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Herbaceous and Woody Plant Properties in Abandoned Kraal Areas in a Hardveld Botswana

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ABSTRACT

Herbaceous and woody plant species in abandoned traditional kraals were investigated. To achieve the aim of this study, nutrient status of soil in addition to vegetation composition and communities from the kraal sites were analyzed and results compared with those from control sites. A total of 25 kraals that had been abandoned between 5 and 45 years were sampled. Data were analyzed using multivariate procedures; a two-way indicator species analysis (TWINSPAN), detrended correspondence analysis (DCA) and canonical correspondence analysis (CCA) to establish classification of the plant communities. The significant environmental variables identified with *t*-values above 2.1 that determined the composition and patterns of the plant communities were organic matter, plant available nitrogen, calcium and moisture content. The results show major differences in soil physio-chemical properties and also in patterns and composition of vegetation communities between kraals and their surrounding areas. Evidence from the results show that kraal areas play an important role in determining key resource areas by influencing systematic distribution of nutrients. With kraals tending to increase the heterogeneity in the natural distribution of nutrients, it is apparent that animal waste deposited in the kraals modify vegetation patterns as high nutrient tolerant species gain competitive advantage over those that are not. The findings provide some important information that could explain herbaceous and woody species community patterns particularly in semi-arid environments where livestock management by the use of traditional kraals is a common practice.

Keywords: environmental variables, plant communities, multivariate procedures, traditional kraals

INTRODUCTION

Contemporary pastoralism in semi-arid regions is heavily based on traditional knowledge of historical transhumant techniques such as the use of kraals. Often, after the kraals are abandoned, kraal owners rarely consider the effects of the accumulated livestock waste within the kraals on the environment. This is exacerbated by disuse of the kraal manure for soil amendment, a common practice in most semi-arid regions. This constitutes loss of nutrients because the nutrients generated within the kraals decrease with time after the kraal abandonment.

Accumulated wastes at abandoned kraal areas have been reported to have ecological effects particularly in peri-urban semi-arid ecosystems where disturbances due to anthropogenic activities are high. Various studies have reported the effects of accumulated waste on soil (Muchiru *et al.* 2008; Mahmoodabadi *et al*. 2010) and vegetation (Reeder and Schuman 2002; Augustine and McNaughton 2004).

Historically, traditional ways of mixed farming were common in most semi-arid environments. Within the last three decades however, erratic rainfall patterns have forced farmers to shift emphasis from crop production to livestock farming (Harris 2002; Kangalawe *et al*. 2008). Presently, livelihood options for most farmers have narrowed to dependence on cattle rearing. This has led to an increased stocking density in these environments stretching the area's marginal grazing resources to the extent that overgrazing is now recognized as a major concern in these environments (Olsson *et al*. 2005; Mbourou *et al*. 2010). This problem is aggravated by the shrinking pastoral lands due to the growth urbanisation.

In peri-urban areas, such as Tlokweng village in Botswana, population growth and urbanization have accelerated rapidly. Only elements of the earlier distinct traditional village systems can be identified and instead a local pattern of integrated small scale arable lands and livestock (mostly kraaled) has emerged. A process of urban-rural integration associated with an evolution of the settlement has gradually been created such that grazing lands are increasingly getting lost to residences and/or industrial use. In addition to the rapid urbanisation and social cultural practices related to kraal abandonment (Marshall 2008), a high density of abandoned kraals is now a common feature as has been the case in many other similar semi-arid environments. The characteristic nature of Tlokweng village represents other semi-arid environments where rapid urbanisation has highly influenced traditional ways of livestock management and limitations in grazing lands. It is therefore an ideal study area to examine the influence of abandoned kraal areas on the environment. The focus of this paper therefore is to investigate the effects of abandoned kraal manure accumulation on vegetation composition and communities. The findings will provide information on the potential effects of accumulated waste at kraals on soil and vegetation. This is particularly important in semi-arid areas where livestock has an important socio-cultural and economic importance.

METHODS

Study area

Tlokweng Village is located east of Gaborone in the South East district of Botswana (**Fig. 1**). The area is characterized by a semi-arid subtropical continental climate with distinctive winter and summer. The mean annual rainfall is 525 mm per year. Given the low and erratic annual rainfall (23% CV) and high rates of evaporation especially in summer, water deficiency is a major constraint on agriculture and plant growth. Mean temperatures range between 25 and 35°C in summer and 11 and 3°C in winter (Depart-

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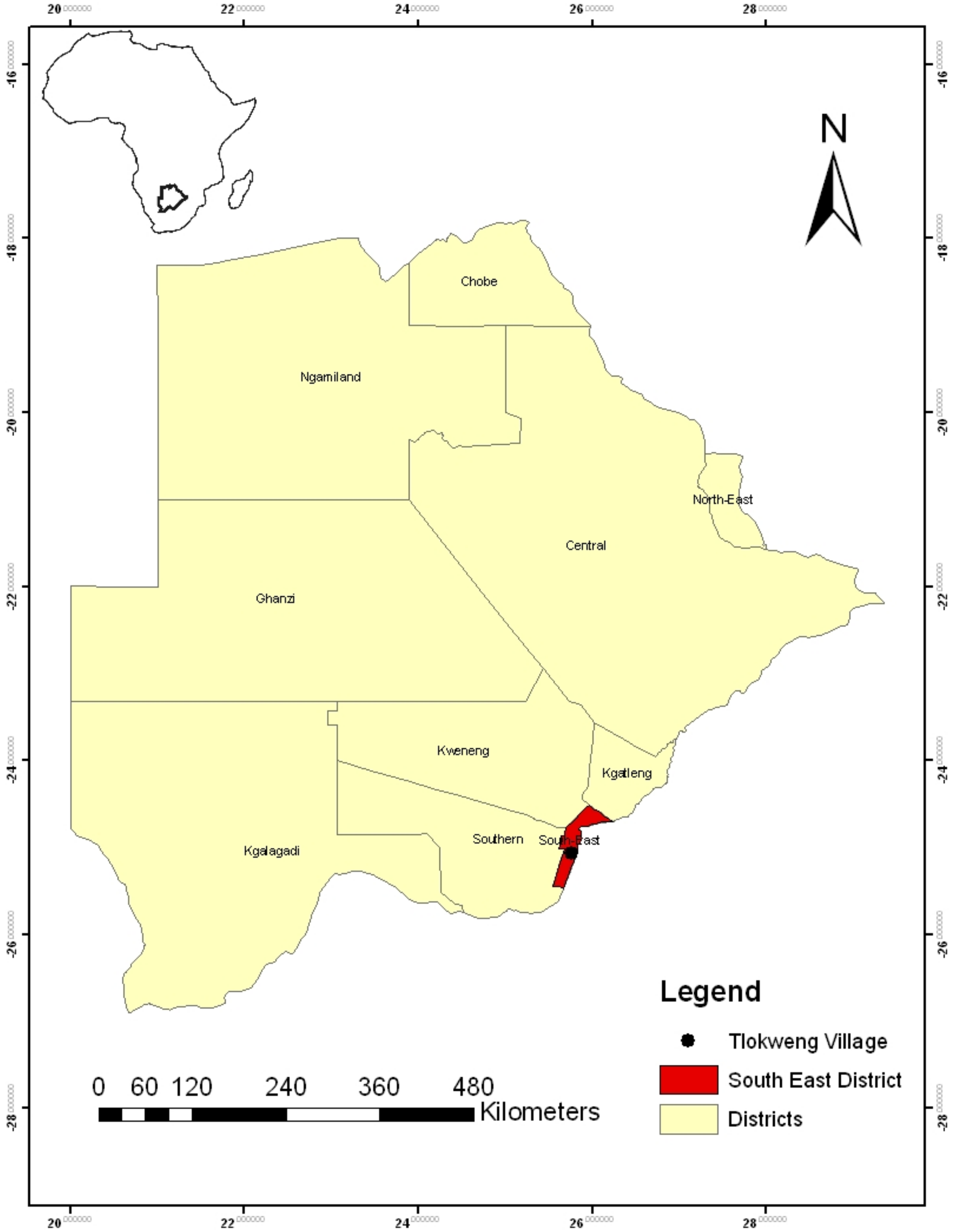

Fig. 1 Location of Tlokweng Village in the South East district of Botswana.

ment of Meteorological Services 2009). The area lies generally between 960 and 1200 m above sea level with Gaborone granite as the major lithological complex underlying the area covering approximately 80% of the area. The soils were derived from granitic parent materials and they are generally coarse textured, with clay enriched subsoils due to downward eluviation of clay minerals in the soil profile. They are dominated by Arenosols and weakly developed Luvisols that are interrupted by Vertisols in riparian corridors (SMASP 2006).

In response to the semi-arid climate with prolonged periods of drought, the vegetation is xeromorphic savanna in which thorny trees especially *Acacia* species are important elements of the flora. Vegetation has been described as tree and shrub savanna (Skarpe 1991). This type of vegetation known as hardveld characterises the more humid eastern part of Botswana. It is more densely wooded than the more semi-arid vegetation developed over the Kalahari sands in the western part of the country.

Data collection

A kraal was defined as an enclosure for livestock. The choice of kraals was limited to those that are traditionally constructed. They are characteristically open (unroofed) with no concrete floors or bedding material such that the livestock dung and urine are deposited directly on the soil surface. Abandoned kraals were defined as those that are no longer actively utilized by livestock and which have been abandoned for a minimum of 5 years. The kraals were classified into 5 groups based on the length of time since abandonment as shown in **Table 1**. In addition to the selected abandoned kraals, 5 sites were chosen outside the kraal sites to serve as controls. These sites were located within the same vegetation unit and covered by the same highly sandy soils as in the kraal sites.

Table 1 Number of herbaceous and woody species of quadrats.

Length of time after kraal abandonment	Number of sites for each kraal category	Number of quadrats for herbeceous or woody species			
		0.25 m^2 quadrats (herbaceous spp.)	900 m^2 quadrats (woody spp.)	Control	Total quadrats of 5 sites
< 5 years	5	3	3	3	9*5 = 45
6 -10 years	5	3	3	3	9*5 = 45
11 – 20 years	5	3	3	3	9*5 = 45
21 – 40years	5	3	3	3	9*5 = 45
> 45 years	5	3	3	3	9*5 = 45
					225

Soil sampling and soil data analysis

Soil sampling was done at three randomly located points within each abandoned kraal and in the control sites. The soils were sampled at depths between 15-35 cm, using mini-soil pits dug at each sampling point. Thus, 6 samples were collected at each kraal, giving a total of 30 soil samples for each kraal group and 150 samples for all the 25 kraals studied. The soil samples were air dried in the laboratory and sieved through a 2-mm sieve for different types of laboratory analyses.

Analysis of the soil samples to determine their physical and chemical properties was based on standard laboratory analytical techniques of soil analyses. Soil pH was determined by using the HANNA 210 Microprocessor with end values being obtained by averaging three readings for each sample. Electrical conductivity, EC (µS/cm) was determined by using a programmable Vacuum Extractor (SampleTek-Smetter Design, Lincoln, Nebraska) to prepare saturated samples that were subsequently analyzed using a Thermo Orion conductivity cell. Plant available nitrogen (PAN) was considered to be the equivalent of mineral N which was estimated from observed values of NH_4-N and NO_3-N that were determined on the basis of extraction procedures developed in USDA (1996) and Okalebo (1993). Olsen phosphorus, Olsen P (mg/kg) was estimated by the Olsen procedure as described by Csuros (1997). Soil organic matter (OM%) content was determined using the Walkley-Black wet combustion method (USDA 1996; van Reeuwijk 2006). Estimation of exchangeable Ca^{2+} and Mg^{2+} ($cmol_c$/kg) was conducted by using a Varian SpectrAA FS (Varian Inc., Victoria, Australia) Flame Atomic Absorption Spectrometer (FAAS). Gravimetric analysis of moisture content of the difference in weight before and after oven drying of sample (van Reeuwijk 2006) determined the soil's moisture content.

Analytical data on the soils of the abandoned kraal and control sites are tabulated in **Table 2**. The values obtained for the different soil parameters analyzed were averaged for the five sampling points in each kraal and also for all kraals in each kraal group. Comparison between abandoned kraals of different duration was done on the basis of the individual soil parameters using both the Student's *t*-test and the analysis of variance (ANOVA). A Statistical Package for Social Scientists, Predictive Analytics SoftWare (PASW) Statistics 18 (formerly ©SPSS) and Microsoft Office Excel (Microsoft® Office 2007) were used to run all statistical operations. Levels of significance were determined at 95% confidence limit.

Vegetation sampling and vegetation data analysis

Herbaceous and woody species sampling was done in summer months between September and April during which vegetation is robust due to rains. Quadrats of 2 different sizes, 0.25 m^2 (0.50 m × 0.50 m) and 900 m^2 (30 m × 30 m), were used to sample herbaceous and woody species respectively. At each kraal area, sampling was done at 6 points; 3 points were randomly selected within the kraal area and the remaining 3 at 500 m beyond the centre of the kraal in the open pasture (control). A total of 225 quadrats from 25 abandoned kraal sites were sampled (**Table 1**). Data from the mean total of species found at each kraal site was used to determine the dominant species and their associations. Vegetation data derived from the number of herbaceous and woody species from the quadrats replicates was used as a measure of species composition in abandoned kraals and their control sites.

Analysis of soil and vegetation relationships

Data obtained from soil analysis represent the selected environmental variables. Plant species data from the 25 sampling sites was analysed using a Two-Way INdicator SPecies ANalysis (TWINSPAN; Hill 1979a) and CANOnical Community Ordination (CANOCO; ter Braak 1988). The techniques were preferred because they are designed to identify major patterns in vegetation species distribution and plant community composition, and also to detect patterns of variation in the species data that can best be explained by the investigated environmental variables. TWINSPAN was used to establish the nature of floristic variation within the multidimensional site-by-species data matrix (Jongman *et al.* 1987) which determined the nature of floristic associations that characterize plant communities at kraals and control sites. Both indirect and direct ordination techniques of CANOCO; Detrended Correspondence Analysis, (DCA) and Canonical Correspondence Analysis, (CCA) respectively were used to confirm and examine the relationships of the TWINSPAN associations. Preliminary analyses showed that environmental variable 'age of kraals after abandonment' did not contribute much to the explanation of the results and was therefore excluded from the final data processing.

RESULTS

Soil properties

Table 2 shows results of the variations in soil nutrient concentrations between control sites and abandoned kraals. Samples from kraals are alkaline (pH-H_2O of 8.4 at 10

Table 2 Properties of soil samples at abandoned kraals and control sites.

Soil parameters	Control site values	Average values of soil sample extracts at abandoned kraals				
		<5 years	10 years	20 years	30 years	>45 years
pH-H_2O	5.6	8.3*	8.4*	7.8*	7.7	7.1
OM (%)	0.6	1.5*	1.3*	1.2	1.2	1.0*
Moisture content (%)	1.2	2.5	2.3	2.2	2.3	2.0
EC (µS/cm)	18.8	29.0*	110.0*	102.0	82.0	38.8
Olsen P (mg/kg)	0.8	22.0*	20.0*	20.3	20.0	20.1*
Exch. Ca ($cmol_c$/kg)	3.5	8.5*	8.4*	8.0*	8.4	7.0*
Exch. Mg ($cmol_c$/kg)	1.0	2.9	2.4*	2.1*	2.0	2.0
NH_4-N (mg/kg)	96.9	100.1	97.8.0*	98.1.0*	95.5*	94.9
NO_3-N (mg/kg)	96.0	110.0*	95.0	96.3	96.0	95.0
Number of samples	5	5	5	5	5	5

*Significant at p = 0.05

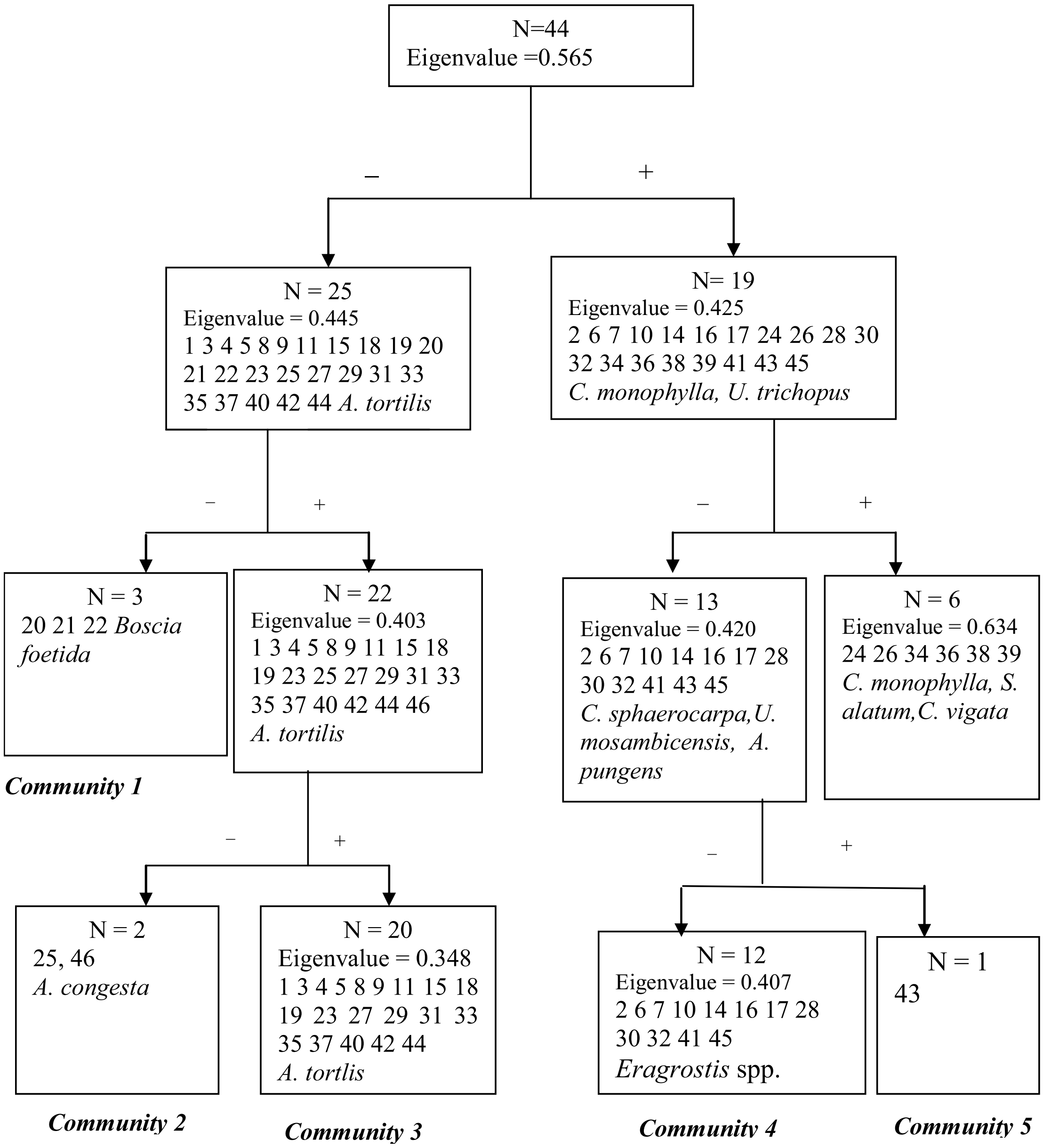

Fig. 2 Dendogram showing TWINSPAN classification of vegetation communities.

years) while control site soils are acidic in reaction with average pH-water of 5.6. Trends in soil nutrient concentrations show lower values for control-site parameters (P = 0.05) compared with their corresponding equivalents from kraals areas. There is a general persistent decrease in levels of concentration for EC, OM content, exchangeable Ca, Mg, NH_4-N and NO_3-N with increase in years after kraal abandonment. Moisture content show an initially increasing trend and eventual stabilization at the kraals while concentrations of Olsen P, exchangeable Ca and Mg show long persistence in the soil at the kraals. Results of higher nutrient concentration in 45 year old abandoned kraals compared to control site soils (t = 0.05) suggest an initial extreme nutrient enrichment at the kraal areas.

Vegetation characteristics

The TWINSPAN and DCA techniques in cluster analysis resulted into species clusters as they occur under natural environmental gradients. The TWINSPAN classified species by sites into dichotomy of seven communities as represented in the dendrogram. Floristic attributes of each of the species included in the analysis determined the preference of various species and sites to belong to a particular side of the dichotomy (negative or positive). On the basis of results from soil analyses, it can be inferred that the basic dichotomy into negative (-) and positive (+) categories of the dendrogram (**Fig. 2**) is linked to kraal areas as environmental determinants influencing the species in each community group. The TWINSPAN analysis showed 7 distinct clusters (only 5 of which are shown in **Fig. 2** each cluster in the dendrogram representing a specific vegetation community). Subsequent divisions of clusters beyond the 5 communities showed some variations in terms of species and sites but meaningful interpretation of these could not be clearly established and thus, only 5 of the 7 TWINSPAN communities are shown. Each community was characterized with one or more predominant or indicator specie(s), which also facilitated comparisons between the community groups (i.e., kraals and their control sites). Names of indicator species are mainly used for descriptive purposes and are considered to be the most dominant species under certain underlying environmental gradients. The community groups thus described are by no means mutually exclusive of each other.

DCA results explained species composition and distribution from eigen values (factor strengths or loadings) of 0.56 and 0.37 along axis 1 and 2, respectively (**Table 3**). The rest of the eigen values in axis 3 and 4 explained less species distribution and composition and are thus not used

Table 3 Comparisons between DCA and CCA eigen values.

Ordination	Eigen values		
	Axis 1	Axis 2	Axis 3
DCA	0.56	0.37	0.21
CCA (all environmental variables)	0.55	0.48	0.30
CCA (retained environmental variables only)	0.39	0.37	0.20

in explaining their variation in the final results. In the cluster analysis technique, the seven community clusters obtained from TWINSPAN were further explained by plotting scores from axes 1 and 2 which accounted for most of the observed variation in composition patterns in the different clusters. Two divisions (clusters 1, 2 and 3) and (clusters 4 and 5) are clearly defined in the DCA ordination diagram (**Fig. 3**). Other clusters which are not clearly defined have species diffused within these clusters. The DCA diagram shows a relatively high dispersion of species of both woody and herbaceous type. The biplot show a clear separation of species composition as revealed by the TWINSPAN classification. Continuous lines (ellipses) in the DCA biplot (**Fig. 3**) emphasize the basic dichotomy between the two groups. One group found within abandoned kraal areas and the second at control sites. The abandoned kraals communities can be identified in the diagram, the communities of control sites are represented within a single ellipse (**Fig. 3**).

Community clusters 1, 2 and 3 with *Acacia tortilis* and *Boscia foetida* as indicator species have many woody species suggesting a plant community type comprising of mainly woody and shrub species. The *Acacia tortilis* group characterized control sites; the herbaceous layer of this group is dominated by *Aristida congesta* spp. along with *Chenopodium album*, *Sida cordifolia*, *Indigofera daledoides* and *Acanthospermum hispidium*. On the other hand, community clusters 4 and 5 with *Urochloa* and *Chloris* species as indicator species do not have woody species but have a high composition of abundant grasses and forbs. This community forms the abandoned kraal areas. Many of the species in this community such as *Datura* species could not be found at control sites, but some species such as *Urochloa* and *Setaria* occurring at control sites did also occur in abandoned kraals.

Table 4 *t*-values and Variable Inflation Factors of all environmental variables.

Environmental Variable	*t*-Values of regression coefficient		Variable Inflation Factors
	Axis 1	Axis 2	
pH	-20	44	7.24
Electric conductivity	18	-16	4.11
Phosphorous	6	4	8.91
Plant available nitrogen*	32	3	3.28
Organic matter*	4	42	2.60
Potassium	-30	-22	7.17
Magnesium	52	-10	2.57
Calcium*	-40	-3	1.22
% Moisture*	-28	-21	2.53

* variables retained for further analysis

The species comprising community clusters 6 and 7 (not shown in diagram) do not appear as distinct clusters in the DCA diagram due to their dispersion or integration into other clusters and as such are absent in the DCA diagram (**Fig. 3**). The indicator species and the associated sites are distributed in other clusters and could not therefore be fully described and designated as clear clusters. For example, clusters 3 and 4 could as well be regarded to encompass clusters 6 and 7 but sites comprising clusters 3 and 4 dominate, as most of the species and sites belong to these communities.

Application of CCA technique that integrates species data and environmental variables have eigen values for axis 1 decreased to 0.55 (**Table 3**) which is comparingly well above the 0.3 considered common in ecological studies (ter Braak 1988). The reduction of eigen value in **Table 3** from 0.56 (in DCA) to 0.55 (in CCA) show how much variation in species composition and distribution is explained by the collected environmental variables.

Variables pH, EC, Olsen P, K and Mg had absolute *t*-values of less than 2.1 ($P = 0.05$) which is considered insignificant in explaining variations in environmental species data scores (ter Braak 1990) and were therefore eliminated

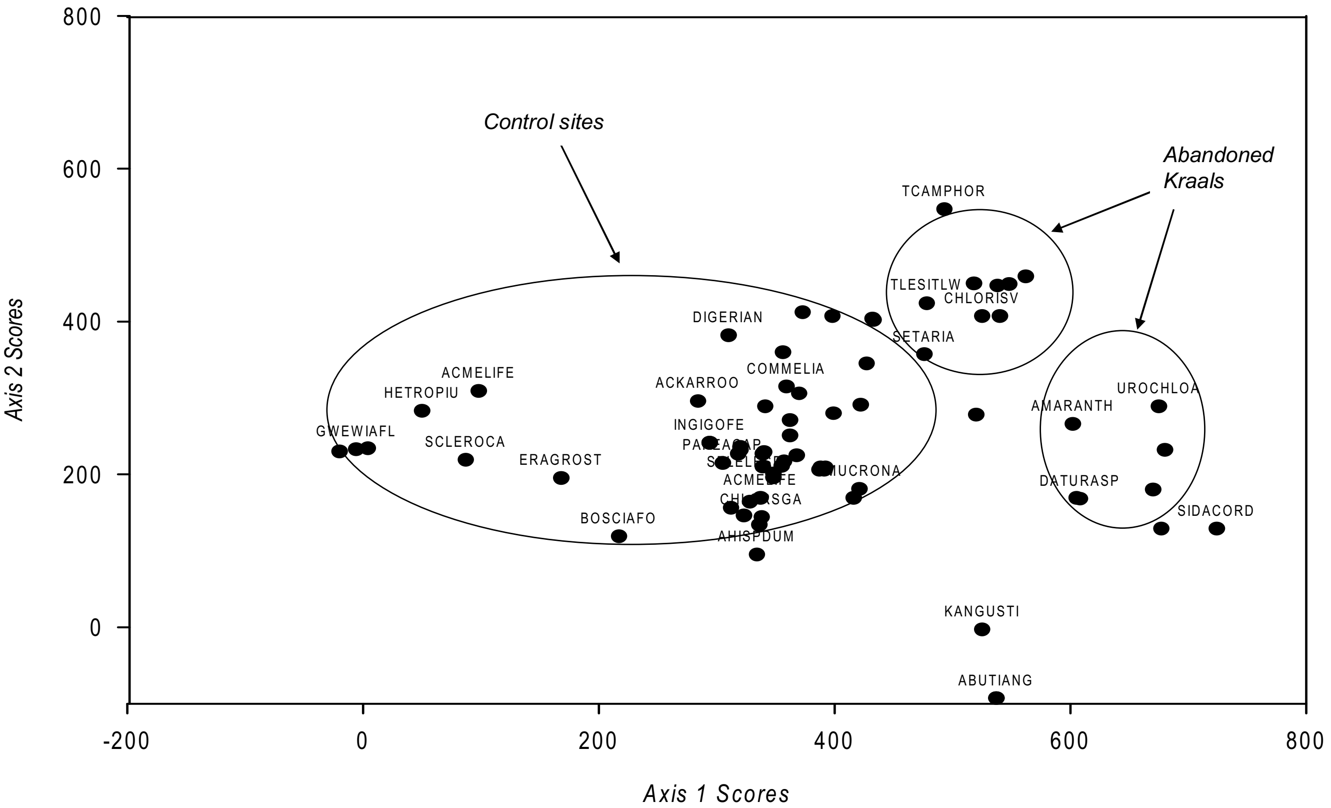

Fig. 3 DCA species and sites ordination.

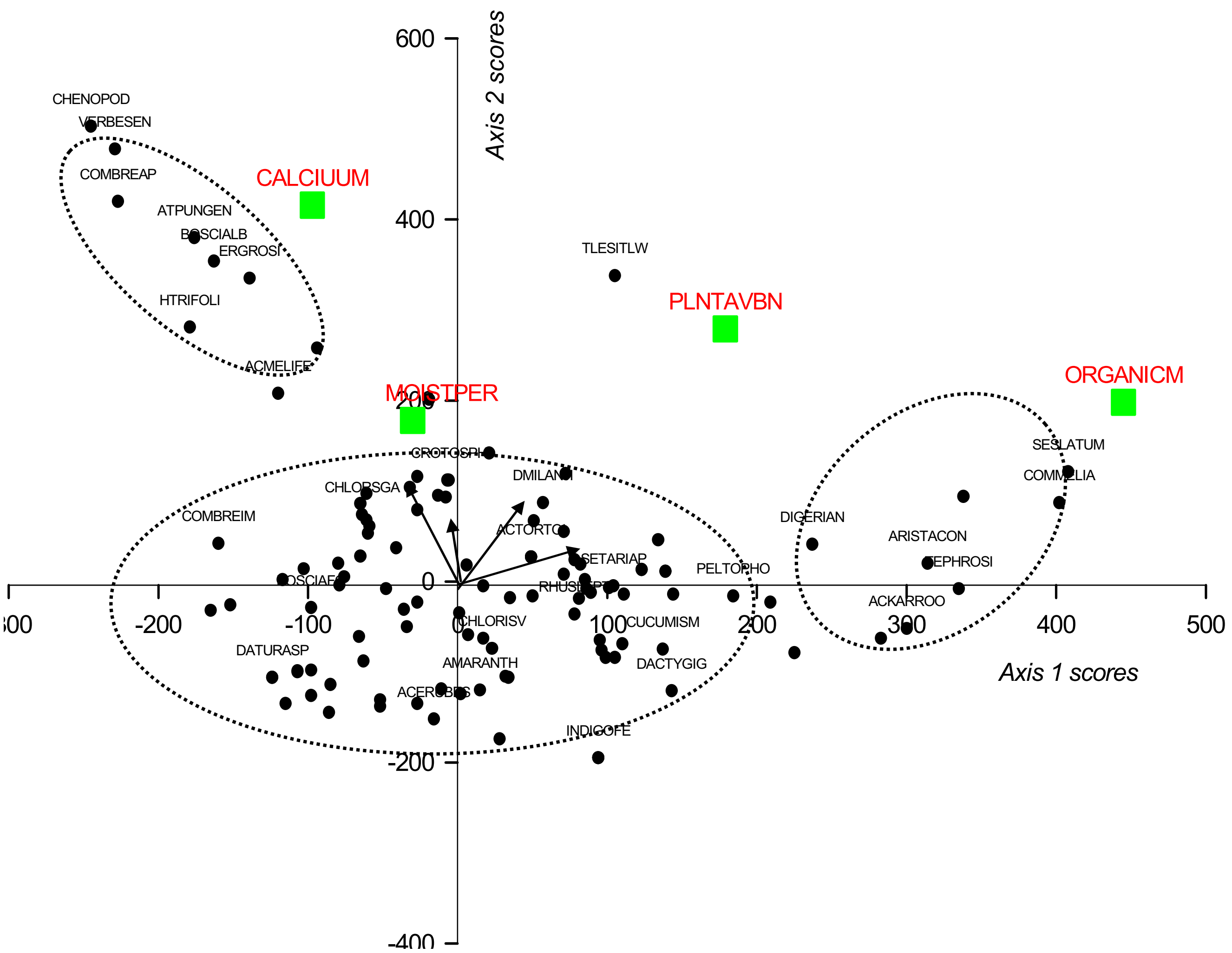

Fig. 4 CCA ordination and environmental variables overlaid.

from the data analysis. The variables also show High Inflation Factors (VIF) which relate to multiple correlation between environmental variables in the analysis. High VIF indicates a multicollinearity problem where few factors explain a greater variation than many factors which has no unique contribution in the regression analysis. **Table 4** shows the 5 environmental variables with *t*-values less than 2.1 and high VIF that were excluded from the analysis. Further analysis based on the 4 retained variables namely plant available nitrogen, organic matter, calcium and moisture content (**Table 5**) showed that high eigen values could still be obtained at the first and second axis (0.39 and 0.37 respectively, **Table 3**). This shows that the limited 4 environmental variables are sufficient to explain a large amount of variance accounted for by the initial 9. The statistical strength of the 4 retained variables in explaining the variance is confirmed by the Monte Carlo permutation test that shows both the overall effect of the environmental variables on species and the first canonical axis as significant (P = 0.01) indicating that the observed patterns did not arise by chance. The species–environment variables correlation is also high; 0.82 and 0.79 for CCA axes 1 and 2, respectively showing that the species data are strongly related to the measured environmental variables.

CCA biplot (**Fig. 4**) illustrates the relationship between species data, sites data and environmental variables, generated in the analysis from the three-way relationship. The length and direction of each arrow in the biplot representing a given environmental variable provides an indication of the importance and direction of the gradient of environmental change for that variable. Species response or associations to each environmental variable is represented as individuals

Table 5 *t*-values and Variable Inflation Factors of retained environmental variables.

Environmental Variable	*t*-Values of regression coefficient		Variable Inflation Factors
	Axis 1	Axis 2	
Plant Available Nitrogen	-100	273	1.42
Organic matter	815	10	1.43
Calcium	-341	616	1.05
% Moisture	-81	241	1.01

[or cluster of individuals] along orthogonal projection of that variable. Application of CCA indicated that organic matter, soil moisture, calcium and plant available nitrogen are the most important of the measured environmental variables in accounting for the variation in species composition. These gradients are closely related to the first two canonical axes, and accounted for 68% of the species–environment relationship among the sites. These results suggest a strong association between vegetation and the measured environmental variables presented in the biplot. Forward Stepwise Selection based on the 4 most important environmental variables showed that organic matter contributed the highest variance in species data (39%), moisture content the least (23%) while plant available nitrogen did not account for any variation despite its retention. Inter-set correlations with axes also show organic matter as having the highest positive correlation along the first axis (753), moisture the lowest and along the second axis (-81).

DISCUSSION

Investigation of vegetation species within and around abandoned kraal areas shows that kraal areas have different patterns of vegetation communities and composition compared with their surroundings. The 2 vegetation communities at kraal sites compared with 5 at control sites provide evidence of the relatively lower species diversity at kraal sites. TWINSPAN and Ordination analyses showed that vegetation species react differently to elevated soil nutrients within kraals and this response can be used to explain their distribution patterns. The difference in vegetation patterns between kraals and control sites makes comparative analysis of the vegetation characteristics easy. Trends in the results show that kraal areas induce profound changes in soil properties that influence vegetation distribution. The long persistence of soil nutrients-enriched patches at kraals over 45 years is indicative of a persistent modification in the vegetation structure. The high soil nutrient tolerant vegetation species gain competitive advantage over those that are not potentially altering the vegetation spatial patterns.

Similar results of the linkage between accumulated waste in the soil and plant properties have been reported in other savanna and veld systems. For instance, van der Waal *et al.* (2009) report a change in vegetation structure and long-lasting habitat quality at abandoned livestock ranches in a South African lowveld area.

The pattern of difference in the distribution of herbaceous and woody species identified shows some affinity of herbaceous species to the high nutrients in kraal areas. Association of forbs particularly *Datura* species to kraal sites suggests their tolerance of high nutrient content in the soil. The dominance of herbaceous communities at nutrient-rich kraals in comparison with woody species suggests a poor establishment of woody species seedlings and a constrained recruitment of the same at the kraals. This is indicative of the effects of the elevated nutrients on the vegetation and soil properties and is consistent with reports of 'open patches' that have been described to be associated with similar nutrient-rich sites (Kizza and Areola 2010; van der Waal *et al.* 2011). In another related study, Blackmore *et al.* (1990) showed a similar relationship between change in vegetation communities and nutrient-enriched patches in Nylsvley area in Southern Africa. In contrast, Reid and Ellis (1995) report a facilitation of *Acacia tortilis* recruitment at abandoned cattle bomas in Turkana, Kenya. Their results have been attributed to a low rainfall where grass competition is weak and an ability of some *Acacia* species to colonise nutrient hotspot areas (Blackmore *et al.* 1990; Muchiru *et al.* 2008). In addition to the enriched soil nutrients, the continued pressure exerted by livestock activities particularly trampling or hoof action at kraal areas cause disturbance which improve soil conditions that favour the proliferation and dominance of the forbs.

Elevated nutrients at kraal areas result in a concentration of environmental gradients of nutrients in the kraal area ecosystem which could also explain the variety of floristic patterns and distribution at control sites. At areas away from kraals (control sites), the environmental gradients are spread out which translate into high habitat heterogeneity and corresponding species diversity and composition. The accumulated nutrients at kraal areas result in gradients of available nutrients which play an important key role in modifying plant available nutrients, soil moisture and thus, the vegetation species patterns.

Variations in the results of soil nutrients and vegetation communities at the kraals and control sites suggest that at the start, before the establishment of the kraals, the soil nutrients are as poor as those at control sites. The three techniques in the analysis of vegetation deduced inter relationship of kraal areas and the vegetation within the kraals' environment. On a much broader scale, the results illustrate that kraal areas may modify the environment by influencing the type of species that occur at any particular area which could have a potential ecological significance.

In addition to kraal soil nutrients, patterns of vegetation communities in similar semi-arid ecosystems have been reported to be related to other factors such as fire and herbivory (Van Langevelde 2003; Holland and Bennett 2007) and moisture (Walker and Langridge 1997; Van der Waal 2009; Hassler *et al*. 2010) which possibly contributed to the observed vegetation patterns in this study. However, inspite of the possible ecological variations resulting from the influence of these factors, vegetation divisions on the basis of indicator species appears to reflect differences associated with kraal areas characteristics.

CONCLUSION

Kraal areas form focal points of soil nutrients accumulateons that are key determinants of vegetation patterns, composition and communities. This study shows that kraal areas influence the availability and distribution of soil nutrients which has a potential ecological significance on vegetation in and around the kraal area ecosystem. The findings of the study thus emphasize the importance of kraal areas in creating nutrient gradients that highly influence soil and herbaceous patterns. The patterns and distribution in the vegetation communities are influenced by varied environmental variables mainly moisture and plant available nutrients which are associated with kraal areas.

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