rest after drinking. In the free range grazing conditions, livestock kraals or abandoned old kraals exist within the vicinity of the borehole, which often make the area look more of a sacrificial area.

On the controlled grazing conditions (ranch) forage samples were collected along three transects for each grazing system. The grazing systems were replicated twice. Forage samples were taken at 0, 600, 1200, 1800 and 2400 metres from the hub. Samples were taken during clipping periods. Samples included both stems and leaves (whole plant) of grass or forbs. Samples were oven dried and ground using the Wily mill through a 1 mm screen and kept in labeled air - tight bottles until chemical analyses were done. The samples were analyzed for nitrogen (Kjeldahl method), according to Association of Official Analytical Chemists (AOAC 1996), phosphorus through ultra-violet visible spectrophotometer and crude fibre using moisture – free and ether extracted sample digested first with weak acid solution, then a weak base solution. The organic residue was collected in a filter crucible and the loss of weight on ignition is crude fibre.

Three forage species were collected at all five points along the transect from the water point. These forage species were U. trichopus, E. lehmanniana and E. rigidior. In addition, other grass species, thought to be of importance, were collected only at one point (middle) of the paddock. These grasses included D. eriantha, S. pappophoroides, P. maximum, S. uniplumis, M. albescens, D. aegyptium, A. congesta, and A. graciliflora. Forbs included C. biensis, I. daleoides, A. thumbergii and T. terrestris.

6.2.1 Statistical Analysis

Descriptive statistics were used to summarize the data according to relevant parameters. The main effects of the season, grazing system and distance from water point on the nutritive content of the forage species were determined by General Linear Model (SAS 1990). Where differences were significant at the 5% level, Scheffe’s test was used to separate the means. All differences discussed in the results or discussions are significant at the 5% level unless otherwise noted.

6.3 RESULTS

6.3.1 Seasonal nutrient content of forage species in controlled grazing conditions - Makhi ranch

The seasonal variation in crude protein, phosphorus and fibre of individual plant species in controlled grazing conditions and the surrounding free range grazing area is illustrated in Table 6.1. Nutrient concentration in forage species varied between species, season and stage of maturity. Significantly ($P<0.05$) higher levels of crude protein, phosphorus and lower fibre content occurred in summer for all plant species and the opposite trend was observed in winter. More than 7% crude protein was generally present in the herbage during the growing seasons and only 4% during the dormant season.

Table 6.1. Seasonal concentration in crude protein (%), phosphorus (ppm) and fibre (%) of plant species occurring in controlled grazing at Makhi ranch

Plant species	Seasons											
	Summer			Autumn			Winter			Spring		
	Protein	Phos	fibre	Protein	Phos	Fibre	Protein	Phos	Fibre	Protein	Phos	Fibre
D.eri	7.73	.063	34.11	4.39	.036	35.71	4.06	.036	35.86	4.61	.047	35.80
E.leh	6.04	.052	34.82	4.05	.040	34.73	3.83	.037	36.46	4.55	.048	36.85
E. rig	5.67	.057	32.98	4.06	.043	33.36	4.12	.044	33.02	4.02	.049	35.65
S. pap	4.98	.073	36.21	3.72	.041	38.26	3.55	.035	38.71	4.27	.044	37.30
S. uni	5.66	.061	37.02	3.98	.043	38.90	3.17	.034	38.72	4.49	.047	41.17
P. max	8.03	.081	34.00	6.80	.055	37.06	5.21	.071	34.92	5.59	.076	34.34
U. tri	9.13	.110	30.85	5.38	.048	32.46	5.42	.049	35.28	4.89	.052	35.55
M. alb	7.81	.072	25.55	3.58	.040	32.89	3.86	.043	31.49	3.32	.041	32.55
E afr	13.67	.209	30.21	6.07	.068	33.41	-	-	-	-	-	-
D. aeg	15.16	.225	29.89	9.34	.087	30.23	-	-	-	-	-	-
Aristida spp	4.67	.062	40.94	3.24	.042	40.31	3.31	.039	43.03	2.86	.022	42.36
A.thu	11.69	.289	21.70	11.2	.217	25.0	-	-	-	-	-	-
C. bei	13.71	.192	23.09	8.61	.195	29.01	-	-	-	-	-	-
I. dal	16.41	.095	23.81	6.92	.044	30.10	-	-	-	-	-	-
T. ter	13.11	.283	25.60	11.77	.213	26.70	-	-	-	-	-	-
Mean	9.27	.123	30.75	6.22	.082	33.19	4.06	.049	36.39	4.29	.053	36.84
Std Dev.	± .64	± .01	± .42	± .90	± 0	± 5.37	± .01	± .01	± 3.02	± .16	± .01	± 2.78

The highest crude protein and phosphorus and lowest fibre content occurred in all forbs and annual grass species except the Aristida species, during the growing season. Their crude protein and phosphorus content declined rapidly after summer. Table 6.1 illustrates that high nutrient levels were more pronounced for those forage species concentrated in the vicinity of the water point (A. thumbergii, T. terrestris, D. aegyptium and E. africana). Unfortunately the forage availability was limited to the growing season. The Aristida species had a very low crude protein or phosphorus content and the highest fibre content of all plant species during all seasons. Amongst the perennial grasses, the crude protein and phosphorus content of D. eriantha and P. maximum peaked at over 7% and 0.06%, respectively during summer and the fibre was as low as 34% (Table 6.1). Of the perennial grasses, S. uniplumis had the highest fibre content in all seasons. Cassia biensis and I. daleoides, representing the perennial forb component, were very high in both crude protein and phosphorus and low in fibre content but that their foliage shattered at the end of the autumn season due to leaf senescence and finally death of the above ground stems.

Fluctuations in seasonal nutrient contant in the free range grazing area followed the same pattern shown in controlled grazing (Table 6.2). On an average basis, however,the nutrient content of the forage, especially crude protein and phosphorus, tended to be lower in the free range grazing management system compared to controlled grazing management system.

Table 6.2. Seasonal variation in crude protein (%), phosphorus (ppm) and crude fibre (%) in the free - range grazing area

Plant Species	Seasons											
	Summer			**Autumn**			**Winter**			**Spring**		
	Protein	Phos	Fibre	Protein	Phos	Fibre	Protein	Phos	Fibre	Protein	Phos	Fibre
D. eri	5.20	.051	36.63	3.59	.035	36.20	2.81	046	35.58	3.48	.037	35.42
E. leh	5.83	.053	35.82	4.21	.036	37.35	3.69	.033	36.12	3.69	.043	35.19
E. rig	5.83	.050	31.90	3.86	.053	33.77	3.37	.027	34.23	3.50	.042	35.41
S. pap	5 .45	.046	37.10	4.48	.052	35.90	3.99	.032	36.84	3.89	.041	38.85
S. uni	4.65	.040	35.55	4.41	.031	39.75	4.34	.045	40.83	3.53	.052	41.47
U. tri	6.01	.060	29.57	4.67.	.039	34.82	4.46	.039	35.20	3.64	.037	33.95
M. alb	6.03	.051	31.65	5.48	.041	33.81	4.61	.032	33.57	3.68	.032	33.67
D. aeg	12.16	.205	29.89	8.34	.089	30.23	-	-	-	-	-	-
E. afr	10.67	.197	30.21	6.07	.079	31.41	-	-	-	-	-	-
Aristida spp	4.50	.035	41.30	3.46	.028	42.24	2.70	.017	43.35	2.92	.024	42.24
C. bie	12.22	.098	26.73	10.08	.097	29.85	-	-	-	-	-	-
I. dal	14.32	.061	21.70	9.90	.062	28.20	-	-	-	-	-	-
T. ter	12.01	.222	24.09	10.56	.158	26.97	-	-	-	-	-	-
Mean	6.46	.069	32.00	5.88	.057	34.44	3.75	.034	36.91	3.54	.039	37.03
Std Dev.	± .82	± .02	± 4.34	± .7	± .01	± .42	± .17	± .01	± 2.34	± .17	± .01	± 2.52

6.3.2 Nutrient content of three forage species growing along the transect from the water

The nutrient content of the three forage species growing along the transect, from the water point at both controlled grazing conditions and the free range grazing area, is illustrated in Fig. 6.1. Significantly ($P<0.05$) high crude protein and phosphorus of the three forage species was limited to the vicinity of the water point. Urochloa trichopus contained higher levels of crude protein and phosphorus and slightly lower fibre content than either E. lehmanniana and E. rigidior at all points along the transect from the water point. Nutrient content at 500m zone and beyond was more or less constant for both the controlled grazing and the free range grazing area. Fibre content of the three forage species was slightly lower at the first point, but the points along the transect did not differ significantly ($P<0.05$). The fibre content of E. lehmanianna was higher (36%) compared to about 34% that of U. trichopus and E. rigidior. The nutrient enrichment near the water point was reflected in the crude protein and phosphorus of the forage grown on these soils, compared to the fibre content which tended to be more or less uniform at all points throughout the transect.

The fibre content tended to be higher in forage on the free range grazing area. This might be due to the high proportion of stems to leaf in forage on free range grazing area compared to controlled grazing conditions since the whole plant sample were analyzed.

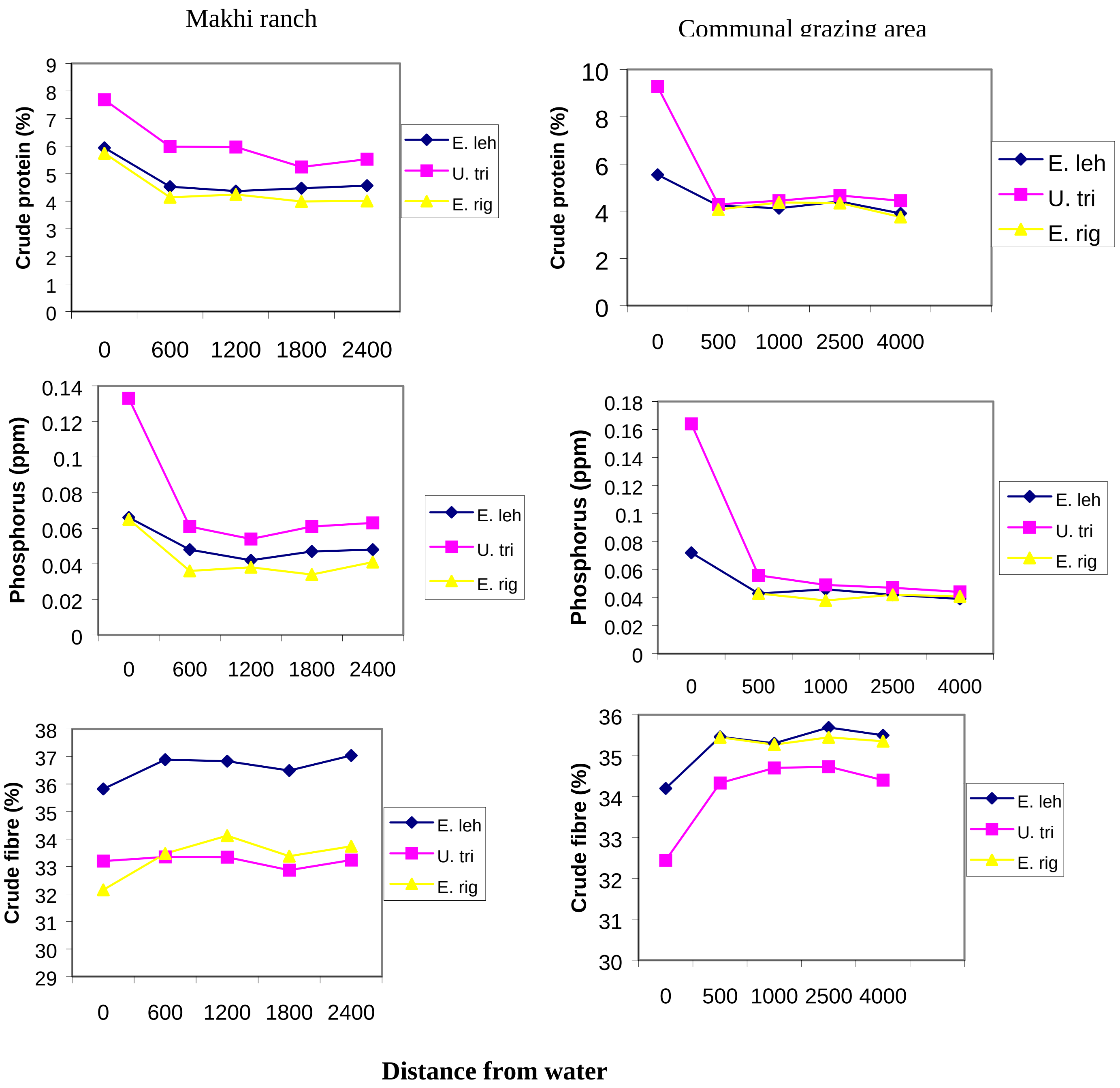

Fig. 6.1 Nutrient content of forage species growing along the transect from water point From both free range grazing and controlled conditions

Fig. 6.1 illustrates that crude protein and phosphorus contents were slightly higher in the free range grazing area than on the controlled grazing conditions at the vicinity of the water point. This might be the result of high stocking rates practiced in the free range grazing area and the greater the impact at the water point (chapter 2).

6.3.3 Nutrient content of forage species between the grazing systems at Makhi ranch

The crude protein, phosphorus and crude fibre were not significantly (P>0.05) influenced by the grazing system when considered on average over two years (Table 3). Fourie et al. (1986) and Rosiere (1975) found no significant difference in crude protein content of forage on continuous and rotational grazing. Seasonal trends were similar for the two systems. However, studies by (Heithold *et al*. 1980) showed that continuous systems had considerably more in crude protein than rotational systems, especially in spring.

Table 6.3. Concentration of crude protein (%), phosphorus (ppm) and crude fibre % between the grazing systems

Plant species	Crude protein			Phosphorus			Crude fibre		
	1 – P	3 - P	9 – P	1 - P	3 - P	9 – P	1 - P	3 – P	9 - P
D.eriantha	4.73	5.66	5.20	.047	.048	.042	34.85	36.42	37.09
E. lehmanniana	4.43	4.66	4.76	.044	.046	.043	36.93	36.26	36.96
E. rigidior	4.18	4.54	4.48	.047	.039	.042	34.77	34.10	33.25
S. pappophoroides	4.77	4.04	4.32	.055	.049	.041	37.55	37.15	38.15
S. uniplumis	4.17	4.51	4.76	.048	.043	.048	39.53	38.70	38.63
P. maximum	6.12	6.49	6.62	.064	.059	.090	36.44	36.11	37.31
U. trichopus	6.21	6.78	6.24	.057	.062	.053	32.78	33.39	34.02
M. albescens	4.80	5.27	4.86	.040	.048	.050	30.86	30.77	30.23
D.aegyptium	12.90	10.79	10.04	.177	.178	.148	28.43	31.33	30.42
Aristida spp	3.55	3.70	3.31	.046	.041	.037	40.72	40.20	41.06
C. biensis	10.82	16.74	10.57	.089	.083	.122	29.90	29.98	30.40
I. daleoides	9.62	9.79	9.58	.072	.059	.082	24.60	24.74	24.51
T. terrestris	13.29	11.58	12.47	.281	.250	.280	24.45	24.25	26.70
Mean	4.59	6.42	5.31	.069	.051	.055	34.36	35.20	35.55
S.Dev	± 1.06	± 2.74	± 2.95	± .022	± .019	± .027	± 3.68	± 1.38	± 3.86

6.4 DISCUSSION

The development of borehole technology imposed a new environmental gradient on the savanna ecosystems with a directional nutrient transport towards the water point by deposition of dung and urine through grazing livestock (chapter 2). The change in distribution of soil nutrients is of significance for plant growth. This nutrient enrichment was reflected in the nutrient content of those herbaceous plants growing in the vicinity of the water point. In both management systems, higher nutrient levels were significantly concentrated at the location in the vicinity of the water point. The tendency for the slightly lower fibre on forage next to the water point might also be due to the heavily grazed plants with fewer stems and/ or absence of old plant material.

Seasonal differences in nutritional status of forage species have been reported widely in literature (eg. Prachett *et al*. 1977; Fourie *et al* 1986; Tolsma et al. 1987b & O'Reagan & Mentis 1990). Such differences have been shown to have a more significant influence on the quality of ingested forage than range condition (O'Reagan & Mentis 1990). There was a gradual improvement in quality as plant accumulated nutrients during the growing season, followed by a decline to the lowest level during plant dormancy. This decline was steep for nitrogen, more gradual for phosphorus or fibre. Despite the lower phytomass provided by forbs and annual grasses (U. trichopus and M. albescens), they supplied a high quality diet to livestock during the growing season.

These data illustrate that the amount of nutrients available for livestock that feed on forage varies considerably during the year. The decline in nutrients is accounted for by decline in concentration of nutrients and loss of herbage weight (chapter 4). According to Louw (1969), a crude protein content of 7 to 9% in the forage appears to be sufficient to sustain beef cattle production. These results suggest crude protein and phosphorus may limit to livestock since both were below their respective animal maintenance requirements (4% and 0.2%, respectively) during winter and /or spring. A decline in crude protein with advanced maturity and reduced availability of forage (Chapter 4) is in agreement with many other grazing studies. Despite not being statistically significant for the autumn, winter and spring seasons, the general decrease in forage quality is of biological significance to the animal. The shortage of phosphorus was not related to season. It was below the 0.2% requirement for maintenance and growth (APRU 1980; Bransby 1981& Church 1986) through out the year. Supplementary feeding is indicated as a possible method of overcoming the problems of crude protein and phosphorus during dry periods.

It should, however, be born in mind that nutrient quality determined from clipped samples had been shown to be not an accurate reflection of what the animals select from the range (Prachett et al. 1977; Shackleton & Mentis 1992). Clipped samples provide only an estimate of the sward quality because plant parts of different quality are pooled together. As such, they are lower in crude protein and higher in fibre content compared to fistula samples (Van Dyne & Heady 1965; Prachett et al. 1977; Fourie et al. 1986; Kreuter & Tainton 1989). However, clipped samples may be adjusted towards more meaningful results since a relatively constant relationship exist between crude protein of clipped and fistula samples from the same area (Shackleton & Mentis 1992).

6.5 CONCLUSION

Range plants exhibit seasonal variations in quality. An understanding of the variation in quality should aid in forage management by indicating peak periods in quality for grazing management. Knowledge of changes in forage quality under grazing is essential in designing efficient grazing management and supplementary programmes. Crude protein and phosphorus during the dry periods were believed to be the major limiting nutrients in the maintaining nutritional quality in grazing animals. Mature forage is generally only adequate to meet maintenance requirements of animals and may require supplementation of crude protein and phosphorus. The nutritional requirements of animals may also be met by conserved forages such as hay and rested / stockpile paddocks may be developed to provide for deficit periods. An other approach is the encouragement of those grass species having above average levels of crude protein, by using certain grazing systems or other rangeland manipulations. Crude protein, phosphorus and fibre were not, however, significantly influenced by the grazing systems. The nutrient enrichment of soil and forage through cattle in the vicinity of the water point was reflected in the nutrient content of forage. This zone was however, very narrow and beyond 500m, plants are not influenced by such enrichment.

CHAPTER 7

FORAGE UTILIZATION AROUND WATER POINTS

7.1 Introduction

Uneven use of rangeland by livestock has been and, continues to be, a major problem confronting range resource managers. An ideal distribution of grazing animals means that grazing pressure is spread over as large a rangeland area as possible. Distribution problems are most severe in arid or desert areas and in mountainous terrains. Factors causing uneven use of rangelands include distance from water, mountainous topography, diverse vegetation and the wrong type of animal. Poor water distribution has been reported to be the chief cause of poor livestock distribution on most rangelands (Holecheck *et al*. 1998). In semiarid environments, water is in short supply and is often poorly distributed. Where available water points are infrequent, large sacrifice areas around such points often occur.

The utilization of the Kalahari sandveld of Botswana on a permanent basis has been facilitated by the deep borehole technology that overcame restrictions of a lack of surface water. Most of these rangelands, especially the communal grazing areas, are today grazed continuously. Even those areas that are properly stocked may be overgrazed near the water points, while remote areas are often grazed lightly, or not at all, due to the fact that with increasing distance from the water point there is an exponential increase in the size of grazing area.

The percentage utilization of different species in most situations is considered an index of preference, or palatability, of a plant species and hence comparative utilization between species often expresses the preference that an animal shows for one species over another. In this context, the term utilization refers to the amount of total herbage production that has been removed currently. Selective grazing, due to differences in relative palatability of species, is confronting all who are concerned with the correct utilization of the rangeland. Theron & Booysen (1966) indicated two forms of selective grazing: species selective grazing and area selective grazing. The causes for differences in palatability between both grasses and vegetation types are not as yet clearly understood in spite of the fact that numerous attempts have been made to relate palatability differences to a number of factors (Heady 1964; Theron & Booysen 1966; O'Reagain & Mentis 1989). When forage plants on a given rangeland are evaluated on the basis of economic importance to grazing animals both the quantity present and the percent utilization need to be considered. The influence of grazing on plants is dependent on several important variables. These include the intensity, degree, frequency and season of grazing. All of these are important in determining the standards of use for range plants.

Many methods have been proposed for measuring the percentage utilization of range plants. The accuracy and interpretation of the measurements obtained have, however, varied widely (Holechek *et al.* 1998). As a result, the concept of utilization and method of calculation are not well understood and remain a controversial subject.

Generally speaking, range utilization, as a whole will be determined by the impact of livestock grazing on the decreaser and increaser plant species. If the ecology of the area is reasonably understood the approach to utilization may be further simplified by selecting one or two key species upon which to base proper utilization. This study was designed to evaluate the impact of livestock grazing on the individual plant species, as affected by the distance from the water point.

7.2 Material and methods

The degree of herbaceous plant utilization was assessed at the same location where plant phytomass was recorded (chapter 5). A single pin was placed into the ground. The area around the pin was divided into four quarters by drawing two imaginary lines through the pin. Within each quarter of the sampling unit the nearest plant to the pin was assessed and recorded by species. The assessment procedure followed that used by Daines (1976), which arbitrarily classified plant utilization into four classes.

These classes were:

Class 4.	Ungrazed plant. No sign of plant having been grazed by the animal.
Class 3.	Less than 50% of the plant removed.
Class 2.	More than 50% of the plant removed.
Class 1.	Totally utilized. All material removed, only stubble remaining.

Each point consisted of four plants. A total of fifty points (200 plants) were recorded at each distance in a straight line at every two meter interval.

7.2.1 Statistical Analysis

Descriptive statistics were used to summarize the data according to relevant parameters. The main effects of season, grazing system and distance from water on forage utilization was determined by General Linear Model (SAS 1990). Where differences were significant at the 5 percent level, Scheffe’s test was used to separate the means.

7.3 RESULTS

7.3.1 Seasonal forage utilization in controlled grazing conditions

The mean utilization of individual plant species between the seasons is illustrated in Table 7.1. There were significant differences between the seasons in the utilization of each species. Significantly ($P<0.05$) higher utilization of individual plant species was observed during spring and was lowest in summer of both years. Utilization of each plant species was higher during the 1997/98 dry season than in 1996/97 dry season. This might have been accounted for by the low available phytomass experienced during 1997/98, due to the poor rainfall (chapter 2).

The utilization of D. aegyptiun, E. africana, T. terrestris and A. thumbergii increased significantly ($P<0.05$) from summer through autumn and winter into spring to the extent that available forage could not be found during spring. P. maximum followed a similar trend. Among the other perennial grasses, D. eriantha, E. lehmanniana and S. pappophoroides were more heavily utilized than S. uniplumis, E. rigidior and miscellaneous grasses. However, the utilization of D. eriantha was markedly lower during summer compared to other seasons. While the forb component was generally poorly utilized in all seasons, U. trichopus and M. albescens were notably better utilized than grasses such as S. uniplumis and E. rigidior.

Table 7.1. Seasonal utilization (%) of forage species in the sward over two years in controlled grazing condition at Mahki ranch

Plant Species	**Season of year**							
	Summer 1996/97	Autumn 1996/97	Winter 1996/97	Spring 1996/97	Summer 1997/98	Autumn 1997/98	Winter 1997/98	Spring 1997/98
D. eri	2.0^{d}	18.0^{c}	31.0^{b}	60.75^{a}	3.5^{d}	19.75^{c}	32.75^{b}	62.5^{a}
E. leh	7.75^{d}	15.25^{c}	26.5^{b}	50.25^{a}	5.75^{d}	15.0^{c}	26.25^{b}	50.0^{a}
E. rig	6.75^{c}	6.0^{c}	17.0^{b}	34.25^{a}	6.0^{c}	16.0^{b}	27.0^{b}	44.25^{a}
S. pap	4.0^{d}	9.25^{c}	26.5^{b}	49.75^{a}	7.5^{d}	17.25^{c}	34.5^{b}	57.75^{a}
S. uni	1.5^{c}	3.5^{c}	15.0^{b}	40.75^{a}	3.75^{c}	4.5^{c}	19.0^{b}	44.75^{a}
P. max	30.5^{d}	53.0^{c}	69.5b^{c}	87.5^{b}	38.5^{c}	70.75^{b}	87.25^{b}	100.0^{a}
Misc grass	1.0^{c}	8.5^{b}	10.5^{b}	43.5^{a}	.75^{c}	3.0^{c}	5.0b	38.0^{a}
M.alb/U.tri	1.5^{e}	4.75^{d}	22.75^{c}	52.75^{b}	6.75^{d}	19.75^{c}	37.75^{bc}	67.75^{a}
C.bie/I.dal	0.25^{c}	1.0^{c}	4.25^{b}	47.25^{a}	.5^{c}	2.75^{b}	6.0^{b}	49.0^{a}
D.aeg/E.afr	26.5^{d}	52.25^{c}	75.0^{b}	100.0^{a}	47.0^{c}	73.0^{b}	95.75^{a}	100.0^{a}
A.thu/T.ter	16.5^{d}	56.25^{c}	74.25^{b}	100.0^{a}	39.0^{c}	54.75^{c}	77.25^{b}	100.0^{a}
Misc forbs	.25^{c}	2.75^{c}	11.25^{b}	26.5^{a}	1.25^{c}	5.5^{c}	17.0^{b}	32.5^{a}
Mean	8.20	19.79	25.83	57.77	13.35	25.42	38.79	62.21

Means in each column followed by the same superscript are not significantly different between the seasons

7.3.2 Forage utilization along the transect from the water point in controlled grazing conditions

The mean percentage utilization of all plant species at each point along the transect from the water point was 69.25, 22.75, 21.25, 20.00 and 14.5 at 0, 600, 1200, 1800 and 2400m, respectively (Table 7.2). Grazing tended to be more uniformly distributed between 600 and 1800m zone along the transect and was slightly lower at 2400m.

The point in the immediate vicinity of the water point contained no D. eriantha, S. uniplumis, S. pappophoroides and I. daleoides/ C. biensis probably due to trampling or over utilization in the foregoing years. The utilization of annual grasses and forbs growing in the vicinity of the water point was higher than that of other annual grasses growing elsewhere (U. trichopus and M. albescens).

Panicum maximum was the most heavily utilized throughout the transect from the water point while forbs were the most lightly utilized. Digitaria eriantha and S. pappophoroides were generally more heavily utilized than E. lehmanniana and E. rigidior, which in turn were better utilized than S. uniplumis or miscellaneous grasses. Excluding the first point along the transect where, because of trampling, S. uniplumis and the perennial forbs (I. daleoides and C. biensis) were absent, these species were utilized 13% and 6%, respectively.

Table 7.2. Percent utilization of forage species at each point along the transect from the water point in controlled grazing.

Plant species	Distance from water (m)					
	0	600	1200	1800	2400	Mean
D. eri	n/a	32.75^{a}	26.50^{b}	21.00^{c}	17.75^{d}	39.60
E. leh	44.00^{a}	29.75^{b}	22.00^{c}	15.00^{d}	15.75^{d}	25.30
E. rig	66.75^{a}	20.75^{b}	13.25^{c}	12.00^{c}	12.25^{c}	25.00
S. pap	n/a	32.75^{a}	23.75^{b}	18.75^{c}	20.25^{c}	39.11
S. uni	n/a	17.75^{a}	13.75^{b}	11.25^{b}	11.25^{b}	30.80
P. max	62.00^{a}	40.25^{b}	31.25^{b}	40.75^{b}	45.75^{b}	44.00
Misc grasses	38.25^{a}	13.50^{b}	8.85^{c}	7.25^{c}	8.85^{c}	15.34
M. alb / U. tri	46.75^{a}	19.75^{b}	11.50^{c}	8.75^{d}	9.75^{d}	19.30
C. bie / I.dal	n/a	8.25^{a}	3.25^{a}	3.50^{a}	9.75^{a}	24.94
D. aeg / E. afr	56.50^{a}	46.25^{b}	n/a	n/a	n/a	51.38
T. ter / A. thu	41.00^{a}	n/a	n/a	n/a	n/a	41.00
Misc forbs	21.00^{a}	10.00^{b}	4.50^{c}	3.00^{c}	.50c	7.80
Mean	69.25	22.75	21.25	20.75	14.50	30.30

Values in each column followed by the same superscript are not significantly different between the distances

7.3.3 Forage utilization between grazing systems

The mean utilization of all plant species was not significantly ($P>0.05$) different on the different grazing systems although the 9 – paddock system tended to be slightly more heavily utilized (Table 7.3). The stocking rate applied might be not have been sensitive enough to give differences between the grazing systems. Miscellaneous grasses were only slightly more heavily utilized in the 9 – paddock system compared to other systems, while forbs were poorly utilized in all grazing systems. Panicum maximum and annual grasses or forbs growing around the water point were utilized more heavily than other plants and their utilization was higher in the 1 – paddock and 3 – paddock systems than the 9 – paddock system. In general, D. eriantha, E. lehmanniana and S. pappophoroides were utilized more than other perennial grasses, with the exception of P. maximum.

Table 7.3. Percent utilization of forage species in each grazing system at Makhi ranch

Plant species	**Grazing System**		
	1 – P system	3 – P system	9 – P system
D. eri	23.50^{b}	25.25^{a}	24.00^{a}
E. leh	19.50^{c}	22.00^{b}	28.25^{a}
E. rig	20.50^{a}	18.00^{a}	14.25^{a}
S. pap	22.50^{b}	25.75^{a}	23.25^{b}
S. uni	14.75^{a}	10.75^{b}	12.50^{ab}
P. max	58.75^{a}	61.5^{a}	55.25^{a}
Misc grasses	10.50^{a}	10.25^{a}	11.00^{a}
M. alb / U. tri	11.75^{b}	14.25^{a}	12.75^{b}
C. bie / I. dal	4.50^{a}	4.75^{a}	6.25^{a}
D. aeg / E. afr	59.50^{a}	61.75^{a}	47.75^{b}
A. thu / T. ter	41.75^{a}	43.25^{a}	23.50^{b}
Misc forbs	7.25^{a}	8.00^{a}	4.00^{b}
Mean	24.5	25.46	26.75

Values in each column followed by the same superscript are not significantly different between the grazing systems

7.3.4 Seasonal forage utilization in the free range grazing areas

The mean utilization of individual plant species between the seasons in free range grazing areas is illustrated in Table 7.4. Significantly (P<0.05), higher utilization of the individual forage species was achieved by spring and was lowest in summer of both years. Utilization of most plant species tended to be higher during the 1997/98 grazing year compared to that of 1996/97. This was probably due to the lower forage availability in that season due to the low rainfall.

Significantly (P<0.05) higher utilization rates of annual plant species growing in the immediate vicinity of the water point during the growing seasons was observed and they were totally utilized during the dry periods. Utilization of miscellaneous grasses and forbs was relatively light compared to D. eriantha, E. lehmanniana and S. pappophoroides. Amongst the perennial grasses, D. eriantha was in the first order of being utilized by grazing animals. Panicum maximum was notably absent from this rangeland. Animals also tended to utilize E. lehmanniana and S. pappophoroides more heavily than S. uniplumis or E. rigidior. However, D. eriantha tended to be lightly utilized during the summer period compared to the other major perennial plants of this sandveld.

Table 7.4. Seasonal utilization (%) of forage species in the sward in the free – range

grazing area

Plant species	Season of year							
	Summer 1996/97	Autumn 1996/97	Winter 1996/97	Spring 1996/97	Summer 1997/98	Autumn 1997/98	Winter 1997/98	Spring 1997/98
D. eri	4.25^{e}	6.00^{e}	25.50^{d}	53.75^{b}	3.75^{e}	42.00^{c}	61.00^{b}	89.75^{a}
E. leh	21.75^{b}	19.00^{c}	27.75^{b}	58.25^{a}	14.75^{c}	23.50^{b}	32.25^{b}	61.75^{a}
E. rig	5.25^{d}	14.75^{c}	18.75^{c}	46.00^{a}	8.00^{c}	24.25^{b}	28.25^{b}	55.50^{a}
S. pap	1.50^{e}	13.50^{d}	31.00^{c}	46.25^{b}	8.25^{de}	12.25^{d}	44.50^{b}	59.75^{a}
S. uni	2.25^{bc}	6.75^{b}	8.50^{b}	40.25^{a}	1.00^{e}	1.00^{c}	9.50^{b}	41.25^{a}
Misc gr	5.25^{d}	10.25^{c}	25.50^{b}	49.00^{a}	4.75^{d}	10.25^{c}	31.50^{b}	59.00^{a}
M.alb	6.75^{e}	13.00^{c}	25.25^{b}	50.25^{a}	7.50^{e}	12.00^{c}	24.25^{b}	53.25^{a}
C.bie	1.00^{b}	4.50^{b}	8.00^{b}	38.00^{a}	$.75^{b}$	2.00^{b}	3.50^{b}	35.50^{a}
D.aeg	50.00^{d}	57.00^{c}	75.00^{b}	100.0^{a}	50.00^{d}	68.50^{b}	76.00^{b}	100.0^{a}
T.ter	47.50^{c}	74.00^{b}	75.00^{b}	100.0^{a}	57.75^{c}	57.75^{c}	87.50^{b}	100.0^{a}
Misc.for	6.50^{c}	7.75^{c}	19.00^{b}	39.00^{a}	7.75^{c}	9.25^{c}	21.75^{b}	37.75^{a}
Mean	13.82	20.59	30.84	56.39	14.93	23.89	38.18	63.05

Values in each column followed by the same superscript are not significantly different between the seasons

7.3.5 Forage utilization along the transect from the water point in free – range grazing areas

Table 7.5 illustrates the utilization of the individual plant species along transects from the water point in the free range grazing area. Significant ($P<0.05$) differences in the utilization of each species occurred between the points. The mean herbage utilization for all plant species at each point was 68.73, 45.82, 20.78, 15.40 and 9.44 at the 0, 500, 1000, 2500 and 4000m from the water point, respectively. In the immediate vicinity of the water point, perennial grasses were completely absent, and only annual plants occurred. Forage utilization was 23% higher at the 0m point than at 500m (68.7% vs. 45.8%), which was also 36.4% higher than at the 4000m point. The average utilization of the major perennial grasses was 48% higher at 500m point (a zone where they start to occur) than at the 4000m point along the transect from the water.

Digitaria eriantha was utilized more heavily at 1000m point compared to other perennial grasses and the miscellaneous grasses were the least utilized. Eragrostis rigidior and S. uniplumis become more available at 1000m point, while D. eriantha and E. lehmanniana were about 60% grazed at 2500m point from the water. The influence of grazing had not tapered off at 4000m from the water point indicating that animals travel beyond this point.

Utilization of D. aegyptium, E. africana, A. thumbergii and T. terrestris at the 1000m point or beyond was minimal or not present because these species were largely limited to where soil disturbance occurred. Miscellaneous forbs and grasses were poorly utilized throughout the transects.

Table 7.5. Percent utilization of forage species at each point along the transect from the water point in the free range grazing area

Plant species	**Distance from water**					
	0	500	1000	2500	4000	Mean
D. eriantha	100.00	60.50^{a}	52.00^{b}	30.00^{c}	10.50^{d}	50.80
E. lehmanniana	75.00^{a}	56.50^{b}	28.00^{cd}	33.75^{c}	23.50^{d}	45.35
E. rigidior	100.00	58.50^{a}	24.25^{b}	7.50^{c}	4.50^{c}	38.95
S. uniplumis	100.00	55.00^{a}	18.25^{b}	14.00^{b}	9.75^{b}	39.40
S. pappophoroides	100.00	66.50^{a}	26.50^{b}	22.25^{b}	10.00^{c}	45.10
Misc grasses	53.75^{a}	40.25^{a}	15.50^{b}	13.50^{b}	13.50^{b}	27.30
M. alb / U. tri	68.00^{a}	31.75^{b}	16.50^{c}	12.25^{c}	7.25^{d}	27.15
C. bie / I. Dal	8.55^{a}	7.25^{a}	5.50^{a}	3.50^{a}	3.50^{a}	5.66
D. aeg / E. afr	65.75^{a}	62.50^{a}	n/a	n/a	n/a	64.12
A. thu / T. ter	51.00^{a}	48.50^{a}	18.75^{b}	n/a	n/a	49.75
Misc forbs	34.00^{a}	16.75^{b}	2.75^{c}	1.50^{c}	2.75^{c}	11.55
Mean	68.73	45.82	20.78	15.40	9.44	36.65

Values in each column followed by the same superscript are not significantly different between the distances

7.4 DISCUSSION

The determination of forage utilization of different species is necessary as all grasses are not equally utilized by grazing animals. By considering the forage utilization of dominant grasses in a particular area, one can obtain an indication of their grazing potential.

The above results indicate that the utilization of forage species varied with season, species and distance from the water in both 1996/97 and 1997/98 seasons. Forage utilization was heaviest during spring and lowest in summer period. These differences were caused by the different phenological growth stages of plant and cumulative utilization, after growth, of the available forage by the grazing animals. Utilization during early phenological growth stages (eg. Summer) appeared to be low because plants were growing actively and being grazed at the same time. The highest percentage forage utilization was in the year of low production and the lowest percentage forage utilization was in the year of high production, confirming the findings of Martin & Ward (1970) and Cook *et al.* (1965) working in the desert grassland. If high forage utilization rates coincide with drought, then the vigour of preferred perennial species might diminish; and an increase in annual plant species may be expected the following year due to a reduction in cover.

Forage utilization of grasses in the zone within 600m of the water was at least double that in the zone 600 – 1500m zone under controlled grazing management. Comparisons between 600 – 1800m from water showed no difference in forage utilization at Makhi ranch. Utilization of the five major perennial grasses was affected to different degrees by the distance from water (Table 7.2 & 7.5). Digitaria eriantha was the most affected followed by E. lehmanniana and S. pappophoroides by the end of the grazing season. Digitaria eriantha is considered to be a decreaser while E. lehmanniana and S. pappophoroides are considered increasers II in terms of grazing response. S.uniplumis is the other abundant perennial grass found in the sandveld. It was not utilized much by cattle, and exhibited no definite trend with distance from water. This grass is highly fibrous and lower in nutritional value than other perennial grasses (Chapter 6). Eragrostis rigidior was slightly better utilized than S. uniplumis.

The degree of utilization along the transect from water did not taper off at the 4000m point in the free range grazing area, suggesting that livestock travel beyond this point. Farmers in the free range grazing area usually water their cattle every other day to increase their range of grazing during periods of forage scarcity. Maximum “piosphere” size is determined by the distance livestock travel before returning to water. The presence of annual plants, associated with soil disturbance at the 1000m point from water, were indications that the ‘sacrifice’ zone was larger in the free range grazing management area than in the controlled ranch management condition (Table 7.2 & 7.5).

Most grazing systems do not attempt to improve plant production around the water points, but either accept it, as it occurs, or simply do not concern themselves with this problem. It should be noted that many of the plants growing in these ‘sacrifice’ zones are frequently toxic to livestock and may cause problems at certain seasons. Improved plant composition around water points is certainly a worthy goal, if it will help alleviate these problems. Grazing distribution is the major problem that grazing systems seek to solve. It then becomes critical to select a grazing system that allows forage plants near water points to increase or maintain their productiveness while the grazing animals make better use of the plants some distance away from water. These sacrifice zones are often accepted as inevitable and it is generally thought that the larger the paddock and, the longer the animals stay in the paddock, the bigger the sacrifice zone. Such factors have a negative impact on forage production in the free range grazing management areas, where animals stay permanently on the same area. One grazing system that addresses this problem is rotating access to water (Martin & Ward 1970). This system may be suited for borehole dependent livestock such as those found in Botswana free range grazing areas, where distances between boreholes is greater and grazing often does not overlap between water points.

7.5 CONCLUSION

Livestock use forage plants more heavily near water points compared to areas away from water. Data from this study confirms that forage utilization in both free range grazing and controlled grazing management systems was heaviest in the zone around the water point. The utilization of perennial grasses in the 500m zone was 59 % in the free range grazing area while only 26 percent was recorded in the ranch condition. Forage utilization and the ‘sacrifice zone’ were greater in the free range grazing management system than the controlled management system.

In general, utilization was higher following a drought year, when grazing pressure was concentrated on reduced available forage. Forage utilization was greatest in spring and least in summer. Amongst the perennial grasses D. eriantha, E. lehmanniana and S. pappophoroides were in the first order of utilization following those annual species growing in the vicinity of the water point. Panicum maximum, where it occurred, was the most palatable. Forbs, excepting those found near the water point, were general poorly utilized by livestock.

Grazing along the transect from the water point tended not to taper off in the free range grazing area suggesting that livestock travel beyond 4000m. Piopshere size, as determined by the distance livestock can travel, was greater in free range grazing management area than in the ranch management condition.

Rotating access to water by livestock has been indicated as a method to promote production of forage around water points and to reduce the grazing impact in this zone.

CHAPTER 8

Diet Preferences of Livestock

8.1 Introduction

Diet selection in terms of both quantity and quality is primarily a function of the types and amount of feed on offer. Selective grazing, due to differences in relative palatability, is a problem confronting all who are concerned with the practices of correct range utilization. Theron & Booysen (1966) identified two forms of selective grazing, namely species selective grazing and area selective grazing. The causes for differences in palatability amongst both grasses and vegetation types are as yet not clearly understood in spite of the fact that numerous attempts had been made in the past to relate preference differences to a number of factors (; Heady 1964; Theron & Booysen 1966; Gammon & Roberts 1978; O'Reagain & Mentis 1989).

The measurement of animal preferences presents numerous problems that, as yet, have not been entirely overcome. The result is that no standard method has been devised by which animal preference can be successfully measured under a variety of conditions. In this study, conducted under both controlled grazing and free–ranging conditions, research was aimed at answering pertinent questions regarding the botanical composition of diets selected by cattle, sheep and goats in different seasons and to clarify the dietary interrelationships between the animal species.

8.2 Material and methods

Freshly dropped dung or pellet samples were collected at the water point in the case of cattle, and from rectal samples in the case of sheep and goats. One or two pellets from each individual goat or sheep and a small grab sample from each mound of cattle dung were taken. At least fifteen sub - samples were collected from each animal species at a time. Sub - samples of each animal species were composited into a single sample and about 70 grams was kept for the final sample. Samples were collected over four days within each season throughout the year. Samples were preserved immediately by adding an equal amount of coarse sodium chloride as indicated by Hansen *et al.* (1978) and air dried.

Samples of herbaceous species in the study area were collected for microhistological reference slides. Leaf samples were prepared for the slides. Sample preparation for both faecal and reference plant material were ground using a Wiley mill through a 1 mm screen. A 5 - 10 g ground sub - sample (faecal or reference plant material) was soaked in household bleach for 30 minutes to remove the pigments (Holechek *et al.* 1982). After soaking, the sub - sample was placed over a 200 mesh screen for washing with hot water for about ten minutes, making sure that all the bleach was removed. A metal templet, 2.5cm x 51cm x 1mm with a 5 - 6 mm bore opening was used to simplify the making of slide samples. A small sub - sample was filled on the bore opening when using a 75mm x 25mm slides and 40mm x 22mm cover slips. Two drops of Hertwig's clearing solution (Appendix 1) were added on the sub - sample. The slide was heated over the open flame until most of the Hertwig's solution had evaporated without burning the sample. Hover's mounting medium (Appendix 1) was then added and thoroughly mixed with the sub - sample and spread over the slide for cover slipping. A cover slip was placed over the sample and the slide was again heated until the sample mixture was bubbling evenly. The slide was pressed after being placed on a cool wet cloth until all bubbles were withdrawn from under the cover slip. Slides were dried at 50 - 55 ^{0}C.

Five slides per faecal sample were prepared for each animal species (cattle, sheep and goats) and two slides for each plant species for the reference plant material.

A microscope using 100X objective was used to identify plant species or genera based on the epidermal characteristics. At each location (field) in the slide, plant species present were recorded. Twenty fields were read from each of the five faecal slides, resulting into a total of 100 fields per sample. The characteristics in the sample slides were matched with those in the reference material. The percentage frequency of each identified plant species was converted to density of particles per microscope field (Dearden *et al.*1975; Sparks &

Malechek 1968). The relative density of fragments was then obtained from the frequency figures.

Example:

Frequency of five slides from sheep faecal sample
5 slides x 20 fields/slide = 100 microscopic fields examined
Digitaria eriantha occurred in 33 of the fields
% frequency = 33 / 100 occupancies X 100 = 33%

Density of fragments per microscopic field

Density = In [1 - (F/100)]
where In = natural logarithm and F = frequency (%)

$$\text{Relative Density} = \frac{\text{Density of fragments per species}}{\text{Sum of densities of fragments of all species}} \times 100$$

8.3 Statistical analysis

Plant species diversity was calculated to indicate the diet breadth, on the basis of Shannon-Wiener Function (Krebs 1989) formula:

$$H' = \sum^{n}_{1=1} (p_i)(\log_e P_i)$$

Where p_i = the proportion (%) of total sample belonging to the i^{th} species in the diet
and n = total number of resource states

Plant species diversity indices indicates variety and evenness of components in the diet. The index increases with an increasing number of plants in the diet. High species diversity indices indicate that the animals do not rely on a few plant species for most of their diet, but feed on a broad spectrum. Animal species characterized by high species diversities are potentially better able to adapt their diet changes in plant composition. H' was selected because it is independent of sample size. Wolda (1981), however, indicated that it was sensitive to changes of rare species in the community.

Food habit studies of more than one animal species usually compare diet overlaps between any combination of two diets. Dung analyses for botanical composition can be used to estimate the appropriate amount of diet overlap between different animal species. Overlap between diets was calculated using Morisita's similarity index (Morisita 1959)

$C = 2 \sum n_{ij} n) / [(\lambda_1 + \lambda_2) N_j N_k]$

Where C_λ = Morisita's index of diversity of similarity between samples j and k (e. g. between cattle and sheep)

$N_{ij}\ n_{ik}$ = no. of individual of species i in sample j and sample k

$N_k = \sum n_{ik}$ = total no. of species in sample k (e.g. cattle)

$\lambda_1 = \sum^n [n_{ij\ (ij} (n_{ij} - 1) / N_j (N_j - 1)]$

A similarity index represents the percentage of the diet that is identical, or the percentage of the diet that is shared by two animals. This index was preferred over other similarity indices because it is independent of sample size and species diversity (Wolda 1981) and it shows potential for forage competition between animals.

Relative preference indices (RPI) for different plant species by different animals were determined using Krueger's (1972) formula:

RPI = % frequency in the diet composition / % frequency on the range composition

Following calculations, the main effects of seasons and animals were determined using GLM procedure SAS (1985). Where significant differences occurred, Scheffe's test was used to separate the means.

8.4 RESULTS

8.4.1 Livestock Diet Compositions under free ranging conditions

The list of plant species identified in the dung samples of cattle, sheep and goats grazing under both controlled and free ranging conditions is presented in Table 8.1. Thirty six plant species comprised the diet of these animal species. Three grasses, two forbs and one woody plant could not be identified from the dung samples. Of the eighteen grass species found in the dung samples, 78%, 68%, and 55% were found in the dung of cattle, sheep and goats, respectively. Forbs were insignificant in the diets of these animals.

Table 8.1 List of plant species occurring in seasonal diets of cattle, sheep and goats for both controlled grazing conditions and free – range grazing

Grasses	**Forbs**	**Woody plants**
A. congesta	C. beiscensis	A. fleckii
A.graciliflora	I. daleoides	A. gerrardii
D. aegyptiun	Sida cordifolia	B. albitrunca
D. eriantha	T. terrestris	B. petersiana
E. lehmanniana	FOR1	C. gratissimus
E. pallens	FOR2	D. cinerea
E. rigidior		G. flava
E. africana		G. retinervis
M. albescens		M. sericea
M. repens		R. bravispinosum
P. maximum		T. sericea
P. squarrosa		WD1
S. pappophoroides		
S. uniplumis		
U. trichopus		
GRA1		
GRA2		
GRA3		

8.4.2 Diet composition of cattle

Seasonal diet compositions of cattle, sheep and goats are illustrated in Fig. 8.1. A total of 25 plant species were found in the diet of cattle of which included 75% grasses, 23% browse and 2% forbs. Seasonally, cattle diets were dominated by grass species. Nine grass species with >1% density, occurred in the diet of cattle throughout the year and eight browse species were observed in the dung samples during the wet and dry seasons (Table 8.2). Dichrostachys cinerea was observed only during the summer period. The occurrence of forbs in the dung was insignificant. That epidermal tissues of forbs were not easily found in cattle and sheep faeces (Free *et al.* 1970; McInnis 1977) or in that of grey rhebuck (Ferreira & Bigalke 1987). The dominant grasses occurring in the diet of cattle included D. eriantha, U. trichopus, S pappophoroides, E. lehmanniana, M albescens, E. rigidior and S. uniplumis while woody species included G. flava. M. sericea, C. gratissmus, B. petersiana, B. albitrunca and A. gerrardii.

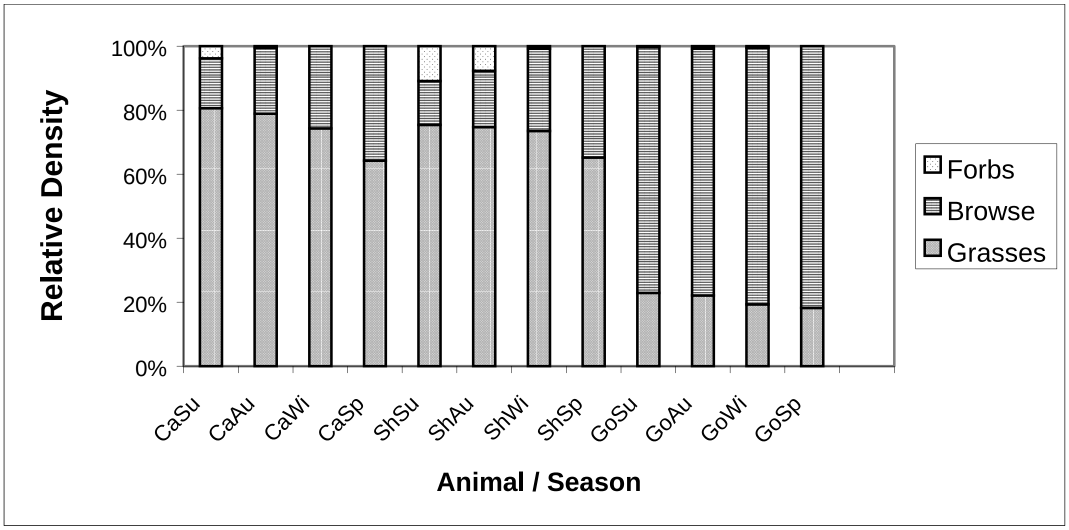

Fig 8.1 Average seasonal plant species class distribution between diets of cattle, sheep and goats in free ranging conditions.

Key to animal / season: Ca = cattle, Sh = sheep,

Go = goats, Su = summer, Au = autumn, Wi = winter and Sp = spring.

Table 8.2 Average relative densities (%; mean ± SE) of plant species in seasonal diets of cattle in free ranging conditions

Plant species	Summer	Autumn	Winter	Spring	Mean
A. congesta	0.3 ± 0.2	0.2 ± 0.1	0	0.1 ± 0.1	0.15
A. graciliflora	0.3 ± 0.1	0.1 ± 0.1	0.3 + 0.1	0.4 ± 0.2	0.28
D. aegyptium	0.3 ± 0.3	0.4 ± 0.1	0	0	0.18
D. eriantha	9.9 + 1.2	15.1 + 0.6	14.4 + 1.2	10.7 + 0.6	12.53
E. lehmanniana	9.3 ± 0.4	10.2 ± 1.2	9.9 + 0.7	8.7 ± 0.7	9.53
E. pallens	0.8 ± 0.1	0.3 ± 0.1	0.2 + 0.1	0.2 ± 0.1	0.38
E. rigidior	7.4 ± 1.1	8.3 ± 0.8	9.4 + 0.5	13.8 ± 1.2	9.73
E. africana	1.9 ± 0.1	0.7 ± 0.1	0	0	0.56
M. albescens	12.7 ± 1.3	11.0 ±1.1	8.7 ± 0.9	3.9 ± 0.9	9.1
P. squarrosa	0.4 ± 0.1	0	0	0	0.10
M. repens	0.9 ± 0.1	0.4 ± 0.1	0	0	0.31
S. uniplumis	7.8 ± 0.5	9.3 ± 1.4	10..8 ± 0.6	13.3 ± 1.8	10.3
S.pappophoroides	10.4 ± 1.3	12.2 ± 1.6	11.7 ± 0.9	9.8 ± 0.9	11.0
U. trichopus	13.9 ± 1.2	10.7 ±0.9	6.3 ± 0.7	3.6 ± 0.7	8.6
C. beiscensis	1.3 + 0.1	0.5 ± 0.1	0	0	0.45
S. cordifolia	0.2 ± 0.1	0	0	0	0.05
T. terrestris	2.3 ± 0.2	05 ± 0.2	0	0	0.7
B. albitrunca	2.6 ± 0.4	3.1 ± 0.2	4.3 ± 0.4	6.1 ± 0.2	4.0
B. petersiana	2.9 ± 0.1	2.3 ± 0.3	2.9 ± 0.3	3.5 ± 0.1	2.90
C. gratissimus	3.4 ± 0.4	4.7 ± 1.2	5.9 ± 0.8	7.6 ± 0.5	5.40
D. cinerea	0.4 ± 0.1	0	0	0	0.10
G. flava	4.4 ± 0.3	4.9 ± 0.6	6.2 ± 0.7	8.7 ± 0.8	6.10
G. retinervis	0.4 ± 0.1	2.1 ± 0.1	2.0 ± 0.3	2.3 ± 0.2	1.70
M. sericea	3.4 ± 0.2	3.9 ± 1.3	6.7 ± 0.9	6.5 ± 1.2	5.13
T. sericea	0.1 ± 0.1	0	0.1 ± 0.1	0.8 ± 0.1	0.25

8.4.3 Diet Composition of sheep

Diet of sheep consisted of twenty one plant species; of which 74% were grasses, 21% woody species and 5% forbs (Fig. 8.1). The dominant grass species included D. eriantha, S. pappophoroides, M. albescens, U.trichopus, E. lehmaniana and major woody species included G. flava, M. sericea, C. gratissimus (Table 8.3). Higher amount of grass and forbs were found in the diet of sheep during the summer period than in spring. The relative densities of browse in sheep diets were lower during wet seasons and higher during dry seasons.

Table 8. 3 Average relative densities (%; mean ± SE) of plant species in seasonal diet of sheep in free ranging conditions

Plant species	Summer	Autumn	Winter	Spring	Mean
A. graciliflora	0.3 ± 0.1	0.2 ± 0.2	0.2 + 0.1	0.3 + 0.1	0.25
D. aegyptium	3.7 ± 0.5	2.8 ± 0.2	1.3 ± 0.3	0	3.90
D. eriantha	13.1 ± 1.0	13.8 ± 0.6	11.9 ± 0.8	10.6 ± 0.6	12.35
E. lehmanniana	10.3 ± 0.5	9.8 ± 0.8	9.2 ± 0.5	8.4 ± 0.6	9.45
E. rigidior	6.7 ± 1.3	8.4 ± 0.5	8.4 ± 0.6	9.3 ± 0.7	8.20
Eragrostis spp.	0.9 ± 0.1	0.8 ± 0.1	0	0	0.43
M. albescens	13.0 ± 0.7	11.2 ± 0.4	12.7 ± 0.6	6.9 ± 1.3	10.95
M. repens	1.4 ± 0.9	0.8 ± 0.2	0	0	0.55
S. uniplumis	1.0 + 0.1	2.7 ± 0.3	3.5 ± 0.5	4.4 ± 0.6	2.90
U. trichopus	16.3 ± 1.2	13.4 ± 1.1	12.5 ± 0.7	7.8 ± 0.9	12.50
S. pappophoroides	9.5 ± 0.8	11.1 ± 0.8	13.9 ± 1.2	17.6 ± 1.5	13.10
C. beinscensis	6.3 ± 0.5	4.3 ± 0.7	0.8 ± 0.1	0	2.85
T. terrestris	4.7 ± 1.4	3.4 ± 0.8	0	0	2.0
Forb 3	0.2 + 0.1	0	0	0	0.05
A. fleckii	0.2 ± 0.1	0.4 ± 0.1	0	0.5 ± 0.1	0.28
A. gerrardii	0	0.8 ± 0.3	1.4 ± 0.8	3.4 ± 0.2	1.40
B. albitrunca	1.5 ± 4.4	1.8 ± 0.4	2.8 ± 0.4	4.5 ± 0.4	2.65
B. petersiana	1.4 ± 0.6	2.2 ± 0.2	2.8 ± 0.6	2.8 ± 0.5	2.33
C. gratissimus	2.9 ± 0.3	3.6 ± 0.6	5.3 ± 0.4	7.6 ± 0.6	4.60
D. cinerea	1.2 ± 0.2	1.6 ± 0.4	2.1 ± 0.1	2.8 ± 0.2	1.93
G. flava	3.3 ± 0.7	4.0 ± 0.5	5.8 ± 0.7	8.1 ± 0.5	5.30
M. sericea	2.8 ± 0.2	3.2 ± 0.6	4.7 ± 0.8	5.3 ± 0.3	4.0
R. bravisponosum	0.5 ± 0.1	0	0.7 ± 0.1	0	0.30

8.4.4 Diet Composition of goats

The diet of goat was composed of 78% woody species, 20% grasses and 2% forbs (Fig. 8.1). Seasonally, the goat diet composition contained over 72% browse. In summer, the diet was 72% browse and this increased to 82% in spring. Species of woody plants occurring in goat diets included G. flava, G. retinervis, M. sericea, C. gratissmus, D. cinerea, B. petersiana, B. albitrunca, A. gerrardii (Table 8.4). The dominant grasses in their diet included D. eriantha, E. lehmanniana, S. pappophoroides, U. trichopus and M. albescens. Seasonally, the goats were found to concentrate on woody species. Plant species composition of their diet tended to vary little throughout the year.

Table 8.4 Average relative densities (%; mean ± SE) of plant species in seasonal diet of goats in free range grazing conditions

Plant species	**Summer**	**Autumn**	**Winter**	**Spring**	**Mean**
A. congesta	0.3 ± 0.1	0.2 ± 0.1	0	0	0.13
D. aegyptium	0.3 +0.2	0.3 + 0.2	0	0	0.15
D. eriantha	4.5 ± 0.2	4.4 ± 0.2	3.4 ± 0.1	3.3 ± 0.1	3.90
E. lehmanniana	3.5 ± 0.4	3.2 ± 0.3	2.7 ± 0.3	2.3 ± 0.3	2.93
E. pallens	0.5 ± 0.3	0.7 ± 0.2	0.3 ± 0.1	0.4 ± 0.2	0.48
E. rigidior	1.2 ± 0.2	1.3 ± 0.1	1.5 ± 0.1	1.5 ± 0.1	1.38
M. albescens	3.4 ± 0.2	3.5 ± 0.1	2.8 ± 0.2	2.9 ± 0.1	3.15
S. uniplumis	0.7 ± 0.1	0.9 ± 0.2	0.6 ± 0.1	0.9 ± 0.1	0.78
U. trichopus	3.4 ± 0.4	3.6 ± 0.3	3.8 ± 0.2	3.5 ± 0.3	3.58
S. pappophoroides	4.1 ± 0.5	4.0 ± 0.4	4.0 ± 0.2	3.8 ± 0.4	3.98
GRA 1	0.2 + 0.1	0.3 + 0.1	0	0	0.13
I. daleoides	0.4 + 0.2	0.3 + 0.1	0	0	0.18
S. cordifolia	0.3 ± 0.1	0.8 ± 0.1	0.5 ± 0.1	0	0.40
T. terrestris	0.6 + 0.3	0.3 + 0.1	0	0	0.23
A. fleckii	0.5 +0.1	1.5 + 0.1	0.8 + 0.1	0	0.70
A. gerrardii	4.1 ± 0.2	3.9 ± 0.3	4.3 ± 0.5	3.8 ± 0.3	4.0
B. albitrunca	6.6 ± 0.4	7.1 ± 0.2	8.4 ± 0.8	7.8 ± 0.4	7.48
B. petersiana	11.3 ± 0.9	11.7 ± 0.3	9.7 ± 0.3	8.4 ± 0.4	10.28
C. gratissimus	10.9 ± 1.2	12.7 ± 0.9	13.5 ± 0.6	15.9 ± 0.6	13.25
D. cinerea	13.4 ± 0.4	13.5 ± 0.9	12.9 ± 0.5	11.9 ± 0.7	12.93
G. flava	12.2 ± 0.6	13.6 ± 1.4	14.3 ± 0.3	16.6 ± 1.1	14.18
G. retinervis	2.1 ± 0.4	2.2 ± 0.2	3.1 ± 0.3	3.4 ± 0.2	2.70
M. sericea	9.6 ± 0.3	12.2 ± 0.7	13.6 ± 0.4	14.9 ± 0.7	12.58
R. bravispinosum	0.6 ± 0.1	0.7 ± 0.1	0	0	0.33
T. sericea	0.2 + 0.1	0	0	0	0.05
WD1	0.4 ± 0.2	0.6 ± 0.2	0	1.0 ± 0.6	0.5

8.5 Plant species diversity in cattle, sheep and goat diets

The annual mean of plant diversity for cattle, sheep and goats was 21.1 (Table 8.5). Seasonal species diversity was significantly ($P<0.05$) higher in summer and lowest in spring. Average plant species diversity for cattle, sheep and goats was 19.4, 21.4, and 22.5, respectively.

Table 8. 5. Average plant species diversities (%) of seasonal diets of cattle, sheep and goats in free ranging conditions

	Livestock Type			
Season	**Cattle**	**Sheep**	**Goats**	**Mean**
Summer	22.4^{a}	21.8^{a}	24.5^{a}	22.9^{a}
Autumn	20.9^{b}	21.5^{a}	22.7^{b}	21.7a
Winter	19.2^{b}	21.2^{ab}	22.9^{b}	21.1^{b}
Spring	17.1^{c}	18.7^{b}	19.9^{c}	18.6^{c}
Mean	19.9	20.8	22.5	21.1

Means within each animal species followed by the same letter are not significantly different (>0.05)

Diets of goats were highest in average species diversity and cattle were lowest. Plant species diversity in cattle, sheep and goats diet were higher during the plant growing seasons (summer and autumn) and lower during dormant seasons (winter and spring). Probably the high quality and greater availability of forage during growing periods permitted animals to concentrate their diets selection on a wider range of plant species with little or no risk of nutritional stress. Animal foraging habits changed as the dormant seasons approached and shifted their diets to include woody plants during dormant seasons because of the decline in herbaceous quality and loss of most of the ephemeral annual species.

In general, low plant diversity indicates the inability of an animal to withstand periods of scarce forage as the ability to shift from one resource to another become a crucial adaptational tool. This means that goats can withstand harsh conditions better than cattle or sheep

8.6 Diet overlaps of cattle, sheep and goats in free ranging conditions

Diet overlaps of any combination of two livestock species differed significantly ($P<0.05$) by season (Table 8.6). The overlaps ranged from high for combinations involving animals that share similar forage types (eg. cattle and sheep) to low for combinations involving different foraging habits (eg. cattle and goats). The overlap of diets was greatest during the dry periods (winter and spring) and lowest in during wet periods (summer and autumn) for each animal combination. The observed overlaps reflect seasonal influences as animals shift diet focus.

Table 8.6 Seasonal diet overlaps (%) of cattle, sheep and goats in free range grazing conditions

	SEASONS				
Animal	**Summer**	**Autumn**	**Winter**	**Spring**	**Mean**
Cattle vs sheep	47^b	44.7^b	59.3^a	57.8^a	52.2
Cattle vs goats	14.3^b	16.3^b	15.0^b	21.0^a	16.65
Sheep vs goats	38.1^a	35.0^a	37.0^a	41.2^b	37.5
Mean	33.0	32.0	37.1	40.0	

Means within each season followed by the same letter are not significantly ($P>0.05$) different

Overlaps of diets during the growing seasons are less likely to result in serious competition for forage between animals, than overlaps occurring during dormant seasons, because forage phytomass is abundant during the growing seasons. However, during years of subnormal forage production/availability, competition between animals may also be high during the growing seasons.

8.7 Relative Preference Indices of cattle, sheep and goats

Fifteen of the most frequently occurring herbaceous species in the diets of cattle, sheep and goats were compared with their respective frequencies of occurrence on the rangeland to determine the individual species preference by the study animals (Table 8.7). Cattle preferred (RPI >2) five of the fifteen herbaceous species in the following order: D. eriantha, S. pappophoroides, U. trichopus, M albescens and E. lehmanniana. The relative preference order of sheep was S. pappophoroides, D. eriantha, U. trichopus and E. lehmanniana. Goats showed a weak preference (RPI 1 - <2) with the following order S. pappophoroides, D. eriantha, U. trichopus and E. lehmanniana. Therefore, the relative preference for cattle (grazer), sheep (mixed feeder) and goat (browser), showed the greatest potential competition for only four grasses (D. eriantha, E. lehmanniana, S. pappophoroides and U. trichopus). However, the relative preference indices of grasses found in goat diets tended to be low. The competition for the latter grasses tended to be high for cattle and sheep.

Table 8.7 Relative preference indices (RPI) of herbaceous plant species occurring in cattle, sheep and goats diets for vegetation in free – range grazing

Herbaceous spp.	**Cattle**	**Sheep**	**Goats**
A. congesta	0.1	0	0
A. graciliflora	0.3^{d}	0	0
D. eagyptium	0.35^{d}	0.21^{d}	0
D. eriantha	5.58^{a}	3.74^{b}	1.23^{a}
E. lehmanniana	2.11^{c}	2.21^{bc}	1.02^{a}
E. rigidior	1.7_{cd}	1.51^{c}	0.91^{b}
M. albescens	2.6^{bc}	1.75^{c}	0.53^{c}
P. squarrosa	0.01^{d}	0	0
M. repens	0.03^{d}	0	0
S. uniplumis	1.89^{cd}	0.94^{d}	0.50c
S. pappophoroides	4.02^{b}	4.52^{a}	1.38^{a}
U. trichopus	3.4^{b}	$2.26b^{c}$	1.2^{a}
C. beiscensis	0.01^{d}	0.53^{d}	0
S. cordifolia	0	0	0.12^{c}
T. terrestris	0.13^{d}	0.10^{d}	0
Mean	**1.48**	**1.18**	**0.45**

Means within each animal followed by the same letter are not significantly ($P>0.05$) different

Eleven woody species were selected for comparison with their respective frequency on the rangeland to determine ranks in the diets (Table 8.8). Competition for browse plant species tended to be less for cattle, sheep and goats compared to the grass component. In general, cattle and sheep tend to have a weak mean preference for browse. However, certain plants species had higher relative preference indices. Cattle and sheep preferred five browse species (C. gratissimus, G. flava, M. sericea, B. albitrunca and B. petersiana).

Table 8.8 Relative preference indices (RPI) of browse species occurring in cattle, sheep and goats diets for vegetation in free range grazing conditions

Browse spp	**Cattle**	**Sheep**	**Goats**
A. fleckii	0	0.02^{d}	1.20^{e}
A. gerrardii	0.01^{d}	0.02^{d}	4.20^{c}
B. albitrunca	2.87^{a}	2.90^{a}	6.71^{b}
B. petersiana	0.91^{a}	1.21^{c}	3.01^{d}
C. gratissimus	2.27^{ab}	2.25^{b}	8.68^{a}
D. cinerea	0.01^{d}	0.05^{d}	4.71^{c}
G. flava	2.93^{a}	3.04^{a}	6.90^{b}
G. retinervis	0.05^{d}	0	1.05^{e}
M. sericea	1.92^{b}	1.40^{c}	3.57^{cd}
R. bravispinosum	0	0.03^{d}	0.91^{e}
T. sericea	0.01^{d}	0	0
Mean	**0.99**	**0.99**	**3.73**

Means within each animal followed by the same letter are not significantly (P>0. 05) different.

Goats preferred seven of the browse species but browsed all but one of the ten species (Table 8.8). The mean relative preference index for browse by goats was more than three times that of cattle and sheep. The greatest relative preference index for any species (likely to compete for) was that by cattle, sheep and goats for G. flava and C. gratissimus and B. albitrunca.

Cattle did not prefer plant species in order of availability, for instance, the six most highly ranked grasses in their diet were not the most available (gm^{2}) on the rangeland. For example, S. pappophoroides, one of the most highly preferred in the diet of cattle, was not only among the least common on the rangeland, but also the least available in terms of phytomass. On the other hand, S. uniplumis, one of the less preferred species was one of the most frequently occurring and most available (gm^{-2}) of all the herbaceous species throughout the year (chapter 5).

8.8 Diet composition of cattle under controlled grazing conditions at Makhi ranch

The plant species observed in the dung of steers under controlled grazing conditions at Makhi ranch is presented in Table 8.1. Cattle diet consisted of 74%, 23% and 2% of grasses, browse plants and forbs, respectively Fig. 8.2).

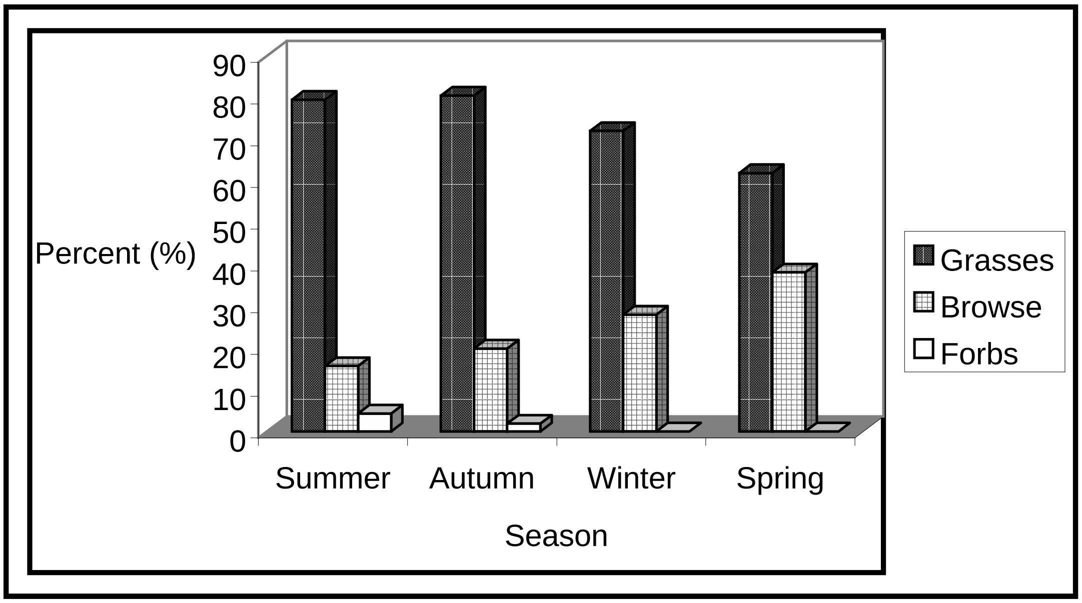

Fig. 8.2 Seasonal plant class distribution occurring in cattle diets under controlled grazing conditions

Cattle diets consisted of 80% grass during the wet seasons. This declined to approxmately 60% in spring. Browse in the diet of cattle was 16%, 20%, 28% and 38% in summer, autumn, winter and spring, respectively. Seasonal steer diets were dominated by grasses. Fifteen grasses, with a relative density >1%, occurred in the diet throughout the year (Table 8.9). Seven browse species were found during summer and autumn seasons and six during the winter and spring. Insignificant numbers of forbs occurred in the diet during the growing seasons and no observations were recorded during the dry season. Dominant grasses were the same as those at Masaane or Motshwagole cattle posts.

Table. 8.9 Average relative densities (%; mean ± SE) of plant species occurring in seasonal diet of cattle under controlled grazing conditions.

Plant species	**Summer**	**Autumn**	**Winter**	**Spring**	**Mean**
A. graciliflora	0.3 ± 0.1	0.2 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.28
D. aegyptium	0.9 ± 0.2	0.6 ± 0.2	0	0	0.38
D. eriantha	11.1 ± 0.9	14.9 ± 0.1.1	15.4 ± 0.9	17.8 ± 1.2	14.80
E. lehmanniana	10.3 ± 1.2	9.2 ± 0.6	8.3 ± 0.8	7.5 ± 0.6	8.82
E. rigidior	6.7 ± 0.6	8.4 ± 0.7	8.3 ± 0.9	8.8 ± 1.3	8.12
M. albescens	13.3 ± 1.3	11.5 ± 0.8	9.4 ± 0.6	4.5 ± 0.7	9.68
M. repens	0.5 ± 0.2	0.2 ± 0.1	0	0	0.18
P. maximum	0.8 ± 0.2	1.3 ± 0.2	0.8 ± 0.3	0	0.73
P. squarrosa	0.3 ± 0.1	0.2 ± 0.1	0	0	0.13
S. pappophoroides	13.2 ± 1.4	13..2 ± 1.2	11.2 ± 1.7	9.1 ± 0.6	11.68
S. uniplumis	6.3 ± 0.5	8.7 ± 1.3	10.7 ± 1.1	8.4 ± 0.9	8.53
U. trichopus	15.6 ± 1.4	12.3 ± 0.9	7.6 ±0.4	4.8 ± 0.6	10.08
GRA1	0.3 ± 0.1	0	0	0	0.08
C. beiscensis	1.2 ± 0.3	0.6 ± 0.2	0	0	0.45
I. daleoides	0.6 ± 0.2	0.4 ± 0.1	0	0	0.25
T. terrestris	2.1 ± 0.2	0.9 ± 0.2	0	0	0.75
FOR2	0.4 ± 0.1	0	0	0	0.1
B. albitrunca	2.1 ± 0.3	2.9 ± 0.3	4.2 ± 0.8	6.9 ± 0.5	4.03
B. petersiana	2.5 ± 0.6	2.6 ± 0.6	2.9 ± 0.3	3.8 ± 0.7	2.95
C. gratissimus	3.5 ± 0.5	4.7 ± 0.6	6.2 ± 0.4	8.4 ± 0.9	5.70
D. cinerea	0.6 ± 0.1	0.2 ± 0.1	0	0	0.20
G. flava	3.8 ± 0.8	4.4 ± 1.2	7.3 ± 1.0	9.9 ± 0.5	6.35
G. retinervis	0.7 ± 0.1	1.2 ± 0.7	2.1 ± 0.6	2.0 ± 0.6	1.50
M. sericea	2.8 ± 0.6	3.9 ± 1.4	5.6 ± 1.5	7.1 ± 0.6	4.85

8.9 Seasonal species diversity of steer diets under controlled grazing conditions

The mean annual species diversity for cattle grazing under controlled grazing conditions was 18.9 (Table 8.10). The seasonal species diversities were highest in summer and lowest in spring seasons. As under free ranging conditions, cattle diet diversities were high during growing periods and low during the dormant periods.

Table 8.10 Seasonal species diversity of steer diet for three grazing systems at Makhi ranch

	Grazing systems			
Season	**1 – pd**	**3 – pd**	**9 – pd**	**Mean**
Summer	22.9^a	22.4^a	23.5^a	22.9^a
Autumn	21.8^a	22.0^a	22.8^a	22.2^a
Winter	14.6^b	15.1^b	18.2^b	16.0^b
Spring	13.1^b	13.4^b	16.7^b	14.4^b
Mean	18.1	18.2	20.4	18.9

Means within each grazing system followed by the same letter are not significantly (P>0.05) different

Steers might have responded to the seasonal fluctuations in forage quality by consuming a greater variety of plant species during the wet seasons because of increased forage quality. Seasonal diet for steers was more diverse with the 9 – pd grazing system and less with 1 – pd system. Steers in 1 – pd system concentrated on fewer species (probably high quality) that could satisfy their stomach fill, while the 9 – pd system could not supply enough quality species to satisfy their needs and were forced to utilize other species because of the small size of the paddocks and reduced opportunity for selection. The 3 – pd system tended to be very similar to the 1 – pd system.

8.10 Relative preference indices of steers under controlled grazing conditions at Makhi ranch

The most frequently occurring herbaceous species in the diet of steers at Makhi ranch were compared with their respective occurrence on the rangeland (i.e.% frequency in diet / % frequency on range) to determine the individual species preference by steers (Table 8.11). Steers preferred (RPI >2) seven of the fifteen herbaceous species in the following order of preference: D. eriantha, P. maximum, D. aegyptium, E. africana, S. pappophoroides, U.trichopus and E. lehmanniana. It should be noted that D. aegyptium and E. africana were only found where animals concentrate their dung and urine, while P. maximum was confined to under tree canopies where high organic matter resulted from leaf drop.

Table 8.11 Relative preference indices (RPI) of plant species occurring in steer diets under controlled grazing conditions

Grass species	**RPI**	**Woody species**	**RPI**
A. congesta	0.1^{d}	B. albitrunca	2.91^{ab}
A. graciliflora	0.2^{d}	B. petersiana	1.27^{c}
D. aegyptium	5.1^{a}	C. gratissimus	2.39^{b}
D. eriantha	5.5^{a}	D. cinerea	0.01^{d}
E. lehmanniana	2.1^{b}	G. flava	3.3^{a}
E. pallens	0.1^{d}	G. retinervis	0.5^{d}
E. rigidior	1.9^{c}	M. sericea	1.9^{c}
E. africana	4.6^{a}	WDY1	0.01^{d}
M. albescens	2.5^{b}		
M. repens	0.1^{d}	**Forb species**	
P. maximum	5.8^{a}	C. beiscensis	3.7^{a}
P. squarrosa	0.1^{d}	I. daleoides	0.
S. pappophoroides	4.5^{a}	T. terrestris	2.7^{b}
S. uniplumis	1.9^{c}	FOR1	0.1^{d}
U. tricopus	3.2^{b}		
GRA1	0.1^{d}		
GRA2	0.1^{d}		

In general cattle tended to have a weak preference for browse compared to herbaceous plants. The most preferred (RPI >2) were utilized in the following order: G. flava, B. albitrunca and C. gratissimus. Cassia beiscensis and T. terrestris (forbs) were preferred by cattle than any of forbs.

Cattle did not prefer species in order of availability, for instance, the most highly ranked grasses in their diet were not the most frequently occurring on the rangeland. P. maximum, although one of the most highly preferred in the diet of cattle, was among the least available in terms of phytomass. On the other hand, S.uniplumis and E. rigidior, some of the less preferred species, were some of the most frequently occurring and most available (gm^{-2}) of all the species throughout the year (chapter 5).

8.11 DISCUSSION

The microhistological technique is a useful tool for estimating the botanical composition of livestock diets. As reported by Storr (1961), Free *et al.* (1970) and McInnis (1977), the technique under-estimates the forbs in the diet of livestock. Plant characteristics of the fragments were also more easily identified for woody plants than grasses.

Seasonally, cattle diets were dominated by grasses. This emphasized the feeding habit of cattle as mainly grass feeders. The woody species occurring in their diet during the dry periods are in agreement with the findings of various workers. Le Houérou (1980) found woody species in the diet of cattle. Omphile (1997) reported that greater quantities of woody plants in the diets of wildlife during the dry seasons, reflect a period during which grass was less available in quantity and low in quality and animals may then supplement their diet from woody plants.

The dominance of woody species in the diet of goats confirms that this species is a browser. The ability of selectively foraging on browse ensures them of continuous supply of a high quality diet. Goats can withstand conditions were natural vegetation has degenerated because of overgrazing or bush encroachment while populations of grazers, like cattle, decline, because goats probably exhibit an opportunistic feeding strategy (Le Houérou 1980)

Cattle and sheep may have responded to the seasonal fluctuations in forage availability or quality by exploiting more foraging species during wet periods because most plant species were succulent and nutritive. However, some plant species were utilized more than others. As the dry period approached, the availability of heavily utilized species was reduced and animals satisfied themselves by consuming more of less preferred species. During dry periods, especially during the spring period, species diversity declined because annual plants (grasses and forbs) disappeared. On the other hand, goats tended to concentrate on fewer plant species in response to the reduced forage quality.

The overlaps tended to be low during the growing seasons and high during dormant seasons because of the reduced plant diversity. Competition for forage between cattle, sheep and goats occurs more often during the dormant seasons and is more pronounced during years of subnormal rainfall when forage phytomass is low (chapter 5 and 7).

8.12 CONCLUSION

It is safe to say that browse constitutes a necessary and adequate supplement to herbage, in the dry seasons, as dry season grasses are extremely deficient in most nutrients needed to meet livestock maintenance requirements. Cattle are mainly grazers, but browse as well, in order to balance their diet. Browse plants remain higher in nutritional quality than grasses. Therefore, there is no need for browser (goat) to shift its diet seasonally as do cattle. An understanding of the variation of forage quality should aid in supplementary programmes for livestock. The combination of cattle and goats in range management may result in more efficient utilization of the range plants.

Overlaps of diets are generally high during dry seasons, because of the scarcity of forage, when the potentials of forage selections are restricted to limited species diversity and availability. The problems of competition for any plant species can be resolved by reducing the livestock units.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

The implications which the foregoing results hold for range management scenarios in Botswana deserve intensive consideration by organizations responsible for developing policy for such scenarios. The distribution of borehole dependent cattle grazing in the Kalahari sandveld has led to the development of piospheres on an unprecedented scale. The daily incidence of livestock concentrations at such water points and in the immediate vicinity, as opposed to the more distant areas, implies an uneven use of the rangeland, with areas adjacent to the water point being more heavily utilized than those further away from water. This problem results in under-utilization of some areas at the expense of other.This piosphere effect, which often forms the basis of the ecological impact of livestock grazing in the Kalahari sandveld, is often overlooked.

The degree of the vegetation utilization around the water points has not however, been extensively studied and evidently needs urgent attention. Where the level of utilization is excessive, the creation of alternative permanent water sources should be considered to spread such impacts. The greater the distance from the water point, the more available herbage phytomass is usually found, implying that range use was concentrated in those areas adjacent to the water points. Such uneven utilization negatively affects areas in the immediate vicinity of the boreholes seriously and the provision of water in under-utilized areas, to attract animals, is, therefore advocated. A system, that may be suited to borehole dependent livestock, such as those found in the Kalahari sandvelds is that of rotating access to water. If rangeland in the vicinity of water points is used to any degree, some impact on the vegetation is expected, or cannot be avoided. What is probably more important is the ecological extent of such sacrifice areas around water points. The main focus should, therefore, concentrate not so much on preventing the changes around the water points, but on controlling the changes in such a means that sustainable livestock production is ensured.

Some practical approaches to minimize degradation and enhance productivity of perennial grasses around the water points are available. Data on the influence of travel distance between water and available forage on cattle performance in Botswana are scarce. Research is, therefore, needed to evaluate how travel distance between water and forage affects the performance of animals, especially during periods of forage scarcity. The sacrifice zones are often accepted as inevitable and it is generally thought that the larger the paddock and, the longer the animals stay in the paddock, the larger the sacrifice zone. Such factors have strong negative effects on forage production, especially in free range grazing systems, where animals stay permanently on a large unfenced area. Fencing of free range grazing areas with adequate paddock size is, therefore, strongly recommended in order to avoid desertification of the Kalahari sandveld. With the development of the new agricultural policy on fencing of the communal grazing range in Botswana, information provided on range condition and utilization within piospheres, as determined by the distance livestock travel, would certainly be of great value in planning the fencing and espacement of water points.

Nutrient enrichment in the vicinity of water points can be attributed, in a large part, to the input of dung and urine. Uneven dung and urine distribution along the transect radiating from the boreholes implies that attempts should be made to distribute such an excreta over a wider area, in such a way that a centripetal movement and background impoverishment of soil nutrient levels is avoided. Soil chemical properties measured showed a consistent response between the transects, and revealed the low background fertility of the Kalahari soil with variation only being registered around the water point. An early step in any management plans, directed at managing the resource, should, therefore, aim at a more even spread of nutrients by improving the distribution of the water points.

While nutrient enrichment occurs in the vicinity of water points, a background impoverishment of soil nutrient levels over the surrounding range occurs, which is reflected in the poor nutrient value of available forage. Although it appears that little can be done about the seasonal decline in nutritional quality of the forage, a commonly used approach in livestock management systems is to supplement the natural forage, when it does not meet the nutritional requirements of the animal. This is easily achieved when livestock are kept in confinement and their nutritional requirements are known. The seasonal decline in forage quality no doubt affects the nutritional status of range animals. The extent of that effect and the role supplementation should be determined with additional research into nutrition of livestock on rangeland.

The encouragement of plant species, which have above average levels of crude protein, by using certain grazing systems or range manipulations should be seriously encouraged. Range fertilization and especially bush management (e.g. prescribed burning, regrowth stimulation etc) may also be practical and profitable considering the economic value of the livestock in Botswana. Constant monitoring of forage production and availability should be done in conjunction with monitoring of animal numbers and their respective needs for forage so that, where necessary, destocking can be based on sound scientific grounds to maintain the correct grazing pressure.

Less selective livestock such as cattle, suffer more from a poor diet quality during dry seasons compared to selective feeders such as goats. Cattle select a poorer quality diet than goats, which select browse. If animal distribution and range condition are maintained through correct stocking rates, selective feeders should have adequate forage from which to select a diet of preferred species and adequate quality during the dry season. Less selective animals will, however, probably suffer during the dry season regardless of forage supply because abundant dry grasses will not contain enough nitrogen or phosphorus. Although, cattle certainly make use of the browse (Chapter 8), studies have indicated that the survival and maintenance of cattle, in the dry season and during drought periods, is more likely to be dependent upon the quantity, rather than quality of forage available.

Because of the differences in herbage nutrient levels due to both season and location along the transect from water, there is need to establish critical levels of some of the key nutrients with respect to their effect on livestock condition. This is especially true for cattle and sheep, which are more sensitive to limitations of both forage supply and quality because of their less selective foraging behavior. When the requirements for these minerals are known, seasonal availability of minerals in vegetation should be assessed.

The potential for competition for forage is higher throughout the year between cattle and sheep than between goats and cattle or between goats and sheep. A reduction in cattle numbers should enhance forage availability for sheep, and vice versa, but reduction in the number of sheep or cattle would have little, or no, effect on enhancing forage availability to the goats. There appears to be relatively few goats in the area, however, and competition for browse is less than that for herbaceous plants between cattle and sheep. The combination of grazers and browsers on common range, such as that practiced in the free range grazing area, will achieve better and more efficient utilization of such range. Feeders such as goats may also be used to manipulate the woody plant canopies so that grazers have better access to herbaceous forage growing under such woody plants.

Another alternative to adjusting animal numbers, is to increase the production of preferred herbaceous and browsing plants. Since some of the most preferred grasses like P. maximum are most common on limited areas (such as those under the tree canopies) increased production of browse species appears to be practical. Bush management research should also be directed at reducing competition for preferred woody species through techniques that stimulate animals (Browse Plus) to eat more of the less preferred woody species so that species such as T. sericea and P. africanum are better utilized. There is also a need to manipulate the height and stimulate the regrowth of preferred browse species to make material more accessible to livestock and thereby increase the amount of browse available.

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Appendix 1

Directions for Preparing Hoyer's Solution

Chloral hydrate crystals	200g
Glycerine	20ml
Gum arabic (photopurified)	30g
Tap water	50ml

Combine chloral hydrate crystals and glycerine. Add gum arabic and water. Place container in a hot water bath and stir until ingredients are combined.

Directions for Preparing Hertwig's Solution

Chloral hydrate crystals	270g
1N Hydrochloric acid	19ml
Glycerine	50ml

Combine chloral hydrate crystal with hydrochloric acid. Add glycerine. Stir until ingredients are combined.