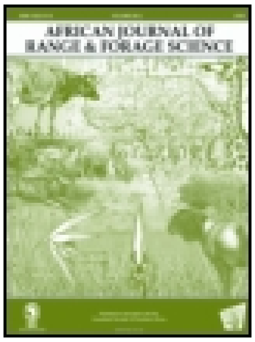

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Vegetation patterns and nutrients in relation to grazing pressure and soils in the sandveld and hardveld communal grazing areas of Botswana

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A major challenge confronting managers of extensive grazing systems is uneven use of herbaceous forage plants by livestock. The concentration of grazing in preferred areas or around foci points (e.g. water points) eventually results in adverse impacts in soil nutrients, vegetation structure, production and composition. In Botswana's communal grazing systems, however, the severity or magnitude of this foregoing problem is little understood. This study therefore investigated herbaceous plant species patterns as a function of grazing pressure and soil nutrients in the sandveld and hardveld communal grazing areas of Botswana. Six boreholes (three in the hardveld and three in the sandveld), with sampling points at distances 50m, 100m, 200m, 400m, 800m, 1 500m and 3 000m formed the investigation. At each sampling distance, two plots measuring 10m x 15m were designated, where soil and herbaceous plant samples were collected for further chemical analysis. Marked differences in soil nutrients, herbaceous plant nutrients, species composition and diversity were prominent between the two land zones. Soils from the hardveld boreholes recorded significantly higher concentration levels for both macro- and microelements relative to the sandveld. Insignificant negative correlations between soil and plant elements were established for the two ecological zones. Herbaceous plant species from the hardveld boreholes contained adequate macro- and microelements to meet dietary livestock requirements relative to the sandveld. The results are here discussed with the view of understanding their management implications for extensive grazing areas.

Keywords: communal, forb, herbaceous, species diversity

Introduction

Grazing pressure has undoubtedly intensified in the communal grazing areas of Botswana due to increases in livestock numbers since 1900 (Moleele 1999). Such increase in livestock in the semi-arid savannas is widely known to cause changes in soil nutrients, vegetation structure, production, composition and productivity (Walker *et al.* 1989b, Moleele and Perkins 1998). In the Sahel, livestock grazing is often regarded as one of the main causes of vegetation and soil degradation (Lusigi and Glaser 1984, Warren and Khogali 1992). Studies by Hiernaux and Turner (1996) in West African Sahel showed that increased grazing pressure can lower forage production by 50% or more while Hiernaux *et al.* (1988) in the same region showed that increased grazing pressure might limit the following year's production of annual rangelands through the depletion of seed stock. In Botswana, however, the severity or magnitude of the foregoing problem in relation to the herbaceous layer is little understood for both the sandveld and hardveld areas. Although considerable scientific attention has focussed on Kalahari rangeland management and degradation (Thomas *et al*. 2000, White 1993, Perkins and Thomas 1993), there have been few in-depth studies directly investigating herbaceous production and productivity along grazing gradients between the sandveld and hardveld communal grazing areas of Botswana. This study therefore investigated herbaceous species patterns as a function of grazing pressure and soil nutrient status in the sandveld and hardveld communal grazing areas of Botswana.

Study areas

The study was conducted in two communal grazing areas, which are dominated by pastoralism. The two communal areas are found in the hardveld and sandveld ecological zones of Botswana (Figure 1). The hardveld has been used for grazing purposes for more than two centuries, and was not as populated as it is today in terms of people and livestock. Ecologically, the hardveld is characterised by deep, fertile and variable active erosional soils with well-defined profile development and mixed vegetation strata and receives about 400–600mm annual rainfall (Bhalotra 1987). On the other hand, deep Kalahari sands that are less fertile with virtually no profile development characterise the sandveld. However, variations in texture with depth have been observed in some sandveld locations (Buckley *et al*. 1987a). The area is mostly composed of bushy savanna vegetation characterised by scattered trees and shrubs (De

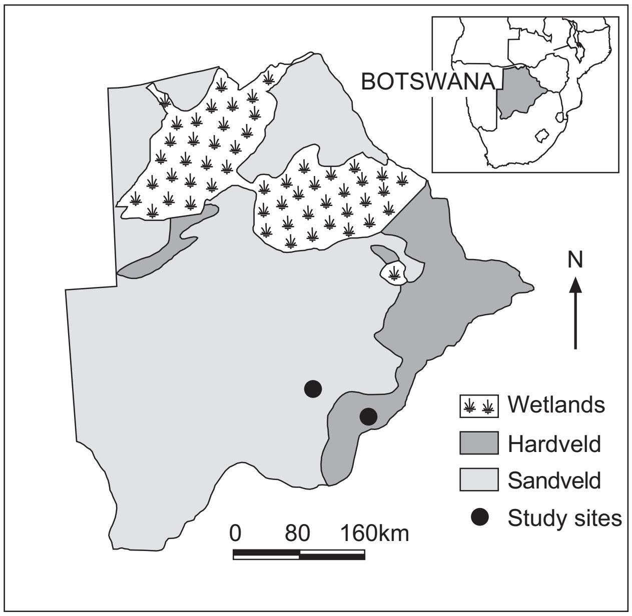

Figure 1: Location of study sites in the hardveld and sandveld zones of Botswana

Wit and Bekker 1990, Thomas and Shaw 1991). In general, the vegetation communities in the sandveld tend to be hardy and low in species diversity (Thomas and Shaw 1991, and receive less than 300mm annual average rainfall (Vossen 1987, Bhalotra 1987). The variation in rainfall within the sandveld is, however, great with the northern part of Botswana receiving higher than the south-western portion.

Over the past 80 years, the sandveld has been exposed to cattle grazing as a consequence of borehole technology. It is therefore of interest to compare grazing patterns in the hardveld and the 'somewhat fragile' sandveld ecosystem. A number of authors have asserted that dry-land ecosystems are particularly fragile (e.g. Dregne *et al.* 1991). However, the move towards non-equilibrium conceptions of dryland ecological dynamics (e.g. Scoones 1995, Warren 1995) was accompanied by an emphasis on the inherent resilience of these systems. This new thinking asserts that vegetation changes are often reversible, so that even systems classified as severely degraded demonstrate rapid recovery characteristics, especially following good rainfall after drought years (Tucker *et al*. 1991, Perkins and Thomas 1993). Vegetation changes around boreholes or permanent water points, particularly in communal grazing areas, are likely to display a unique vegetation pattern, partly due to continuous degradation and loss of grass seedbank. Exclosure studies (Mphinyane 1982) near Tshane showed that changes in biomass and plant species composition along grazing gradients could persist for up to 10 years.

Methodology

Six boreholes, three in each land zone, were randomly selected for sampling. The selection criteria ensured general soil and vegetation homogeneity for boreholes in each land zone. The six boreholes, with two sampling points (10m x 15m) at distances 50m, 100m, 200m, 400m, 800m, 1 500m and 3 000m, formed the investigation that was carried out in the wet season of 2002. The sampling direction at each borehole was selected on the basis of what was anticipated to be the main direction of grazing activity, evident through the density of cattle trails. The strengths and weaknesses of the adopted sampling strategy are discussed in Lange (1969) and Andrew and Lange (1986). This approach allows for a direct comparison of the impact of high grazing pressure close to boreholes and enclosures, with low grazing pressure associated with points further away and exclosures.

Top soil was sampled at 0–20cm depth comparable to the rooting zone of major annuals (Cater 1993), in each of the plots along each transect, for determination of soil pH, organic carbon, macro- (P, Mg, N, Ca, K) and micro- (Fe, Cu, Zn) elements. Dominant herbaceous plant species from the sandveld (*Eragrostis rigidior*, *Aristida congesta*, *Eragrostis pallens*) and hardveld (*Eragrostis rigidior*, *Panicum maximum* and *Sporobolus ioclados*) were clipped at 1cm above ground in 0.5 x 0.5m^2 plots along each transect, for determination of N, crude protein, crude fiber, macro- (P, Mg, Ca, K) and microelements (Fe, Cu, Zn). The samples were dried for 72 hours at 40°C, then ground in a Wily mill to pass through a 2mm mesh screen, and digested by wet ashing (Isaac and Kerber 1971). Nitrogen was determined by the Kjedahl method (Bremer 1965), P by the Ultra Violet Spectrophotometer, K by flame photometer and Ca, Mg, Fe and Cu by atomic absorption spectrophotometer (Perkin-Elmer, 603). Crude protein values were determined by multiplying the nitrogen content of grass samples by 6.25 (Belyea and Ricketts 1993). Herbaceous species composition was determined by using the Line Intercept method (Cook and Stubbendieck 1986).

The plant species data and environmental variables for each sampling site were subjected to a direct gradient analysis technique using the CCA package of Ter Braak (1988). Forward selection of environmental variables was conducted stepwise to select variables that could explain most of the variance in the species data (van Rooyen *et al*. 1994). The Monte Carlo test for significance was performed on the data to show significance of the first canonical axis (Ter Braak 1988). Herbaceous species diversity was determined by using Simpson's diversity index (Bergon *et al*. 1986). Analysis of variance on soil and herbaceous nutrients was determined using the SAS software (Fisher 1921).

Results and discussion

Soil nutrient status

Soils from the hardveld were higher in nutrient content than those of the sandveld (Table 1). This is likely to be so because of the inherent diversity and nature of parent materials in the hardveld (De Wit and Bekker 1990, Thomas and Shaw 1991). Soil data show that acidity (pH), organic carbon (OC), macro- (P, Mg, N, Ca, K) and microelements (Fe, Cu, Zn) decreased with distance from water points in both the hardveld and the sandveld study sites (Figures 2 and 3). Water points are subjected to higher densities of livestock (cattle) compared to grazing points a distance

Table 1: Variation of mean concentration levels of soil pH, organic carbon and macro- and microelements between the sandveld and hardveld study site soils

Element	Sandveld	Hardveld	P
Soil pH	5.27	4.97	<0.0001
OC	0.08 (%)	0.18 (%)	<0.0001
K	0.84 (%)	1.85 (%)	<0.0001
Mg	0.20 (%)	0.28 (%)	<0.0001
P	0.29 (%)	0.85 (%)	<0.0001
Ca	1.93 (%)	3.73 (%)	<0.0001
N	0.04 (%)	0.09 (%)	<0.0001
Mn	0.11 (ppm)	0.20 (ppm)	<0.0001
Fe	0.14 (ppm)	0.31 (ppm)	<0.0001
Zn	0.11 (ppm)	0.19 (ppm)	<0.0001
Cu	0.12 (ppm)	0.19 (ppm)	<0.0001

Key: OC = organic carbon; K = potassium; Mg = magnesium; P = phosphorus; Ca = calcium; N = nitrogen; Mn = manganese; Fe = iron; Zn = zinc; Cu = copper; N = 21

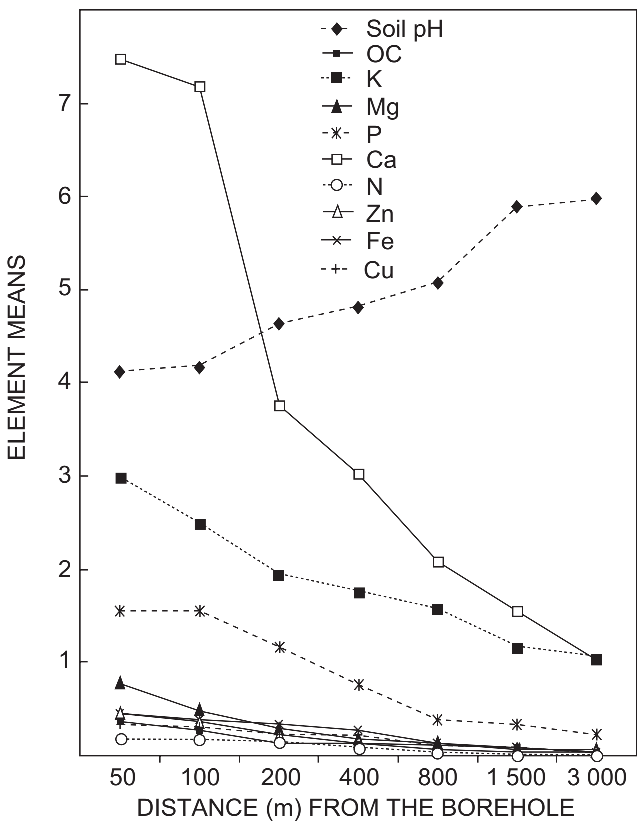

Figure 2: Average soil macro and microelements' distribution along grazing gradients in the hardveld study sites soils during the 2002 wet season

away, hence the concentration of elements close to water points. The transport of nutrients by cattle (via dung and urine) from the surrounding savanna towards the borehole is most likely to increase the macro- and microelement concentrations around boreholes. Studies by Tolsma *et al.* (1987) in eastern Botswana have shown that cattle gathering at boreholes two to seven times a week deposited great quantities of dung and urine near the borehole comparable with the effect of wild herbivores near pans (Weir 1971). A further influence of larger herbivores was very evident on small paddocks of improved pastures of mesic environments in concentration of minerals at campsites and around permanent watering points. Hilder and Mottershead (1963) and Hilder (1966) provide evidence to show that about 22% of dung could be concentrated on as little as 3% of total paddock area to substantially increase cation concentrations, total N (x2) and available P (x4) levels of campsite soil relative to that a short distance away. It is therefore important to note that over a long period, the process is likely to improve the site potential and probably affects plant species distribution.

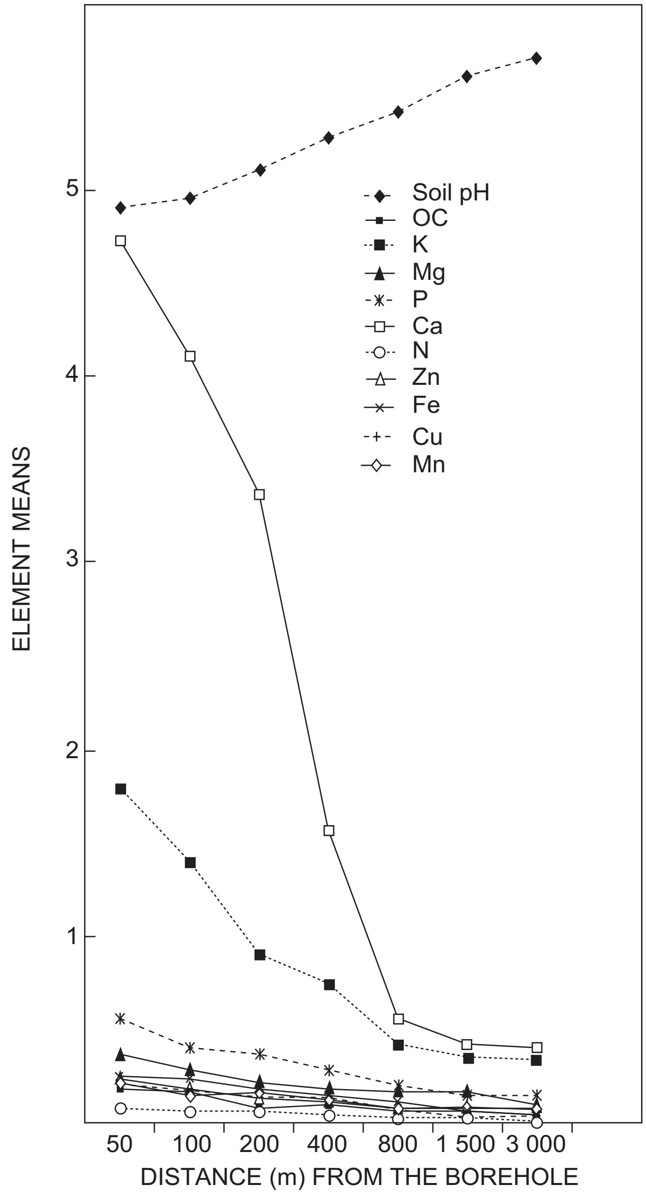

Figure 3: Average soil macro- and microelements' distribution along grazing gradients in the sandveld study sites soils during the 2002 wet season

Plant nutrient status

Macro elements

Significant macroelements' variations were noticed amongst plant species between the hardveld and sandveld study sites (Table 2a). In general, grasses from the hardveld displayed higher macroelement concentration than those of the sandveld. For example, the mean K concentration ranged between 0.9 and 1.03%, and 0.02 and 0.89%, between grasses of the hardveld and sandveld respectively. Similar patterns were also evident in the other four macroelements (Mg, P, Ca and N).

Of the six grass species investigated from the two zones, there seemed to be no significant macroelement variation between *Panicum maximum* and *Sporobolus ioclado*s (hardveld species), *Eragrostis rigidior* and *Aristida congesta* (sandveld species) (Table 2a). In general, *Panicum maximum* seemed to contain higher macroelements, while *Eragrostis pallens* had the least.

Macroelement concentrations from the hardveld grasses were well within the animal dietary requirements, as suggested by Al-Jaloud *et al*. (1994).

Low macroelement concentration in *Eragrostis pallens* (sandveld) can be explained by the fact that it was mostly found in plots 1 500m and 3 000m away from the water points, whereas the other five grass species were observed to be occurring intermittently in plots along the grazing gradients. Studies on soil fertility by Ramolemana and Machacha (2000) indicated that soils of the sandveld were deficient in phosphorus compared to those of the hardveld, a result supported by the current study. A phosphorus level below 0.15% is considered a deficiency (Al-Jaloud *et al.* 1994).

Chapman (1966) reported that grasses containing less than 1.60% N can show deficiency symptoms, although this limit in some grass species can be as high as 2.25%. In this study, most grass species recorded relatively low nitrogen concentrations. A number of factors (e.g. ammonia volatilisation, denitrification and leaching) might have contributed to low nitrogen concentrations in grasses (Skujins and West 1974, McGregor 1972).

Microelements

Significant microelement variations were noticed amongst species between the two study sites (Table 2b). In general, grasses from the hardveld displayed higher microelement concentration than those of the sandveld. For example, the mean hardveld Zn, Fe and Cu concentrations ranged between 31.50 and 36.31mg kg^{-1}, 41.88 and 58.95mg kg^{-1}, and 9.97 and 12.55mg kg^{-1} respectively.

However, the microelement concentration amongst grasses of the hardveld showed little variation in two of the three elements (e.g. Zn and Cu). According to animal dietary recommendations by Chapman (1966) and Underwood (1971), grasses of the hardveld contained adequate microelements compared to those of the sandveld.

Lignin

No significant lignin variation was observed amongst grass samples from the sandveld, and similarly amongst those from the hardveld study sites (Table 3a). However, significant lignin variation was noted with distance from the water point at each study site (Table 3b). Lignin levels ranged from 3.2 to 16.0% along the sandveld grazing gradient while in the hardveld levels ranged from 3.3 to 11.0%. There were no plants at 50m from the water points, due to livestock trampling and/or overgrazing. The variation in lignin levels along the grazing gradient might be associated with species phenological differences. Lignin content is influenced by many factors e.g. age of the plant and stage of growth (David 1996). Buxton and Russell (1988) proved that lignin concentrations on a cell wall basis doubled with maturity in grass stems, but when the stems are immature, they are almost twice as digestible as mature stages on a cell wall-lignin basis. With ageing, plant cell wall lignifies, reaching 12% in forages (Gidenne and Lebas 2002).

Comparatively, the lignin content in grass samples of the hardveld seemed to be lower than those of the sandveld, probably reflecting different species' response to grazing pressure. Grazing pressure would seem to quicken the lignifying process since in most cases leaf fractions are highly likely to be selected over stems, hence the display of higher lignin content in stem fractions.

Crude fiber (CF)

The crude fiber content did not differ between species (Table 3a), but with distance from water points in both the sandveld and hardveld study sites (Table 3b). Crude fiber values

Table 2a: Mean concentration of macroelements in major grasses of the hardveld and sandveld study sites

K		Mg		P		Ca		N	
Critical range		Critical range		Critical range		Critical range		Critical range	
0.3460–0.3923		0.06638–0.07528		0.06543–0.07420		0.1864–0.2114		0.4318–0.4896	
Duncan Grouping mean (%)	Spec	Duncan Grouping mean (%)	Spec	Duncan Grouping mean (%)	Spec	Duncan Grouping mean (%)	Spec	Duncan Grouping mean (%)	Spec
1.03A	Pama*	0.24A	Pama*	0.26A	Pama*	0.84A	Spio*	1.48A	Pama*
0.98A	Spio*	0.22A	Spio*	0.22A	Spio*	0.72A	Pam*	1.48A	Spio*
0.90BA	Erri*	0.15BA	Erri*	0.13B	Erri*	0.27B	Erri*	1.00B	Erri*
0.89BA	Erri†	0.11DC	Arco†	0.02C	Erri†	0.17CB	Erri†	0.57CB	Erri†
0.57B	Arco†	0.08DC	Erri†	0.01C	Arco†	0.14CB	Arco†	0.47C	Arco†
0.02C	Erpa†	0.04D	Erpa†	0.01C	Erpa†	0.03C	Erpa†	0.12C	Erpa†

Key: Spec = species; Pama = *Panicum maximum*; Spio = *Sporobolus ioclados*; Erri = *Eragrostis rigidior*; Erpa = *Eragrostis pallens*; * = grasses from the hard-veld; † = grasses from the sandveld. Means with the same letter are not significantly different, while means with different letters are significantly different

Table 2b: Mean concentration of microelements in major grasses of the hardveld and sandveld study sites

Zn Critical range 9.10–10.32 Duncan Grouping		Fe Critical range 14.34–16.26 Duncan Grouping		Cu Critical range 3.445–3.906 Duncan Grouping	
Mean (meq/kg^{-1})	Spec	Mean (meq/kg^{-1})	Spec	Mean (meq/kg^{-1})	Spec
36.31A	Spio*	58.95A	Pama*	12.55A	Erri*
32.45A	Erri*	47.31BA	Erri*	10.41A	Spio*
31.50A	Pama*	41.88B	Spio*	9.71A	Pma*
13.69B	Erri†	16.98C	Erri†	5.05B	Arco†
7.86CB	Arco†	10.50C	Arco†	4.86B	Erri†
1.67C	Erpa†	4.95C	Erpa†	1.17C	Erpa†

Key: Spec = species; Pama = *Panicum maximum*; Spio = *Sporobolus ioclados*; Erri = *Eragrostis rigidior*; Erpa = *Eragrostis pallens*; * = grasses from the hard-veld; † = grasses from the sandveld. Means with the same letter are not significantly different, while means with different letters are significantly different

Table 3a: Mean lignin, crude fiber and crude protein concentration in major grass samples of the sandveld and hardveld study sites

	Lignin Critical range 2.24–2.36			Crude fiber Critical range 3.96–4.17			Crude protein Critical range 2.92–3.34		
	Duncan Grouping mean (%)	N	Spp	Duncan Grouping mean (%)	N	Spp	Duncan Grouping mean (%)	N	Spp
Sandveld sites	7.52A	42	Erri†	19.51A	42	Erri†	9.25A	42	Pama*
	7.18A	42	Erpa†	18.19BA	42	Arco†	9.25A	42	Spio*
	5.89A	42	Arco†	14.37B	42	Erpa†	6.25B	42	Erri*
Hardveld sites	6.23A	42	Spio*	16.55A	42	Spio*	3.58A	42	Arco†
	6.04A	42	Erri*		16.10A	42 Erri*	2.97A	42	Erri†
	4.43A	42	Pama*	14.14A	42	Pama*	0.76A	42	Erpa†

Key: Spp = species; Pama = *Panicum maximum*; Spio = *Sporobolus ioclados*; Erri = *Eragrostis rigidior*; Arco = *Aristida congesta*; Erpa = *Eragrostis pallens*; * = species from the hardveld study sites; † = species from the sandveld study sites. Means with the same letter are not significantly different, while means with different letters are significantly different

ranged between 0 to 34% for the sandveld species and 0 to 31% for the hardveld species, with high values recorded closest to boreholes. It has been demonstrated in other studies that crude fiber increases with plant maturity (Van Soest 1982, Buxton and Rushell 1988). As the fiber fractions increase, digestibility and intake decrease (Schroeder 1996). Uncontrolled grazing pressure is likely to reduce leaf-to-stem ratio, in the process increasing the lignin content. Reduced leaf-to-stem ratio is a major cause of the decline in forage quality (Butler and Briske 1988).

While it is clear that the most important factor that controls forage quality is the age of the plant or growth stage, continuous grazing pressure also partially contributes, particularly under a communal grazing set-up.

Crude protein (CP)

Results showed no significant CP variation amongst grass samples of the sandveld, while the same could not be said of two of the three grasses of the hardveld (Table 3a). However, CP varied significantly with distance (P = 0.05), where higher figures were recorded mostly closest to boreholes (Table 3b). Crude protein tends to decrease with increased distance from water (Table 3b). Nevertheless, low CP levels were noted, not only at 3 000m but also at distances of 100m and 200m from the borehole. This is not surprising, because sample plants between 50m and 200m were heavily defoliated and therefore had less leaf material on them and hence low crude protein. Van Soest (1982) concluded that the leaf and stem protein represents the actively metabolising matter of living plants, and leaves contain a higher level of proteins than stems. Low levels of CP at 3 000m (as shown in Table 3a) could be associated with low levels of nitrogen. This is so because N levels have also been shown to decline with increased distance from water points (Hilder and Mottershead 1963, Hilder 1966).

As the plant grows, the stem makes up a larger proportion of the total dry matter and the proportion of leaves decreases. The stems are fibrous and rather indigestible compared to the leaves, so the vegetative parts of a plant are usually low in fiber and high in protein (Schroeder 1996). However, as the leaf-to-stem ratio decreases with advancing maturity, the plant contains less protein and more fiber. Based on the CP dietary animal requirements figures provided by Al-jaloud *et al*. (1994) and Jurgens (1997), the sandveld CP levels are relatively low, while those of the hardveld are higher.

Relationships between soil and plant nutrients

Generally, insignificant negative correlations between macroelements (Tables 4a and 5a) and microelements

Table 3b: Mean lignin, crude fiber and crude protein concentration in major grass samples (*vs* distance) from the sandveld and hardveld study sites

Sandveld sites	Lignin			Crude fiber			Crude protein		
	Critical range 3.43–3.94			Critical range 6.05–6.96			Critical range 1.33–1.53		
	Duncan Grouping			Duncan Grouping			Duncan Grouping		
	Mean (%)	N	Dist (m)	Mean (%)	N	Dist (m)	Mean (%)	N	Dist (m)
	15.06A	18	400	33.89A	18	400	5.29A	18	400
	13.41A	18	800	30.84BA	18	800	4.81BA	18	800
	8.24B	18	1 500	26.82BC	18	1 500	4.36BA	18	1 500
	7.62B	18	3 000	21.74C	18	3 000	3.66B	18	3 000
	3.20C	18	200	8.19D	18	200	1.05C	18	200
	0.00C	18	100	0.00E	18	100	0.00C	18	100
	0.00C	18	50	0.00E	18	50	0.00C	18	50
Hardveld sites	**Lignin**			**Crude fiber**			**Crude protein**		
	Critical range 3.17–3.67			Critical range 8.56–9.83			Critical range 2.21–2.54		
	Duncan Grouping			Duncan Grouping			Duncan Grouping		
	Mean (%)	N	Dist (m)	Mean (%)	N	Dist (m)	Mean (%)	N	Dist (m)
	11.09A	18	400	30.91A	18	400	7.56A	18	400
	9.28A	18	800	28.49A	18	800	6.66A	18	800
	5.94B	18	1 500	19.14B	18	1 500	3.37B	18	1 500
	4.83B	18	3 000	12.35CB	18	3 000	2.75B	18	3 000
	4.59B	18	200	11.04CB	18	200	2.02CB	18	200
	3.26B	18	100	7.26D	18	100	0.97CB	18	100
	0.00C	18	50	0.00D	18	50	0.00C	18	50

Key: Dist = distance from borehole; critical range = the confidence limit; Duncan Grouping = the Duncan's Multiple Range test or pair-wise comparison of the means; 0 = no samples. Means with the same letter are not significantly different, while means with different letters are significantly different

(Tables 4b and 5b) in the grass and soil samples were recorded along grazing gradients in both the hardveld and the sandveld study sites. Plants utilise the elements from the soil for their growth and in the process there is a likelihood of depleting elements in the soil, hence the low correlations. Data for this experiment were collected at the peak of the growing season, during the period when element demand by the plants is high. Nutrients in solution are likely to be taken up immediately by plant roots, but they also can move with water and can easily leach below the plant root zone. Loss of minerals through volatilisation and hydrolysis is also likely to result in the low relationships (Walker 1962). Although 60% to 90% of the minerals ingested by grazing animals are returned to the soil, the bulk of the total macroelements are voided in faeces, through volatilisation. Barrow (1967) concluded that nutrients returned to the soil in urine are readily available to plants. However, losses through volatilisation can be high, particularly around water points. This is so because areas around boreholes are usually bare and hotter, compared to those a distance away (Sosebee 1976).

Herbaceous species patterns

Sandveld

Twenty-two environmental variables were related to the species data using the CCA. Nine variables (soil pH, soil K, soil Ca, soil Cu, soil Fe, herbaceous basal cover, *Cynodon dactylon* biomass, *Urochloa trichopus* biomass and *Eragrostis pallens* biomass) were straight away omitted by the CCA programme, due to their negligent variance. The eigenvalues of Axis 1 and Axis 2 were very high: 0.58 and 0.29 respectively. However, on the basis of the t-values of < 2.1 at 5% significance level and high multicollinearity (evident through high variable inflation factors), a further nine environmental variables were dropped. Four environmental variables — soil nitrogen, distance from water, soil magnesium and soil zinc — were retained, and accounted for almost the same variance as the initial 13 variables (Axis 1 = 0.54, Axis 2 = 0.16).

The forward selection of the four environmental variables showed that soil nitrogen, distance from water, soil magnesium and soil zinc explained 24%, 21%, 8% and 5% of the variance in the species data, respectively. The Monte Carlo test showed significance fit of species data along the first canonical axis (P = 0.001). The four retained environmental variables and the species data scores were plotted on the canonical Axis 1 and 2 (Figure 4).

In Figure 4, the key environmental variables are represented by arrows starting from the origin of the figure. The arrowheads represent maximal intensities of that environmental factor and its importance (Ter Braak 1988). Orthogonal projection of environmental variable onto each species relates to the association of that particular species with the environmental variable. For example, *Aristida congesta* and *Eragrostis pallens* are grass species that were associated more with high distance than were *Eragrostis rigidior, Hermbstaedia odorata* and *Schimdtia kalaharensis* (Figure 4). *Eragrostis rigidior, Eragrostis pallens* and *Aristida congesta* are major grass species of the sandveld that were dominant further away from water points (Figure 4). Plant species associated with high soil nitrogen sites were mainly

Table 4a: Correlation co-efficients between macroelements in major grasses and soils of the sandveld study sites

		Macroelements in major grasses				
Dist (m)	Macroelements in soils	K	Mg	P	Ca	N
100	K	0.37 (0.23)				
100	Mg		–0.09 (0.78)			
100	P			–0.43 (0.49)		
100	Ca				0.37 (0.24)	
100	N					–0.19 (0.45)
200	K	–0.17 (0.59)				
200	Mg		0.05 (0.87)			
200	P			–0.55 (0.07)		
200	Ca				–0.83 (0.01)	
200	N					0.52 (0.03)
400	K	0.59 (0.04)				
400	Mg		–0.09 (0.78)			
400	P			–0.06 (0.85)		
400	Ca				–0.06 (0.85)	
400	N					–0.03 (0.90)
800	K	0.13 (0.69)				
800	Mg		–0.01 (0.96)			
800	P			0.03 (0.93)		
800	Ca				0.11 (0.74)	
800	N					–0.04 (0.88)
1 500	K	–0.30 (0.34)				
1 500	Mg		0.14 (0.66)			
1 500	P			–0.41 (0.18)		
1 500	Ca				–0.10 (0.75)	
1 500	N					–0.05 (0.85)
3 000	K	0.49 (0.10)				
3 000	Mg		0.64 (0.02)			
3 000	P			–0.08 (0.79)		
3 000	Ca				–0.51 (0.09)	
3 000	N					–0.01 (0.99)

Key: Numbers in parentheses indicate the level of significance (i.e. the probability of rejecting the null hypotheses – H0 : r = 0). Omitted data at 50m, because there were no plants to be sampled due to degradation or bare soils

Table 4b: Correlation co-efficients between microelements in major grasses and in soils of the sandveld study sites

		Microelements in major grasses		
Dist (m)	Micro elements in soil	Zn	Fe	Cu
50	Zn	0		
50	Fe		0	
50	Cu			0
100	Zn	0.16 (0.62)		
100	Fe		0.20 (0.53)	
100	Cu			0.26 (0.42)
200	Zn	–0.02 (0.95)		
200	Fe		0.44 (0.16)	
200	Cu			0.55 (0.06)
400	Zn	0.17 (0.59)		
400	Fe		0.19 (0.55)	
400	Cu			0.35 (0.27)
800	Zn	0.69 (0.01)		
800	Fe		0.58 (.05)	
800	Cu			–0.58 (0.05)
1 500	Zn	0.33 (0.29)		
1 500	Fe		0.03 (0.91)	
1 500	Cu			0.43 (0.16)
3 000	Zn	0.51 (0.09)		
3 000	Fe		0.71 (0.01)	
3 000	Cu			–0.26 (0.41)

Key: Numbers in parentheses indicate the level of significance (i.e. the probability of rejecting the null hypotheses – H0 : r = 0)

forbs: *Amaranthus thunbergii, Eleusine coracana, Xanthium strumarum* and *Datura ferox*. Most forbs found close to water points are not grazed by livestock, compared to grass species, hence their dominance in the soil-nutrient concentrated zone.

Hardveld

The CCA programme omitted seven of the 22 environmental variables outright. The eigenvalues of Axis 1 and Axis 2 were 0.51 and 0.24 respectively. Further analysis involving t-values and variable inflation factors indicated that eight variables (soil nitrogen, soil zinc, soil manganese, distance from water, *Urochloa trichopus* biomass, *Panicum maximum* biomass, *Sporobolus ioclados* biomass and *Aristida congesta* biomass) accounted for almost the same variance in the species data set (eigenvalues Axis 1 = 0.50, Axis 2 = 0.21) as the 15 variables. Forward selection of the retained variables showed that soil nitrogen accounted for 35% of the variance in the data set, making it the most important variable.

Herbaceous species — *Digitaria milanjiana, Aristida congesta, Kohaustia subverticilata*, *Hermbstaedia odorata, Sida cordifolia* — were found to be associated with higher distance from water points than were *Eragrostis rigidior, Panicum maximum, Acanthosicyosis naudinianus, Helichrysum argysphaem* and *Sporobolus ioclados* (Figure 5). Most of the species associated with water points were forbs that

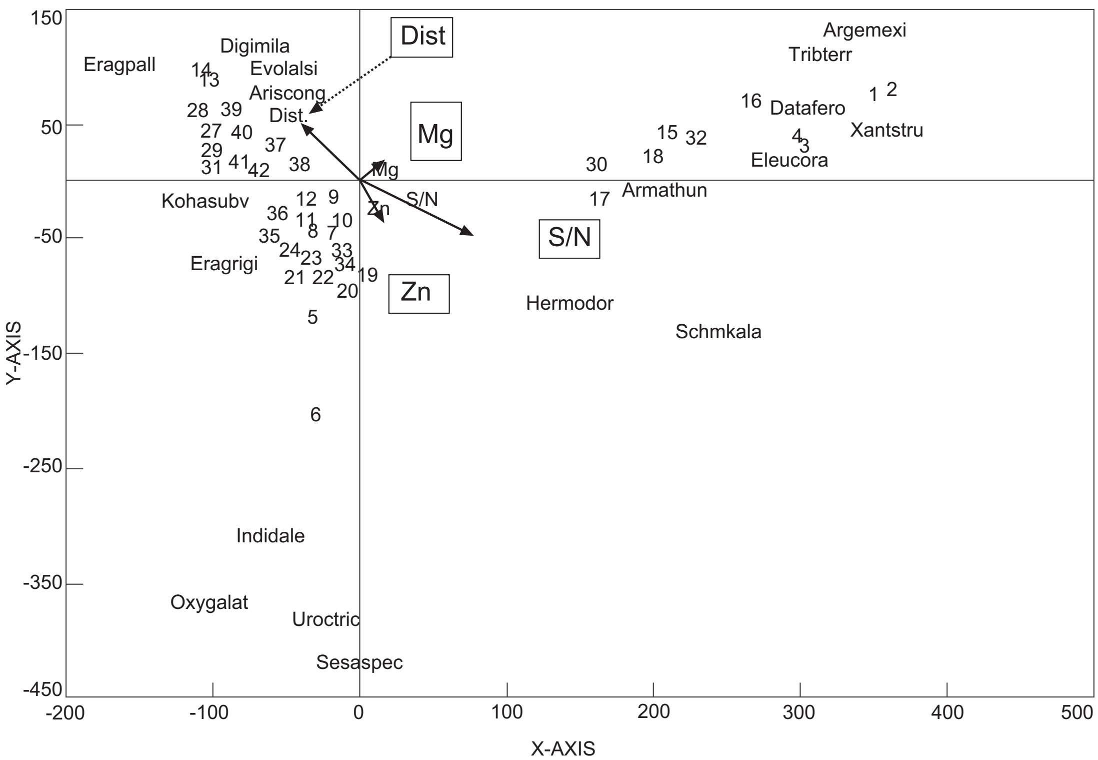

Figure 4: Ordination diagram based on CCA of the species abundance/density data with respect to four environmental variables (soil nitrogen (S/N; distance Dist; magnesium Mg; and zinc Zn) of the sandveld study sites

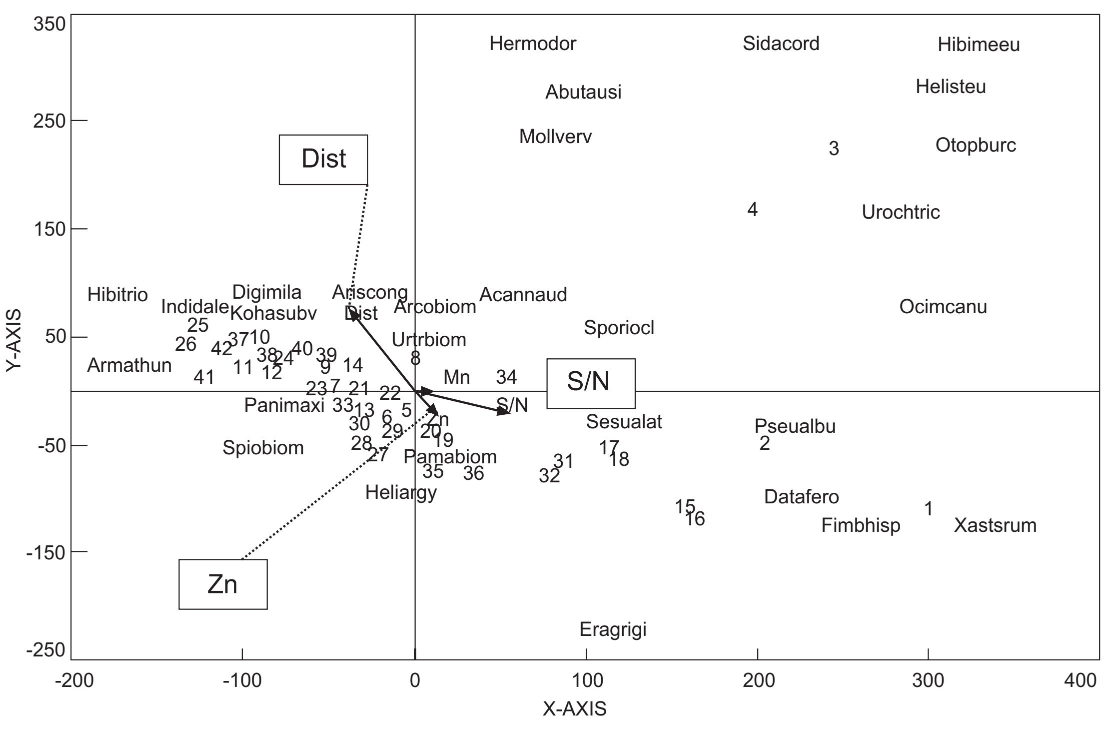

Figure 5:. Ordination diagram based on the species abundance data with respect to eight environmental variables (soil nitrogen S/N; distance Dist; zinc Zn; manganese Mn; spiobom = Sporobolus ioclados biomass; arcobiom = Aristida congesta biomass; urtrbiom = Urochloa trichopus biomass; pama biom = Panicum maximum biomass) of the hardveld study sites

Table 5a: Correlation co-efficients between macroelements in major grasses and in soils of the hardveld study sites

		Macroelements in major grasses				
Dist (m)	Macroelements in soils	K	Mg	P	Ca	N
100	K	–0.09 (0.78)				
100	Mg		–0.50 (0.10)			
100	P			–0.45 (0.15)		
100	Ca				–0.05 (0.89)	
100	N					–0.10 (0.70)
200	K	–0.01 (0.72)				
200	Mg		–0.51 (0.10)			
200	P			0.22 (0.49)		
200	Ca				–0.66 (0.02)	
200	N					–0.26 (0.29)
400	K	–0.013 (0.70)				
400	Mg		0.18 (0.57)			
400	P			0.12 (0.71)		
400	Ca				0.34 (0.28)	
400	N					0.09 (0.73)
800	K	–0.37 (0.23)				
800	Mg		0.15 (0.64)			
800	P			0.48 (0.12)		
800	Ca				–0.38 (0.22)	
800	N					–0.09 (0.71)
1 500	K	–0.01 (0.97)				
1 500	Mg		0.34 (0.28)			
1 500	P			0.49 (0.11)		
1 500	Ca				–0.65 (0.02)	
1 500	N					–0.36 (0.15)
3 000	K	0.53 (0.07)				
3 000	Mg		0.32 (0.3)			
3 000	P			0.26 (0.41)		
3 000	Ca				0.67 (0.02)	
3 000	N					–0.12 (0.63)

Key: Numbers in parentheses indicate the level of significance (i.e. the probability of rejecting the null hypotheses – H0 : r = 0) . Omitted data at 50m because there were no plants to be sampled due to degradation or bare soils

dominated in high soil-nitrogen sites e.g. *Sesum alatum*, *Pseudognaphallium luteo-album*, *Datura ferox, Fimbristylis hispidula* and *Xanthium strumarum. Sporobolus ioclados, Helichrysum argysphaerum* and *Ocimum canum* were herbaceous plant species that only existed in the hardveld sites, while *Eragrostis pallens*, *Schmidtia kalaharensis* and *Oxygonum alatum* occurred only in the sandveld.

Grass species diversity was indicated as very low close to water points and consistently increased with distance for both the hardveld and sandveld study sites (Figure 6). However, the diversity of forbs species was very high close to water points, and drastically decreased with distance. Overall herbaceous species diversity (both grasses and forbs) was higher in the hardveld than the sandveld along the grazing gradients (Figure 6).

It is apparent that most forb species (for example, *Amaranthus thunbergii, Xanthium strumarum, Sesum alatum, Pseudognaphalium* and *Datura ferox*) were recorded very close to boreholes while grass species (for example, *Eragrostis pallens*, *Urochloa trichopus* and *Eragrostis rigidior*) were not. Most of these forb species are annuals that favour nutrient-rich sites around boreholes and probably not palatable to cattle. Heavy trampling, grazing and eutrophication around boreholes seem to be working against the establishment of grasses.

Conversely, another category of forbs, for example *Hibiscuss trionum, Indigofera daleoides, Kohaustia subverticilata* and *Evolvus alsinoides*, is found to be associated with low grazing pressure (see Figures 4 and 5), and these are considered valuable forage for cattle. The forbs are found in association with high grass cover and biomass of *Aristida congesta* and *Urochloa trichopus* in both the sandveld and the hardveld.

A distinct picture relating to the herbaceous species patterns along grazing gradients in the hardveld and sandveld areas of Botswana emerges. It becomes evident that in both areas, the major determinants of herbaceous species patterns are grazing pressure and soil nitrogen. High nitrogen sites, which are also characterised by high grazing pressure, show a high dominance of forbs (e.g. *Sesum alatum, Pseudognaphalium luteo-album, Datura ferox* and *Xanthium strumarum*).

Conclusions

Communal grazing land in Botswana has been blamed for uncontrolled management that subsequently leads to low animal production levels and unprecedented rangeland

Table 5b: Correlation co-efficients between microelements in major grasses and in soils of the hardveld study sites

		Microelements in major grasses		
Dist (m)	Microelements in soil	Zn	Fe	Cu
50	Zn	0		
50	Fe		0	
50	Cu			0
100	Zn	0.68 (0.02)		
100	Fe		–0.074 (0.82)	
100	Cu			0.29 (0.36)
200	Zn	–0.03 (.93)		
200	Fe		–0.04 (91)	
200	Cu			–0.13 (0.68)
400	Zn	–0.06 (0.85)		
400	Fe		–0.25 (0.44)	
400	Cu			0.02 (0.96)
800	Zn	–0.32 (0.30)		
800	Fe		0.27 (0.40)	
800	Cu			–0.09 (0.78)
1 500	Zn	–0.013 (0.68)		
1 500	Fe		–0.15 (0.65)	
1 500	Cu			0.11 (0.74)
3 000	Zn	0.52 (0.08)		
3 000	Fe		–0.31 (0.33)	
3 000	Cu			0.69 (0.01)

Key: Numbers in parentheses indicate the level of significance (i.e. the probability of rejecting the null hypotheses – H0 : r = 0)

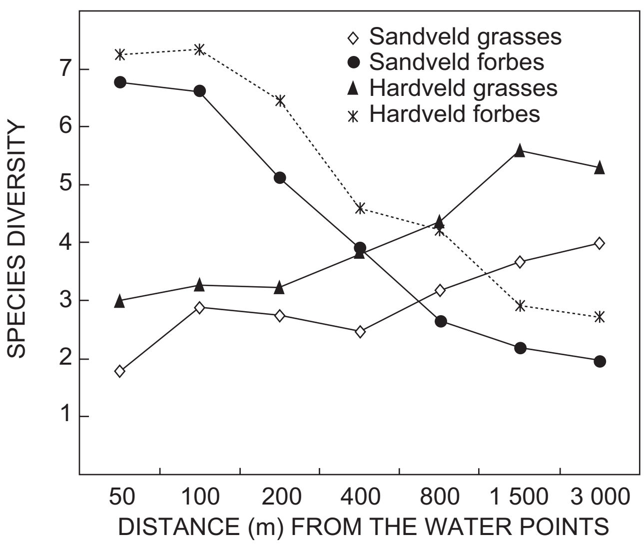

Figure 6: Herbaceous species diversity along grazing gradients in the sandveld and hardveld study sites (2002 wet season, Simpson's diversity index)

degradation (Government Paper No. 1, 1991). In an attempt to combat the foregoing, the Ministry of Agriculture modified and expanded the Tribal Grazing Land Policy (TGLP) to encourage farmers to fence off their land either as individuals, groups or communities, where feasible. Guidelines in zoning and allocation of such grazing land include the availability of information on various land resource parameters e.g. soils, vegetation, climate and hydro-geological data. Therefore, the following management implications are drawn from this study in view of the fencing component of the National Policy on Agricultural Development.

1. Grazing pressure and soil nitrogen are generally the major determinants of herbaceous species patterns in both the sandveld and the hardveld communal grazing areas. For example, most grass species diversity levels tend to increase with distance from water points, while forbs decreased with distance. If the soil is regarded as the basis of sustainability (Warren and Agnew 1988) the 0–0.50m zone around the water trough is irreversibly degraded, due to extreme nutrient enrichment of the soil, which effectively causes toxicity. Herbivore use intensity (HUI), as coined by Georgiadis (1987) in reference to the combined grazing, trampling and excretion effects of livestock, occurs at extreme levels in this 0–50m zone.
2. Herbaceous species patterns are clearly defined into categories: a) forbs highly associated with high soil nitrogen and high grazing pressure, and b) forbs and/or grasses that increase in cover and biomass with distance from boreholes, for both the hardveld and sandveld areas. Intense grazing leads to excessive removal of the most palatable species, which are usually perennial grasses. This reduces ground cover, but ultimately opens the way for less palatable and faster-establishing annual grasses and forbs to take hold.
3. Forbs constitute most of the diversity (see Figure 6) but have largely been ignored in favour of the dominant grasses that are considered important for livestock production. Invader forbs and lack of grass cover close to water points are an indication of local degradation. A well-established premise is that over time, degradation or desertification spreads outwards from boreholes and wells (Goudie 1990) under the continued pressure exerted by livestock. Such areas have been termed 'sacrifice areas' which have effectively been central to arguments that identify pastoralism as a major cause of desertification (Perkins and Thomas 1993). Studies by Perkins (1991) have shown that sacrifice zones extended for up to 400m from communal water points. However, the ground cover beyond sacrifice zones was reasonably high, with grasses affording over 50% cover.
4. Soils from the hardveld are generally more fertile than those of the sandveld, therefore this may imply supplementing livestock, particularly with phosphorus, in the sandveld communal grazing areas. The sandveld soils typically consist of over 95% fine sand-sized, Aeolian-deposited sediment (Thomas and Shaw 1991) and are predominantly deep, structureless and lacking in N, P and organic matter (Dougill *et al*. 1998, Perkins and Thomas 1993). Studies by Dougill and Thomas (2004) have revealed that in the Kalahari, the spatial heterogeneity of soil nutrients is relatively low, a result which is also evident in this study.
5. Is it better to have a specified distance interval between permanent water sources or multiple water sources in an area in order to restrict proliferation of invader forb species? Provision of multiple water sources is likely to reduce concentration of livestock in one area and hence

prevent accumulation of invader forbs. According to Holechek *et al*. (1998), the most economical method for reclaiming deteriorated grazing lands is through the use of methods not requiring planting of desired species. This may be accomplished by control of unwanted plants, concentrating moisture or harvesting precipitation, and/or by grazing management.

6. Since the immediate area around livestock water points (sacrifice areas) will always be degraded, would a strategy of using movable troughs (through piping) alleviate fenced areas of pressure-related invader species? Movable troughs, though labour-intensive, are likely to alleviate pressure on both plants and soil around water points and hence promote better herbaceous plants' succession.
7. What are the ecological implications of (5) and (6) on herbaceous species patterns and mineral distribution within fenced communal areas? Many species are likely to be present in the natural ecosystem at all stages of succession, but because of the changes in the micro-environment (e.g. caused by overgrazing) only certain ones will be dominant at a given time. Unfortunately, in nature, daily, seasonal and yearly changes are so thoroughly superimposed upon successional changes that their measurement and separation have not always been attained, perhaps not even realised (Child *et al*. 1987).

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References

Al-Jaloud AA, Shraukat A, Chaudhary, Quresh II and Al-Shanghitt A 1994. Nutrient evaluation of some arid range plants in Saudi Arabia. *Journal of Arid Environments* **28**: 293–311.

Andrew H and Lange RT 1986. Development of a new piosphere in Chenopod Shrubland grazed by sheep — changes to the vegetation. *Australian Journal of Ecology* **11**: 411–424.

Barrow NJ 1967. Some aspects of the effects of grazing on the nutrition of pastures. *Journal of Australian Institute of Agricultural Science* **33**: 254–262.

Belyea RL and Ricketts RE 1993. *Forages for cattle: new methods of determining energy content and evaluating heat damage*. Agricultural Publication G3150. Department of Animal Sciences, University of Missouri-Columbia.

Bergon M, Harper JL, Townsend CR 1986. *Ecology, Individuals, Populations and Communities (3rd edn)*. Department of Environmental and Evolutionary Biology, University of Liverpool, Liverpool, UK.

Bhalotra YPR 1987. *Climate of Botswana part II: elements of climate rainfall. Department of Meteorological Services, Ministry of Works and Communications, Gaborone, Botswana*.

Bremer JM 1965. Organic forms of nitrogen. Methods of soil analysis. American Society of Agronomy. *Monograph* No. 9 (part 2): 1324–1341.

Buckley R, Gubb A and Wasson R 1987a. Parallel dune field ecosystems: predicted soil nitrogen gradient tested. *Journal of Arid Environments* **12**: 105–110.

Butler JL and Briske DD 1988. Population structure and tiller demography of bunchgrasss *Schizachyrium scoparium* in response to herbivory. *Oikos* **51**: 306–312.

Buxton DR and Russell JR 1988. Lignin constituents and cell wall digestibility of grass and legume stems. *Crop Science* **28**: 553–558.

Cater MR 1993. *Soil sampling and analysis. Canadian Society of Soil Science Library of Congress Cataloguing-in-Publication Data, USA.*

Chapman HD (ed) 1966. *Diagnostic Criteria for Plants and Soils* pp 572–719. University of California Press, Berkerly, CA.

Child RD, Heady HF, Peterson RA, Pieper RD and Poulton CE 1987. *Arid and semi-arid rangelands. Guidelines for Development*. Winrock International, Morriton, AR.

Cook CW and Stubbendieck J 1986. *Range research: basic problems and techniques*. Society for Range Management, Denver, Colorado.

David WP 1996. *Cows, grass and profitability. Livestock and Range Report* No. **961**. Summer, Napa and Solano Counties, UCCE, Livestock/Range Management Program.

De Wit PV and Bekker RP 1990. *Soil mapping and advisory services, Botswana. Explanatory note on the Land Systems Map of Botswana. FAO (UNDP Programme), Government of Botswana.*

Dougill AJ and Thomas AD 2004. Kalahari sand soils: spatial heterogeneity, biological soil crusts and land degradation. *Land Degradation Development* **15**: 233–242.

Dougill AJ, Heathwaite A and Thomas DSG 1998. *Soil water movement and nutrient cycling in the semi-arid rangeland: vegetation change and system resilience*. *Hydrological Processes* **12**: 443– 459.

Dregne HE, Tucker CJ and Wilcomb WW 1991. Expansion and contraction of the Sahara Desert from 1980 to 1990. *Science* **253**: 299–301.

Fisher RA 1921. On the 'probable error' of a coefficient of correlation deduced from a small sample. *Metron* **1**: 1–32.

Georgiadis NJ 1987. *Response of Savanna Grasslands to Extreme Use by Pastoralist Livestock*. PhD thesis, Seracuse University, New York. 142pp.

Gidenne T and Lebas F 2002. *Effect of dietary fiber origin on the digestion. Station de Recherches Cunicoles INRA, Centre de Rechecher de Toulouse*.

Goudie AS 1990. *Desert degradation*. In: *Goudie AS (ed) Techniques for Desert Reclamation*. John Wiley and Sons, Chichester.

Government Paper No. 1 1991. *National Policy on Agricultural Development*. Gaborone, Botswana.

Hiernaux P and Turner MD 1996. The effect of timing and frequency of clipping on nutrient uptake and production of Sahelian annual grasslands. *Journal of Applied Ecology* **33**: 387–399.

Hiernaux P, Diarra L and Maiga A 1988. *Evolution de la vegetation sahelienne Apres la Secheresee Bilan du Suiv*. Du Gourma en 1987. Bamako, Mali. *Centre for Internationale pour L' Elevage en Afrique*.

Hilder EJ 1966. *Distribution of excreta by sheep in pasture*. Tenth International Grasslands Congress, Proceedings, Helsinki, pp.977–981.

Hilder EJ and Mottershead BE 1963. The redistribution of plant nutrients through free-grazing sheep. *Australian Journal of Science* **26**: 88–89.

Holechek JL, Pieper RD, Herbel CH 1998. *Range Management Principles and Practices (3rd edn)*. Prentice Hall, Upper Saddle River, New Jersey.

Isaac RA and Kerber JD 1971. Atomic absorption and flame photometry: techniques and uses in soil, plant and water analysis. In: Walsh LM (ed) Instrumental Methods for Analysis of Soils and Plant Tissue. Soil Science. *Society of America, Madison, Wisconsin*, pp 17–37.

Jurgens MH 1997. *Animal Feeding and Nutrition*. Kendall/Hall Publishing Co., Dubuque, Iowa.

Lange RT 1969. The piosphere: sheep track and dung patterns. *Journal of Range Management* **22**: 396–400.

Lusigi WJ & Glaser G 1984. Desertification and nomadism: a pilot approach in eastern Africa. *Nature and Resources* 20(1): 21–31.

McGregor AN 1972. Gaseous losses of nitrogen from freshly wetted desert soils. *Soil Science Society of America, Proceedings*. **36**:594–596.

Moleele NM 1999. *Bush Encroachment and the Role of Browse in Cattle Production. An Ecological Perspective from a Bush Encroached Grazing System, Oliphants Drift, Kgatleng District, South-east Botswana*. PhD thesis, Department of Physical Geography, Stockholm University.

Moleele NM and Perkins J 1998. Encroaching woody plant species and boreholes: is cattle density the main driving factor in the Olifants Drift communal grazing lands, Botswana? *Journal of Arid Environments* **40**: 245–253.

Mphinyane WN 1982. *Herbaceous plants production in protected and unprotected areas along a degradation gradient in Western Kalahari.* Unpublished paper.

Perkins JS 1991. *The impact of borehole dependent cattle grazing on the environment and society of the eastern Kalahari sandveld, Central District, Botswana*. PhD Thesis, University of Sheffield, Sheffield.

Perkins JS and Thomas DSG 1993. Environmental responses and sensitivity to permanent cattle ranching in semi-arid western central Botswana. In: *Thomas DSG and Allison RJ (eds) Landscape Sensitivity*. Wiley, Chichester.

Ramolemana G and Machacha S 2000. *Preliminary evaluation of the effects of soil type on chemical composition of different grass species consumed by grazing animals*. Proceedings of Livestock Feeding Systems workshop held at the Centre for In-Service and Continuing Education, Botswana College of Agriculture, Goborone, Botswana, pp 149–155.

Schroeder JW 1996. *Quality forage for maximum production and return. NDSU*.

Scoones I 1995. Exploiting heterogeneity: habitat use by cattle in dry land Zimbabwe. *Journal of Arid Environments* **29**: 221–237.

Skujins JJ and West NE 1974. *Nitrogen dynamics in stands dominated by some major cool desert shrubs*. US/BP Desert Biome research. *Memoirs, Range Management* **42**–74, 36pp.

Sosebee RE 1976. Rangeland plant physiology. *Range Science Series* No. **4**, Society for Range Management.

Ter Braak CJF 1988. Program CANOCO Manual. Wageningen, The Netherlands, Ministry of Agriculture and Fisheries, *Agricultural Mathematics Group* (DLO).

Thomas DSG and Shaw PA 1991. *The Kalahari Environment.* Cambridge University Press, UK.

Thomas DSG, Sporton D and Perkins J 2000. The environmental impact of livestock ranches in the Kalahari, Botswana: natural resource use, ecological change and human response in a dynamic dryland system. *Land Degradation Development* **11**: 327–341.

Tolsma DJ, Ernst WHO and Verway RA 1987. *Nutrient in soil and vegetation around two artificial waterfronts in eastern Botswana*. Department of Biology, University of Botswana, Gaborone and Department of Ecology and Ecotoxicology, Biological Laboratories, Free University, Amsterdam, The Netherlands.

Underwood EJ 1971. *Trace Elements in Human and Animal Nutrition*. Academic Press, New York, 543pp.

Van Rooyen N, Bredenkamp GJ, Theron GK, Bothma du PJ and LeRiche EAN 1994. Vegetation gradients around artificial watering points in the Kalahari Gemsbok National Park. *Journal of Arid Environments* **26**: 349–361.

Van Soest PJ 1982. *Nutritional Ecology of the Ruminant*. O & B Books, Corvallis, Oregon.

Vossen P 1987. An analysis of agricultural livestock and traditional crop production statistics as a function of total annual and early, mid and late rainy season rainfall in Botswana. Botswana Meteorological Services, Gaborone.

Walker JW, Heistchmidt RK, De Moraes EL, Kothmann MM and Dowhower SL 1989b. *Quality and botanical composition of cattle diets under rotational and continuous grazing treatments*.

Walker TW 1962. *Problems of soil fertility in a grass-animal regime. Intnational Society for Soil Science Communities 4 and 5 Transitions,* 704–718.

Warren A 1995. Changing understandings of African pastoralism and the nature of environmental paradigms. Transactions, *Institute of British Geographers NS* **20**: 193–203.

Warren A and Agnew C 1988. *An assessment of desertification and land degradation in arid and semi-arid areas. Drylands Paper* No. 2. London, UK, 72pp.

Warren A and Khogali M 1992. Assessment of desertification and drought in the Sudano-Sahelian region 1985–1991. *UNSO, UNDP*, 102pp.

Weir JS 1971. The effects of creating additional water supplies in a Central African National Park. In: *Duffy E and Watt AS (eds) The Scientific Management of Animal and Plant Communities for Conservation*. Blackwell Scientific Publications, London.

White R 1993. *Livestock development and pastoral production on communal rangeland in Botswana. The Botswana Society, Gaborone.*