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Investigating Soils, Vegetation and Land Use in a Lunette Dune-Pan Environment: The Case of Sekoma Lunette Dune-Pan Complex, Botswana

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1. Introduction

The association between vegetation and environmental factors has been a subject of ecological studies over time (e.g. Monier & Amer, 2003; McDonald et al., 1996). Some of these studies have addressed facilitative and competitive interactions between woody and herbaceous plants (Maestre et al., 2003), whilst others focused on the feedbacks in the dynamics of plant communities (Schwinning et al., 2005). On the other hand, there is considerable empirical research work on pans and their associated landforms (e.g. Lancaster, 1986; Goudie & Thomas, 1986; Cooke et al., 1993). Common land forms associated with pans like lunette dunes have particularly received significant attention from researchers (e.g. Lancaster, 1978; Goudie & Thomas, 1986; Holmgren & Shaw, 1996). Most of the afore-mentioned studies have mainly focused on the morphology, sedimentology and the origin of lunette dunes and pans. In addition, they have considered the significance of lunette dunes in palaeo-environmental reconstruction (Holmgren & Shaw, 1996; Lancaster, 1989; Marker & Holmes, 1995).

Livestock production dominated by cattle rearing plays a pivotal economic role in the Kalahari area (van de Maas et al., 1994; Chanda et al., 2003; Mosweu et al., 2010). The most limiting factor in livestock production in Kalahari over the years has been the availability of surface water and fodder resources. Consequently, lunette dune-pan environments continue to play a central role as sources of both water (Figure 1) and fodder resources for livestock in the area. As a result, lunette dune-pan environments exist in the Kalahari as unique interspersed micro-ecosystems that are significantly intertwined with the livelihoods of rural communities of the area (Chanda et al., 2003; Mosweu & Areola, 2008).

Although some research work has been conducted on the lunette dunes, pans, vegetation-environment relationships, and land use in the Kalahari environment (e.g. Chanda et al., 2003; Privette et al., 2004; Shugart et al., 2004; Wang et al., 2007; Mosweu, 2008), paucity still exists in researches that consider lunette dunes, pans and their environs as unique micro-ecosystems of significance to rural communities inhabiting semi-arid and arid regions. This scenario prevails in spite of the fact that the state of lunette dune-pans as micro-ecosystems remains vital in the sustainability of the livelihoods of the Kalahari rural communities and other communities residing in semi-arid and arid regions elsewhere. It is on this basis that the main aim of this chapter was to examine the interrelationships among the soil, vegetation, topography and land use in a lunette dune-pan environment with a view to elucidate their interactions and the consequent environmental changes thereof. Thus, the specific objectives of this study were to investigate the following in a lunette dune-pan environment:

- Soil physical and chemical characteristics;
- Woody vegetation properties;
- Land use attributes; and
- The correlations amongst soil, vegetation and land use characteristics.

Fig. 1. Hand-dug well located in Sekoma pan.

2. The study site

A lunette dune-pan complex located in the Sekoma village (Figure 2) in the Kalahari region of Botswana was chosen as a case study area. The state of the environment, current land use practices and geographical position of the Sekoma lunette dune-pan system present an ideal environment for the investigation of environmental changes and ecosystem dynamics particularly in lunette dune-pan micro-ecosystems. The geographical location of the study site along the Kalahari Transect (KT) 'megatransect' which has been established by the International Geosphere-Biosphere Programme (IGBP) for the study of both regional and universal environmental changes (e.g. Shugart et al., 2004; Wang et al., 2007) positions this study within an international context of studies focusing on environmental changes.

The lithology of the area is characterized by the dolomite Precambrian aquifer system (Geological Survey Department, 1995). The general structure of vegetation in the area is shrub savanna and the vegetation is classified as southern Kalahari bush savanna (Department of Surveys and Mapping, 2001). The mean annual rainfall in the area is about 400 mm (Bhalotra, 1985) and the rainfall season is characterized by erratic rainfall patterns. The lunette dune-pan complex is situated between the former (Sekoma West) and current (Sekoma) locations of the village (Figure 2).

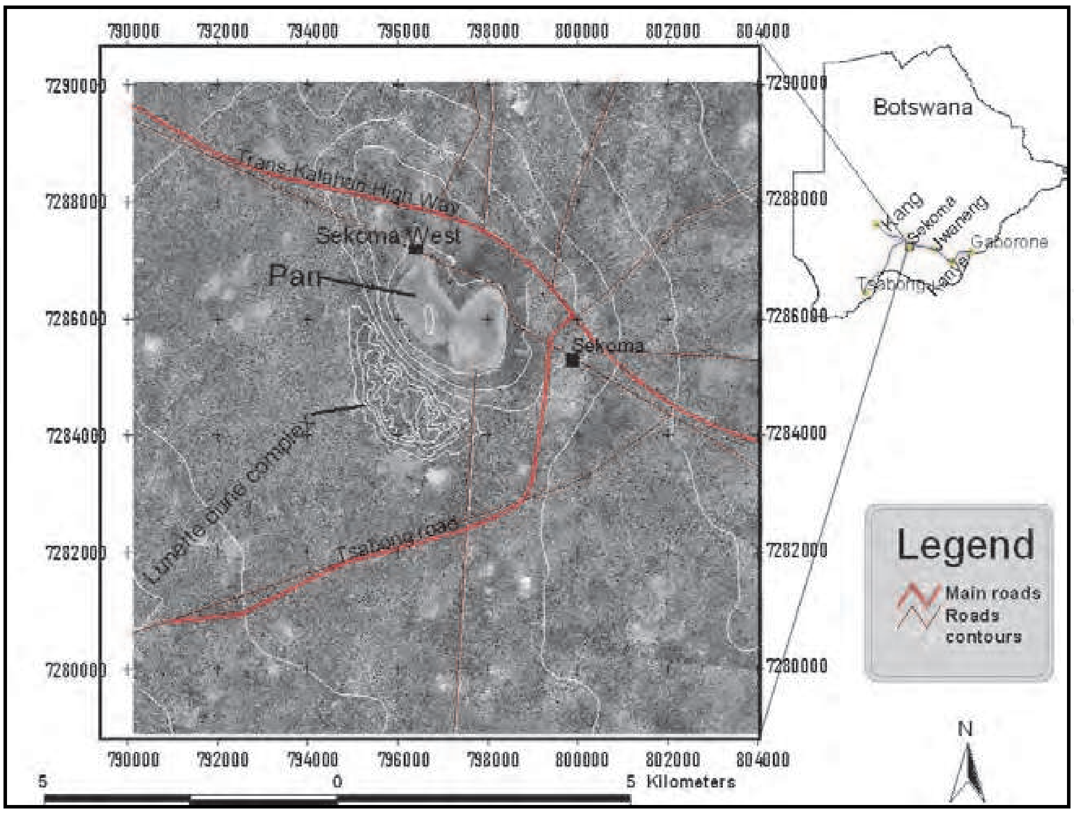

Fig. 2. Study site location (Author using base maps from Department of Surveys and Mapping, Gaborone, Botswana).

3. Research methods

3.1 Sample collection

Stratified transect sampling was used in this study. This is a systematic sampling method in which sampling points were arranged linearly and continuously. Transects were established from the pan fringes across selected lunette dunes (Tshube, Leremela and Kebuang) to the end of the slip face slope of each dune (Figure 3). Sampling was carried out at the pan fringes, wind ward slope, dune crest and slip face slope which were referred to as sampling points 1, 2, 3, and 4 respectively (Figure 3). At the slopes, sampling was carried out at the approximate mid-point of the slopes. A similar method was used with success in other studies including salt-marshes, inter-tidal zones, study of pattern and succession on dunes, altitudinal gradients, from dry to wet heath and across gradients of trampling intensity (Goldsmith & Harrison, 1976).

Three quadrats of 20 m^2 separated by 10 m were located at sampling points marked 1, 2, 3 and 4 (Figure 3) along the transects. The quadrats were identified as indicated in Figure 3 (Tshube 1-12; Leremela 13-24; Kebuang 25-36; 'S' denotes site). Vegetation and soil sampling was conducted in each of the quadrats. Soil samples were collected in the center of each quadrat using an auger that had a sample collection chamber length of 20 cm and a volume of ca. 23.75 mL. Therefore, about 23.75 mL per sample volume were collected. It was observed in the preliminary study that a soil profile established in the dunes did not show soil horizons. Therefore, soil samples were collected at predetermined sampling depths (SDs) of 0-20 cm, 40-60 cm, 80-100 cm, 130-150 cm and 180-200 cm. Methods used in this study to investigate vegetation and soil are summarized in Tables 1 and 2.

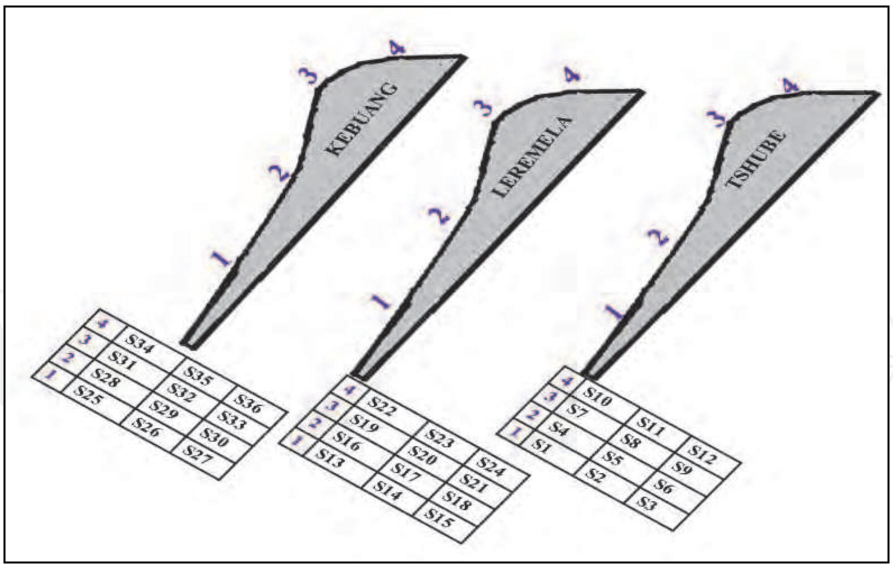

Fig. 3. Detailed layout of quadrats for sampling.

Parameter	*Method of Analysis*	*References*
Species Cover	Crown-Diameter method	Muller-Dombois &Ellenberg, 1974; Krebs (1989)
Species density	Simple counts	Krebs (1989)
Species composition	list of plant species within a particular quadrat	Bonham(1989);Krebs (1989)
Species distribution	Spatial range of species	Bonham(1989);Krebs (1989)

Table 1. Methods of vegetation study.

Parameter	*Method of Analysis*	*Analytical Instrument*	*References*
Available Phosphorus	Olsen's	UV- Visible Spectrophotometer	ISRIC, 1993
Particle size (sand, silt-clay)	Sieve	Retsch shaker and sieve	Buurmanet al. (1996)
Electrical conductivity& pH	1:2 (soil:water) ratio	InoLabcond 730 WTW series electrical conductivity meter & HANNA pH 210 pH meter	Sonnevelt & van den Ende (1971); Janzen (1993) Soon & Warren (1993).
Soil Organic Carbon	Walkley-Black wet oxidation	Various apparatus	Van Reeuwijk (1993)
Effective Cation Exchange Capacity (ECEC) and Exchangeable cations (Ca, Mg, Na, K), Al, Fe &Mn	Barium Chloride ($BaCl_2$)	Atomic Absorption Spectrophotometer (AAS)	Hendershot & Duquette (1986)

Table 2. Summary of methods of soil study.

3.2 Mini-social survey

A non-probability sampling procedure known as purposive sampling (Rea & Parker, 2005) was employed in a mini-social survey to gather data on the perceptions of the communities about the spatial and temporal environmental changes that they had witnessed in the lunette-dune pan environment over the years. The method facilitated the use of professional assessment, instead of randomness, in choosing the respondents (Rea & Parker, 2005). The survey was therefore, restricted only to key informants who were considered to be endowed with indigenous knowledge within the Sekoma community. Consequently, two focused group discussions, one constituted by the chief and village elders and the other by the Village Development Committee (VDC) members were conducted in the village. Open-ended questions were posed to the groups to facilitate freedom of expression. In the questionnaire, the most predictable answers had been pre-stated for data capturing convenience, but were not read out to respondents to minimize the researcher's influence on the respondent's view. Recording of the responses was conducted during the interview process. In addition, notes were made on the relevant additional information provided by the respondents.

4. Results

4.1 Pedo-geomorphological characteristics of the lunette dunes

To explore the distribution pattern of selected soil resources in the lunette dune-pan environment, correlation analysis (Table 3) was used to establish the relationships between soil variables at different sampling depths (SD) and the distance from the pan fringes. It was observed that only sodium indicated a significant negative correlation (*r =0.991, P =0.009*) at SD 0–20 cm in the Tshube lunette dune at α = 0.01. Aluminium and organic carbon also exhibited negative correlations (*r = -0.980, P = 0.020* and *r = -0.958, P = 0.042* respectively) with distance at α = 0.05. At SD 40-60 cm, sodium (*r = -0.958, P = 0.042*) and EC (*r = - 0.985, P = 0.015*) showed negative significant relationships with distance at α = 0.05. It was observed that at SD 80-100 cm all soil variables indicated negative relationships with distance except sand fraction, but the relationships were not significant at both α = 0.01 and 0.05. ECEC was the only soil variable that showed significant and negative relation with distance (*r = -0.998, P = 0.002*) at SD 130-150 cm and α = 0.01. Furthermore, all other soil variables indicated negative relationships with distance except sand fraction, phosphorus and pH. Magnesium (*r = -1, P = 0.011*), manganese (*r = -0.999, P = 0.033*) and phosphorus (*r = 0.999, P = 0.029*) were the only soil variables that exhibited significant relationships with distance at α = 0.05 in relation to SD 180-200 cm (Table 3) in the Tshube lunette dune.
In Leremela lunette dune, none of the selected soil variables showed a significant relationship with distance from the pan fringes (SP1) to the slip face slope (SP 4) at SD 0-20 cm and α = 0.01 and 0.05 (Table 3). However, all variables displayed negative relationships with distance except sand fraction, aluminium and manganese. Magnesium (*r = 0.984, P = 0.016*) was the only soil variable that indicated positive significant relationship with distance at α = 0.05 in relation to the SD 40-60 cm. With the exception of sand fraction, manganese and phosphorus, all other soil variables were negatively related to distance at SD 40-60 cm. From SD 60-200 cm, soil variables and distance were not significantly related at α = 0.01 and 0.05.

All selected soil variables did not show significant relationships with distance at SD 0-20 cm in Kebuang lunette dune. Furthermore, all soil variables were negatively related to distance except sand fraction and aluminium at SD 0-20 cm. Potassium (*r = -0.984, P = 0.016*) and EC (*r = -0.964, P = 0.036*) were the only soil variables that showed negative significant relationships with distance at α = 0.05 with respect to SD 40-60 cm. At SD 80-100 cm, the relationships between all soil variables and distance were not significant at both α = 0.01 and 0.05. In addition, all soil variables were negatively related to distance except sand fraction and aluminium. Only calcium (*r = -1, P = 0.013*) displayed a perfect negative relationship with distance at α = 0.05 and SD 130-150 cm sampling depth. At α = 0.01 and 0.05 significant levels, all selected soil variables were not significantly related to distance at SD 180-200 cm in Kebuang lunette dune (Table 3). It was also observed that all the relationships were negative except for sand fraction and pH.

4.2 Plant species distribution patterns and community composition

In Detrended Correspondence Analysis (DCA) diagram, each site point lies at the centroid of the points of the species that occurs at the sampling site (Hill, 1979). Therefore, Figure 4 mirrors the approximate plant species distribution patterns and plant community composition in the lunette dune-pan environment. On the basis of Figure 4, Inferences were made about the species that were likely to be found at a particular sampling site. Sites that were close to the point of the species were likely to exhibit high density of that particular species, and the density of a species was expected to decrease with the increase in distance from its location.
Two main plant communities were identified in the lunette dune-pan environment. The first one was dominated by *Acacia mellifera* and the other by *Grewia flava* (Figure 4). *A. mellifera* community was dominant particularly at the sampling points that were located on the slip face of the lunette dunes, and between the lunette dune-pan complex and the settlement area. *G. flava* community was predominated the wind ward slope.

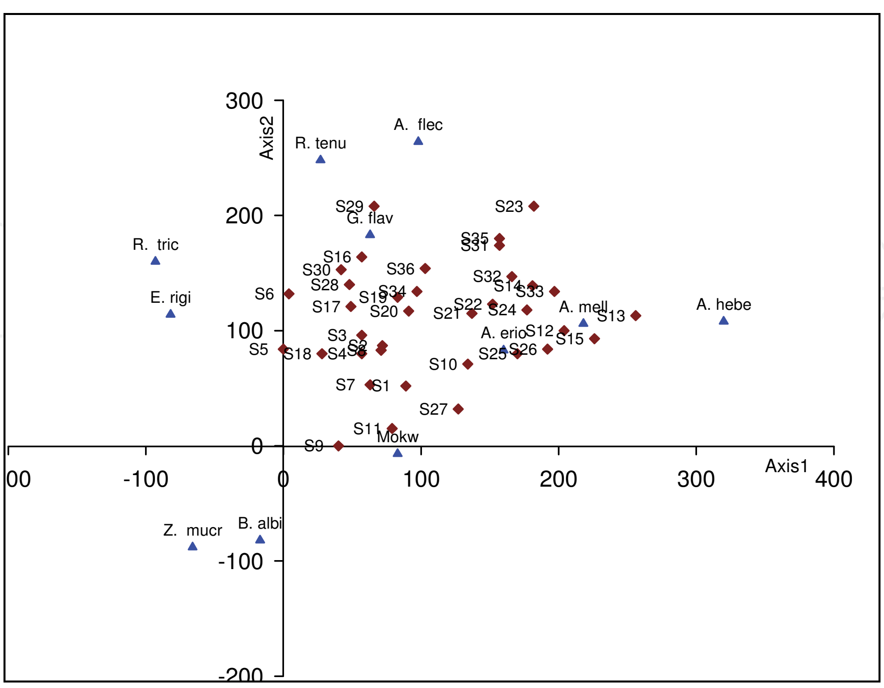

Fig. 4. Plant species distribution in the lunette dune-pan environment (*scale = 1; multiplier = 100*).

	SD (cm)		Sand	SC	K	Mg	Na	Al	Mn	Fe	Ca	ECEC	P	%OC	pH	EC
Tshube	0-20	*r*	0.93	-0.93	-0.91	0.73	-0.99**	-0.98*	-0.38	-0.91	0.65	-0.41	-0.63	-0.96*	-0.70	-0.87
		P	0.07	0.07	0.10	0.27	0.01	0.02	0.62	0.10	0.35	0.60	0.37	0.04	0.30	0.13
	40-60	*r*	0.77	-0.77	-0.92	-0.88	-0.96*	-0.10	-0.36	-0.77	0.80	0.58	0.81	-0.38	-0.23	-0.99*
		P	0.23	0.23	0.084	0.12	0.04	0.90	0.64	0.23	0.19	0.42	0.19	0.62	0.77	0.02
	80-100	*r*	0.92	-0.92	-0.75	-0.54	-0.86	-0.86	-0.56	-0.84	-0.20	-0.93	-0.20	0.40	-0.66	-0.73
		P	0.08	0.08	0.26	0.46	0.14	0.14	0.45	0.16	0.81	0.07	0.80	0.60	0.34	0.27
	130-150	*r*	0.94	-0.94	-0.74	-0.95	-0.78	-0.93	-0.79	-0.83	-0.17	-1.00**	0.67	-0.44	0.88	-0.83
		P	0.06	0.06	0.26	0.05	0.22	0.07	0.21	0.17	0.83	0	0.33	0.56	0.12	0.17
	180-200	*r*	0.98	-0.98	-0.70	-1.00*	-0.99	0.35	-1.00*	0.33	0.37	-0.96	1.00*	0.15	0.54	-0.82
		P	0.14	0.14	0.50	0.01	0.07	0.77	0.03	0.79	0.76	0.19	0.03	0.91	0.64	0.39
Leremela	0-20	*r*	0.88	-0.88	-0.83	-0.75	-0.65	0.28	0.05	-0.62	-0.61	-0.58	-0.26	-0.64	-0.67	-0.87
		P	0.12	0.12	0.17	0.25	0.35	0.72	0.95	0.38	0.39	0.42	0.74	0.36	0.34	0.13
	40-60	*r*	0.89	-0.89	-0.87	0.98(*)	-0.47	-0.66	0.69	-0.75	-0.65	-0.82	0.78	-0.86	-0.82	-0.79
		P	0.12	0.12	0.13	0.02	0.53	0.34	0.31	0.25	0.36	0.18	0.22	0.14	0.18	0.21
	80-100	*r*	0.79	-0.79	-0.99	0.23	-1.00	0.28	0.24	-0.89	-0.92	-0.91	0.94	-0.35	-0.72	-0.86
		P	0.42	0.42	0.09	0.85	0.06	0.82	0.85	0.30	0.26	0.27	0.22	0.77	0.49	0.35
	130-150	*r*	0.61	-0.61	-0.97	0.79	-0.90	-0.09	0.98	0.87	-0.99	-0.97	0.38	0.63	-0.86	-0.83
		P	0.58	0.58	0.15	0.42	0.28	0.94	0.12	0.33	0.08	0.14	0.76	0.57	0.35	0.38
	180-200	*r*	0.95	-0.95	-0.91	0.92	-0.83	0.69	0.86	-0.91	-0.81	-0.83	0.69	0.70	-0.67	-0.98
		P	0.20	0.20	0.28	0.25	0.37	0.51	0.34	0.28	0.40	0.38	0.52	0.51	0.53	0.14
Kebuang	0-20	*r*	0.94	-0.94	-0.94	-0.93	-0.84	0.66	-0.85	-0.24	-0.84	-0.46	-0.72	-0.77	-0.42	-0.92
		P	0.06	0.06	0.06	0.08	0.16	0.34	0.15	0.76	0.16	0.54	0.28	0.23	0.58	0.08
	40-60	*r*	0.84	-0.84	-0.98*	-0.49	0.64	0.82	-0.77	-0.20	-0.71	-0.70	-0.23	-0.58	0.54	-0.96*
		P	0.16	0.16	0.02	0.51	0.36	0.18	0.23	0.80	0.29	0.30	0.77	0.42	0.46	0.04
	80-100	*r*	0.84	-0.84	-0.87	-0.80	-0.85	0.02	-0.99	-0.43	-0.88	-0.78	-0.66	-0.07	-0.15	-0.77
		P	0.37	0.37	0.33	0.41	0.35	0.99	0.08	0.72	0.32	0.43	0.54	0.96	0.91	0.45
	130-150	*r*	1.00	-1.00	-0.93	-0.95	-0.03	0.39	-0.99	-0.80	-1.00*	-0.98	-0.93	0.81	0.85	0.96
		P	0.05	0.05	0.23	0.20	0.98	0.74	0.07	0.41	0.01	0.15	0.24	0.41	0.35	0.18
	180-200	*r*	0.85	-0.85	-0.33	-0.94	-0.94	-0.17	-0.98	-0.66	-0.92	-0.87	-0.13	-0.90	0.97	-0.16
		P	0.35	0.35	0.79	0.22	0.22	0.89	0.14	0.55	0.26	0.33	0.92	0.28	0.16	0.90

* *Correlation is significant at the 0.05 level (2-tailed).*
***Correlation is significant at the 0.01 level (2-tailed). SD: Sampling Depth*

Table 3. Correlation analysis of sampling depth and distance from the pan fringes to SP4.

4.3 Vegetation - Environment relationships

Canonical Correspondence Analysis (CCA) diagrams show the interrelationships between vegetation and selected soil variables that were observed in the lunette dune-pan environment (Figures 5-9). The diagrams display points that represent species and sampling sites, and arrows that symbolize soil variables. The species and sampling points mutually portray the dominant patterns in community composition to the extent that these could be elucidated by the selected soil variables (ter Braak, 1988). The species points and the arrows of the soil variables mutually depict the plant species distribution along each of the soil variable (ter Braak, 1988). It is worth noting that only the direction and the relative length of the arrows convey essential information (ter Braak, 1995). The length of an arrow representing a soil variable was considered to be equal to the rate of change in the score as inferred from Figures 5-9, hence a measure of how much the plant species distribution differ along that soil variable (Gauch, 1982). As a result, important soil variables were represented by longer arrows (Figures 5-9). The species points that are positioned on the edge or very close to the edge of a CCA diagram are often considered to be rare species (ter Braak, 1995), and such species are usually considered to be very insignificant in CCA. Consequently, plant species of that nature were excluded in the analysis.

Similar researches that have been carried out in the past on vegetation-soil associations focused on the 0-20 cm top soil layer (e.g. Moleele & Perkins, 1998; Moleele, 1999; Smet & Ward, 2006). However, it is widely acknowledged that different plant species exhibit various rooting systems as well as different responses to various environmental factors along environmental gradients (Gauch, 1982). For instance, potassium, phosphorus and sodium gradients may not necessarily be the same at SD 0-20 cm and 180-200 cm, and some plant species may not be able to access essential soil resources from the depth of 200 cm and beyond. To this end, an attempt was made to examine the effect of changes in soil properties due to soil depth variation on the vegetation-soil interrelationships. The assessment was premised on the inferences from Figures 5-9. Worth highlighting is the scale of the diagrams (Figures 5-9); 1 unit in the plot corresponds to 1 unit for the sites, to 1 unit for the species and to 10 units for the soil variables.

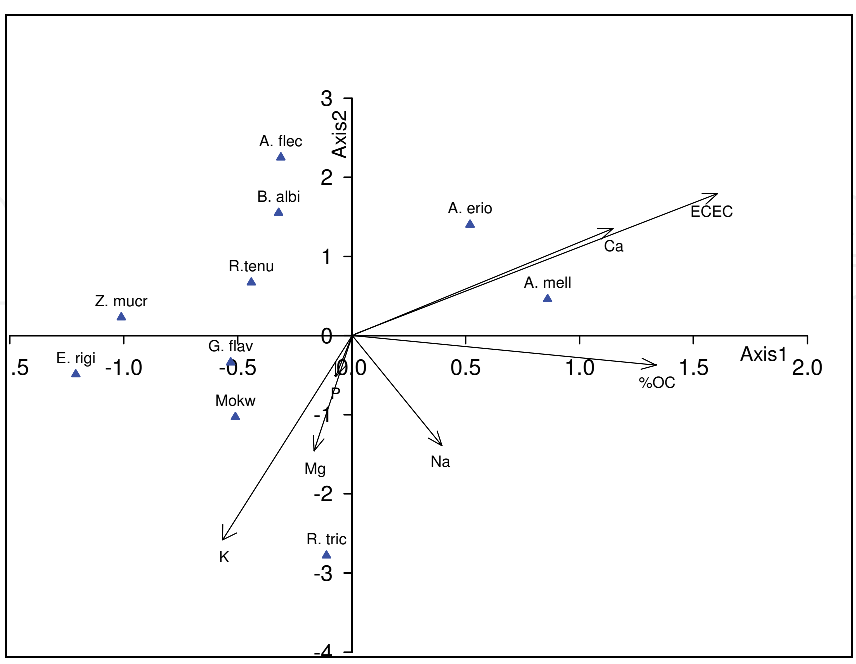

Fig. 5. Relationships between soil properties (SD 0-20 cm) and plant species distribution.

The CANOCO programme excluded pH, electrical conductivity, aluminium, and manganese from the CCA for SD 0-20 cm because they exhibited negligible variance (Figure 5). Silt-clay was also eliminated from the analysis because the programme detected collinearity when fitting the variables. *Acacia hebeclada*, *Gardenia volkensii*, S13, S14, S15 and sand fraction were not displayed in the diagram because they introduced polarity in the data points. This suggested that the distribution of *A. hebeclada* and *G. volkensii* were not associated with the distribution of the selected soil variable. Furthermore, it was evident that S13, S14, and S15 were not inhabited by the common plant species in the lunette dune environment. It was observed that *A. mellifera* was closely associated with sites that had high level of calcium, ECEC and organic carbon. These were sampling sites that were mostly located on the slip face of the lunette dunes. The ranking of selected soil variables at SD 0-20 cm on the basis of their significance was ECEC, organic carbon, calcium, potassium, sodium, magnesium and phosphorus in descending order of significance for plants existing in the lunette dune-pan environment (Figure 5).

Shallow solum (depth >20cm) that existed at S2, S13, S14, S26, and S27 resulted in the exclusion of the sampling sites from the CCA for SD 40-60 cm (Figure 6). S15, S23, S33, *G. volkensii*, *A. hebeclada*, sand, silt-clay were rejected because they polarized data points. EC, pH, aluminium and manganese indicated negligible variance and were therefore removed from the CCA. It was observed that *A. mellifera* still dominated sampling sites that were relatively fertile at SD 40-60 cm, and the distribution of other species were insignificantly influenced by the distribution of selected soil variables at SD 40-60 cm. Figure 6 suggests that up to the depth of 60 cm, *A. mellifera* had a competitive edge over *G. flava* with respect to soil nutrients. The significant soil variables at SD 40-60 cm were potassium, organic carbon, ECEC, and phosphorus (Figure 6).

In the CCA for SD 80-100 cm (Figure 7), EC, pH, aluminium and manganese were excluded from the analysis due to their negligible variance. S1, S2, S13, S14, S15, S25, S26, and S27 were not included in the CCA because the solum at the sampling sites was shallow (depth >60cm). Sand and silt-clay were also excluded from the diagram as they indicated collinearity. It is also worth noting that *G. volkensii*, *A. hebeclada* and *Acacia erioloba* were not displayed because they caused polarity of data points. It was observed that the density of *A. mellifera* was positively related to phosphorus and potassium in the soil and negatively related to other variables at SD 80-100 cm. On the other hand, the density of *G. flava, Ehretia rigida* and *Rhigozum trichotomum* were closely linked to the distribution of ECEC, calcium, and organic carbon in the soil. This may suggest that the competitive capacity of *A. mellifera* for soil nutrients diminished with increase in soil depth. The most significant soil variables at SD 80-100 cm were iron, phosphorus, ECEC, sodium and calcium (Figure 7).

The challenge of shallow solum associated with the pan fringes continued to cause exclusion of some sampling points in the CCA. Consequently, S1, S2, S5, S13, S14, S15, S25, S26, and S27 were excluded for SD 130-150 cm (Figure 8). *G. volkensii* and *A. hebeclada* were also eliminated from the analysis due to data polarity. Sand and silt-clay were disregarded for collinearity. EC, pH, aluminium and manganese were excluded due to negligible variance. It was noted that the number of soil variables that had positive relationships with the distribution of *A. mellifera* continued to decrease with an increase in soil depth. Only phosphorus showed positive relationship with *A. mellifera* distribution in the lunette dune-pan environment. Contrarily, *G. flava* distribution had positive relationships with ECEC, sodium and calcium in the soil. This may indicate that *G. flava* gained a competitive advantage over *A. mellifera* for soil nutrients as soil depth increased. Significant soil variables that had impacts on plant species distribution in the lunette dune environment at SD 130-150 cm were iron, sodium, calcium and ECEC.

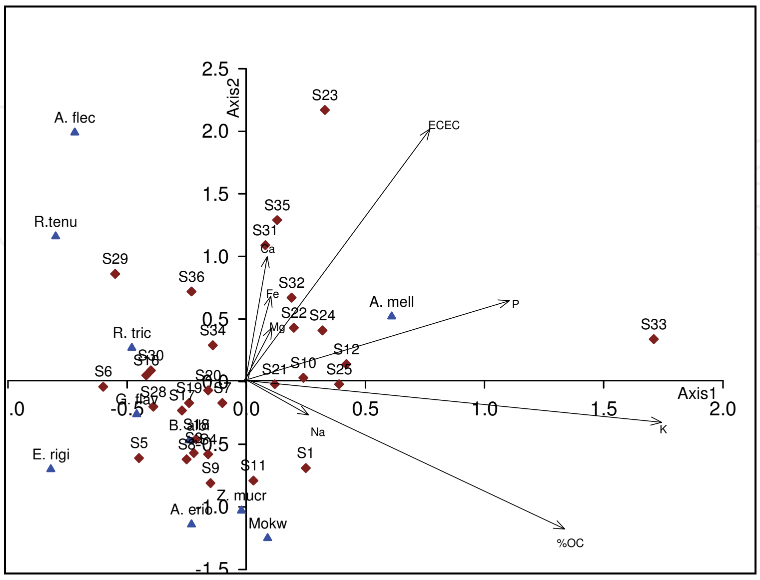

Fig. 6. Relationships between soil properties (SD 40-60 cm) and plant species distribution.

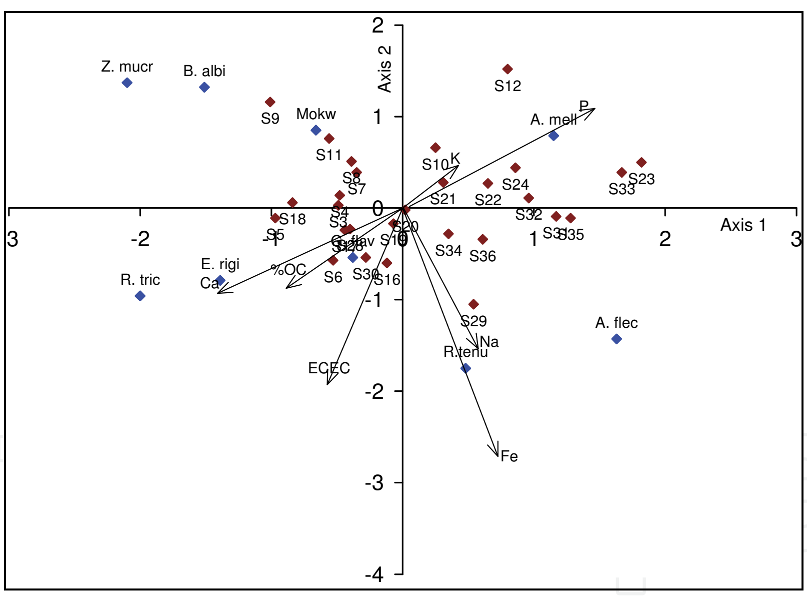

Fig. 7. Relationships between soil properties (80-100cm) and plant species distribution.

Due to the shallowness of the solum, S1, S2, S3, S4, S5, S13, S14, S15, S25, S26, and S27 were not included in the CCA for SD 180-200 cm (Figure 8). Furthermore, *G. volkensii*, *A. hebeclada*, EC, pH, aluminium, manganese, sand and silt-clay were excluded in the CCA owing to negligible variance. It was observed that the number of soil variables that had positive relationships with the distribution of *A. mellifera* still continued to decrease with an increase in soil depth. In addition, similar to SD 130-150 cm, only phosphorus indicated positive relationship with *A. mellifera* distribution in the lunette dune-pan environment. In contrast, *G. flava* distribution had positive relationships with ECEC, sodium, calcium, potassium and iron in the soil. This therefore gave impetus to the observation that *G. flava* gained a competitive advantage over *A. mellifera* for soil nutrients as soil depth increased. Phosphorus, sodium, potassium, iron, calcium and ECEC were identified as significant soil variables in relation to plant species distribution in the lunette dune-pan environment.

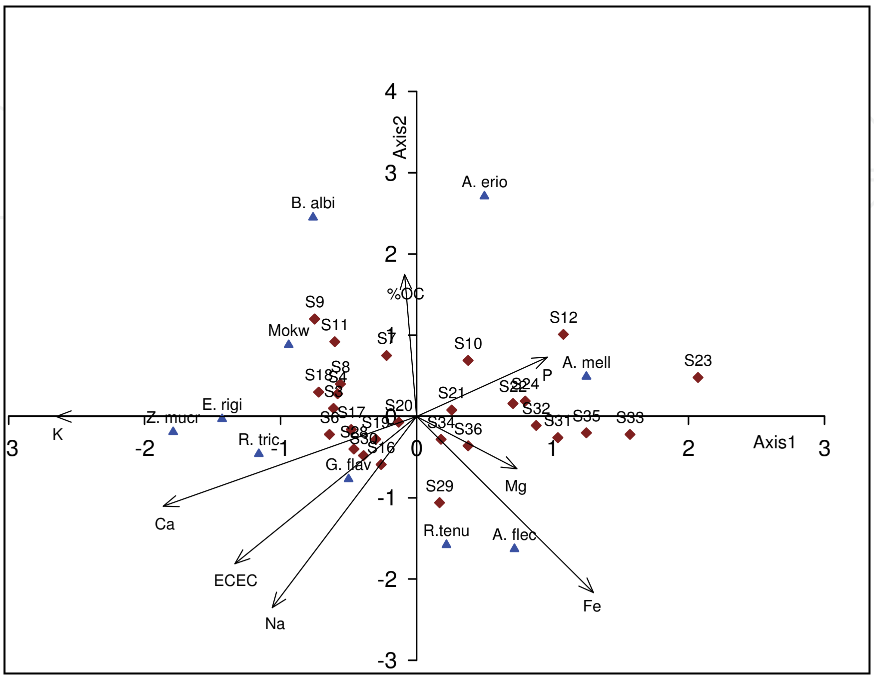

Fig. 8. Relationships between soil properties (130-150cm depth) and plant species distribution.

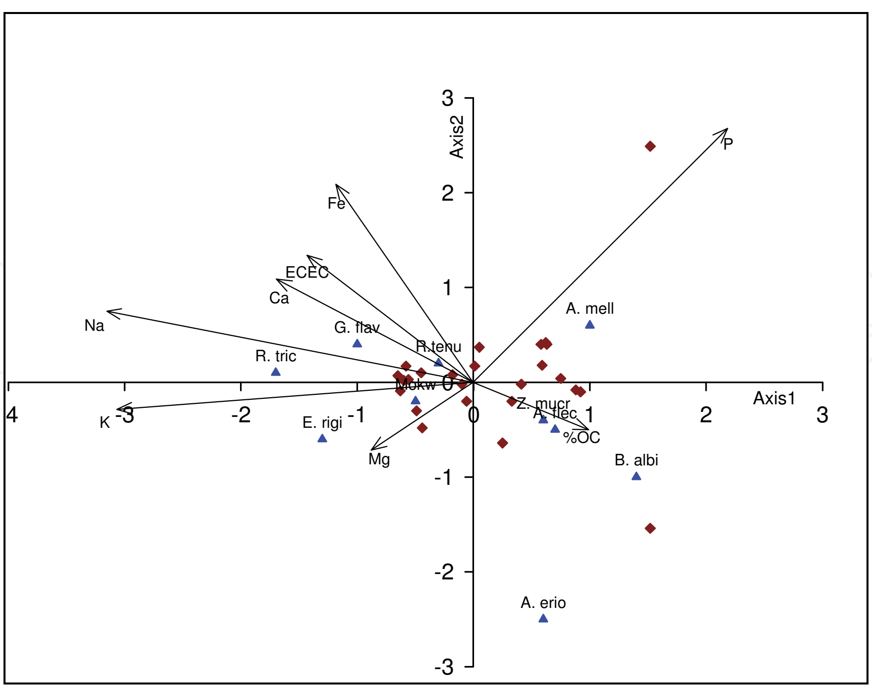

Fig. 9. Relationships between soil properties (180-200cm depth) and plant species distribution.

Axis	DCA	CCA 0-20cm		CCA 40-60cm		CCA 80-100cm		CCA 130-150cm		CCA 180-200cm	
	λ	λ	*r*	λ	*r*	λ	*r*	λ	*r*	λ	*r*
1	0.42	0.26	0.79	0.26	0.87	0.28	0.87	0.27	0.85	0.20	0.81
2	0.26	0.15	0.75	0.19	0.78	0.17	0.83	0.16	0.81	0.19	0.92
3	0.16	0.10	0.65	0.13	0.79	0.12	0.80	0.08	0.73	0.14	0.78
4	0.08	0.08	0.64	0.08	0.67	0.10	0.78	0.08	0.71	0.11	0.82

Table 4. Eigen values of the first four axes and the species-environment correlations.

The eigen values (λ) of the DCA and CCA were determined to further assess the degree to which the selected soil variables could explain plant species distribution in the lunette dune-pan environment (Table 5). The eigen value is usually referred to as the "per centage variance accounted for" (ter Braak, 1988). It always ranges from one (1) to zero (0), and the higher the value the more important the ordination axis. Furthermore, eigen values of ca. 0.3 and higher are usually common in ecological applications (ter Braak, 1988). However, an ordination diagram that explains only a low per centage of the total variance in the species data may still be informative (ter Braak, 1988). Eigen values are usually in the form of a decreasing order with values for axes 1 and 2 being larger than those of axes 3 and 4 as is the case in Table 5 which shows the species-environment correlations (*r*) and the eigen values for the first four axes. It was observed that some eigen values were lower than 0.3 (Table 5). This suggested limitations on the use of data on selected soil variables to explain variation in plant species distribution. This was not out of the ordinary as it is widely acknowledged that plant species distribution in any ecosystem is a function of numerous environmental factors, and that it is practically impossible for any scientific research to exhaustively and concurrently incorporate all environmental factors of potential significance into a particular study. Therefore, the selected soil variables were considered sufficient to comprehensively shed light on the patterns of plant species distribution in the lunette dune-pan environment in Sekoma.

4.4 Social survey

It was established that the village of Sekoma did not originate where it was currently located. The village originated in the western side (Sekoma West) of the lunette dunes and a considerable portion of the community decided to migrate to the eastern side (Sekoma) of the lunette dunes between the years 1924-1927. However, some few members of the community decided to remain in Sekoma West and they still inhabited the area at the period of this research. They indicated that there was nothing major that caused the migration. However, observations indicated that some changes in their environment instigated the migration. For instance, observation of abandoned old hand-dug wells located in the western side of the pan suggested a possible exhaustion of underground water resources at that site. The migration implied a shift in land use pressure from one side of the lunette dune-pan complex to the other. During the discussions, it became apparent that over the years the local community had amassed a wealth of indigenous knowledge with regard to the changes in their environment. The following is an account of the perceptions of the local community pertaining to the lunette dune-pan environment:

- The community perceived the existence of the lunette dunes in their environs as a natural phenomenon.

- They noticed an increase in dune size and height with simultaneous shrinkage of the pan which occurred gradually over the years.
- They recognized that the lunette dunes were not a single hammock of sand, but a dune field of distinct sand dunes. Consequently, they identified the main lunette dunes as Tae, Kebuang, Boisi, Leremela and Tshube from east to west. They were also aware of the perpetual development of some minor dunes in the area.
- Excessive wind erosion was identified as the main agent of soil transfer from the environment onto the lunette dunes. This coupled with the trees which had grown on the lunette dunes trapping the aeolian soil particles, were acknowledged as the main drivers linked with the continuous development of lunette dunes.
- They noticed a rapid increase in the height and size of the lunette dunes between the years 1985-1987 which they attributed to the severe drought that occurred in the area during that period. They pointed out that due to the drought, vegetation was devastated leaving large areas of bare land, creating conducive conditions for rapid soil erosion in the area.
- They associated the drought with bush encroachment or thickening which was evident within the lunette dune-pan environment.
- As evidence to the climatic changes that they observed in the area over a long period of time, they cited a decline in the amount of rainfall that the Sekoma area received over the years. Furthermore, they indicated that in the past, the annual rainfall was sufficient to fill the pan and that the pan was able to hold surface water for longer periods. They realized that this was no longer the case. They attributed the changes to loss of surface water holding capacity due to pan sedimentation. Pan sedimentation was associated with excessive soil erosion that continued to occur over the years causing the pan shrink. As a result, the community relied heavily on hand-dug wells located within the pan as the main source of water for livestock.
- The community indicated that the lunette dunes did not contribute significantly to productivity in pastoral farming in their area due to shortage of fodder resources in the lunette dune-pan environment.
- Finally, they pointed out that the lunette dune-pan environment was subjected to increasing land use pressure due to the increase in the population of the community and livestock in the area. However, they indicated that the situation had been aggravated by some farmers from other villages that had relocated close to Sekoma due to shortage of fodder and water in their areas.

5. Discussion

5.1 Pedo-geomorphology of the lunette dune complex

Soils in the Kalahari area are sandy grains constituted mainly by quartz and small amounts of zircon, garnet, feldspar, ilmenite and tourmaline (Wang et al., 2007; Leistner, 1967). Analysis of soil properties of the Sekoma lunette dune-pan environment did not indicate otherwise as the lunette dunes were more than 95% sandy up to the depth of 200 cm. A soil profile established in one of the lunette dunes indicated no signs of soil horizons up to the depth of 200cm. This showed dominance of sand fraction in the soil texture of the lunette dunes. Goudie and Wells (1995) and Lancaster (1978) pointed out that the deflation of sediment directly from the pan floor during dry climatic condition periods resulted in the formation of the lunette dunes in the Kalahari. Paradoxically, sandy soils were dominant in the lunette dunes compared to the fine textured soil associated with the pan floor. However, Lawson (1998) mentioned that presently sediment deflation from the pan floor was limited in Kalahari. Therefore, the observed soil texture suggested that the Sekoma pan had contributed insignificant amount of sediments to the development of the lunette dunes in the recent years. The dominance of the sand fraction also implied that the sandy environs of the surrounding area had recently contributed significantly to the sedimentation of the lunette dunes compared to the pan floor. This may in turn point to the spatial and temporal environmental changes that had occurred in the area with particular reference to changes in land use, and climatic conditions including, *inter alia*, direction of wind flow, rainfall patterns, increase in livestock population and occurrences of veldt fires.

Correlation analyses indicated that most of the relationships between soil and geomorphological variables were not statistically significant in the three selected lunette dunes. This suggested that the geomorphological properties, particularly the dune slope did not have an influence in the distribution of selected soil variables in the lunette dune-pan environment. Furthermore, lack of distinct patterns in the distribution trends of the selected soil variables in the lunette dune-pan environment pointed to the existence of considerable spatial heterogeneity in the soil resources distribution in the environment. Similar findings in relation to soil resources distribution in arid zones elsewhere have been cited (e.g. Wang et al., 2007; Wezel et al., 2000). Heterogeneity in soil resources in arid regions has often been attributed to the existence of resources islands that normally form under shrub canopies (Wang et al., 2007; Wezel et al., 2000). The islands usually represent micro-sites of favourable conditions for plant growth (Wang et al., 2007; Dhillion 1999).

5.2 Vegetation of the lunette dune complex

Two main plant communities that inhabited the Sekoma lunette dune-pan complex were dominated by *G. flava* and *A. mellifera*. The *G. flava* community occupied the wind ward slopes in all the sampled dunes, but also existed at the crest in the Leremela lunette dune. The *A. mellifera* community inhabited the slip face slope in all the sampled dunes, but also existed at the pan fringes in Leremela and Kebuang and at the crest in Kebuang lunette dunes. The density of *A. mellifera* was higher close to the village as compared to further afield. Leremela and Kebuang lunette dunes were the closest lunette dunes to the settlement area of Sekoma. Furthermore, the hand-dug wells used for livestock watering were located closer to Kebuang lunette dune as compared to the other two lunette dunes. Consequent to this was the evidence of pronounced land use pressure footprints on Kebuang lunette dune. Bush encroachment species predominated by *A. mellifera* was one of the prominent land use pressure footprints in the lunette dune-pan environment. Hence, land use was identified as one of the significant factors that influenced environmental changes, particularly the distribution of plant species and community composition, in the Sekoma lunette dune-pan environment.

The dominance of *A. mellifera* in the lunette dune-pan environment was indicative of the competitive capability of *A. mellifera* in areas that were subjected to intense land use pressure. The abundance of *A. mellifera* under conditions similar to that of the study site has been linked to the species morphological features which enhance its establishment and survival when subjected to harsh environmental conditions (Moleele, 1999). For instance, in spite of the high nutritive value associated with the species, its thorny nature makes it less susceptible to browsing by livestock (Tolsma et al., 1987). Similar studies conducted elsewhere have indicated that species that were more resistant to browsing were normally found in abundance closer to the 'foci-point', which could either be a water source or settlement area (Perkins & Thomas, 1993; Moleele & Perkins, 1998; Moleele, 1999).

Fig. 10. High livestock density in the Sekoma pan with lunette dunes on the background.

Herbaceous cover in the area was non-existent during the time of sampling (Figure 11). It may be argued that this could be linked to the sampling period as it was conducted at the beginning of the rainy season. However, the Kalahari communities have intrinsic inclination towards keeping cattle over small stock. On the other hand, the physiological constraints of cattle limit their movements from their water source (Moleele & Perkins, 1998; Moleele, 1999). Consequently, cattle spent most of their time within the lunette dune-pan environment (Figure 10) close to their water sources. In light of this, the intensity of land use, particularly pastoral farming, was identified as the primary contributing factor to lack of herbaceous cover in the lunette dune-pan environment. In fact, similar researches conducted elsewhere (e.g. Skarpe, 1986; Ringrose et al., 1996; Moleele & Perkins, 1998; Moleele, 1999) have indicated that the development of bare land patches is often caused by overgrazing and trampling due to high livestock density. This condition facilitated the predominance of species like *A. mellifera* and *G. flava* which have innate ability to adapt to hostile environmental conditions through their competitive edge over others (Skarpe, 1990; Moleele & Perkins, 1998; Moleele, 1999) leading to bush encroachment or thickening in the lunette dune-pan environment.
Browse resources contribute significantly to livestock feed in environments where grazing resources are limited (Scholte, 1992; Moleele, 1999). Hence, the scarcity of grazing resources in the lunette dune-pan environment compelled livestock to heavily depend on browse resources. Scholte (1972) and Moleele (1999) indicated that the establishment and survival of woody species is determined by their survival mechanisms against browsing pressure. In view of this, plant species that had the capacity to withstand browsing pressure *(A. mellifera* and *G. flava)* became dominant in the lunette dune-pan environment over the years as land use pressure increased. Therefore, the phenomenon of environmental changes characterized

by the development of imprints of selectivity of livestock on browse resources was inevitable in the lunette dune-pan complex.

Fig. 11. Common bare ground condition in the lunette dune-pan environment.

5.3 Local community perceptions on environmental changes

The social survey provided evidence of a wealth of indigenous knowledge that had been accumulated through informal observations and experiences by the local community. The community perceived wind as the main agent transporting soil particles from the pan and the environs onto the lunette dunes. The perceptions also indicated that the lunette dunes and the plants that grew thereon served as barriers that trapped the aeolian soil particles and lead to continuous process of dune development. The perceptions had considerable overlap with findings from empirical research (e.g. Lancaster, 1978b).

The community perceived the lunette dune-pan environment as an important water source pertinent to their pastoral farming activities. However, it was evident that potential developments in the area of pastoral farming were bedevilled by lack of grazing resources which was a major concern for the community. It was indicated that lack of grazing resources in the area was mainly caused by environmental changes that were characterized by an increase in the livestock population and a decline in the annual rainfall. Therefore, livestock grazing was perceived to be insignificant in the lunette dune-pan environment, hence the lunette dunes were considered insignificant in relation to fodder provision in Sekoma. However, field observations indicated that in spite of the changes in the environment, the lunette dune complex continued to contribute substantially in fodder provision over the years mainly through browsing resources that they sustained.

6. Conclusion

Changes in land use patterns as well as its intensity had affected the lunette dune-pan complex and continue to cause significant spatial and temporal environmental changes in the Sekoma area. The general changes in the climatic factors over the years had influenced changes in the land use patterns, and also contributed to environmental changes observed in the area. The predominance of bush encroachment species, particularly *A. mellifera* was evidence of the precedence of land use intensity over other drivers of environmental changes. The establishment of a sustainable environmental management strategy that could mitigate against the impacts of major drivers of environmental changes in the area was therefore necessary. The fact that the Sekoma community exhibited a wealth of indigenous knowledge in relation to the environmental changes taking place in the lunette dune-pan complex was desirable from the sustainable environmental management perspective. The findings of this study, concomitant with the indigenous technical knowledge of the Sekoma community could therefore form the basis upon which sustainable environmental management planning for the Sekoma lunette dune-pan complex could be established to facilitate natural resources and ecosystem conservation. Furthermore, attention of scientists who conduct their research works in arid environments has been drawn to the need for special consideration of lunette dune-pan complexes that normally exist as interspersed micro-ecosystems in arid environments. More studies are therefore essential to further elucidate environmental changes and ecosystem dynamics of lunette dune-pan micro-ecosystems in arid and semi-arid zones globally. This is particularly important in view of the empirical research observations (e.g., Chanda et al., 2003; Mosweu, 2008; Mosweu & Areola, 2008) which indicated that the livelihoods of most communities living in arid and semi-arid zones revolve around the sustainability of lunette dune-pan micro-ecosystems.

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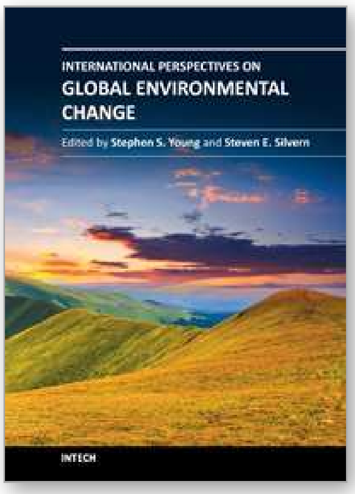

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Environmental change is increasingly considered a critical topic for researchers across multiple disciplines, as well as policy makers throughout the world. Mounting evidence shows that environments in every part of the globe are undergoing tremendous human-induced change. Population growth, urbanization and the expansion of the global economy are putting increasing pressure on ecosystems around the planet. To understand the causes and consequences of environmental change, the contributors to this book employ spatial and non-spatial data, diverse theoretical perspectives and cutting edge research tools such as GIS, remote sensing and other relevant technologies. International Perspectives on Global Environmental Change brings together research from around the world to explore the complexities of contemporary, and historical environmental change. As an InTech open source publication current and cutting edge research methodologies and research results are quickly published for the academic policy-making communities. Dimensions of environmental change explored in this volume include: Climate change Historical environmental change Biological responses to environmental change Land use and land cover change Policy and management for environmental change