Seed-bank analysis for herbaceous species along grazing gradients in the Sandveld and Hardveld grazing areas of Botswana

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ABSTRACT

Grasses and forbs in Southern Africa have been understudied in terms of species richness and factors that affect diversity patterns. To gain a better understanding of factors affecting patterns of herbaceous plant species seedbank around water points, six boreholes (three in each land zone) were randomly selected for sampling. Top soil layers of 20 cm depth were sampled from six boreholes at distances of 50,100, 200, 400, 800, 1500 and 3000 m (the Piosphere approach) in fenced and unfenced plots to determine the density and composition of the seedbank. The samples were allowed to germinate in growth trays (10 x 15 x 8 cm^3) under controlled conditions (temperature, moisture) in a green house followed by daily counting of seedlings. Herbaceous plant species diversity was analyzed by using Simpson's Diversity Index. Analysis of variance on herbaceous species diversity was determined using the SAS software. Herbaceous plant community clustering was determined by using TWINSPAN, a FORTRAN programme. Significant ($p = 0.0001$) germination variations were observed along the distance from livestock watering points. Most grass seedlings recorded germinated from soil samples obtained from fenced plots, while less than 40% of the forb seedlings were. Most of the forbs species were recorded within 400 m from the water points and that soils closer to water points also contain grass seeds despite the level of degradation and/or trampling.

Key words: Seedbank, Grazing gradient, herbaceous species, Botswana

INTRODUCTION

The ecologically sensitive semi-arid areas of southern Africa are increasingly subjected to severe grazing pressures which cause their rapid degradation (O'Connor 1995). The establishment of a species following disturbance depends on the presence of a soil seedbank, persistence of vegetative structures or propagule immigration (Snyman, 1997). Most studies link changes in herbaceous species patterns to livestock grazing and trampling around water points (Noy-Meir & Walker, 1986) because livestock densities are usually highest near water sources. This is likely to be so because that is where cattle must return to water every one to three days. In principle, one would expect a diverse type of vegetation cover around water points since livestock droppings usually contain seeds of plants ingested elsewhere. Instead, invader species such as non-palatable forbs grow around boreholes. The question is, what happens to the rest of the seeds in the seedbank particularly along grazing gradients close to water points?

In the Sahel, livestock grazing is often regarded as one of the main causes of vegetation and soil degradation around boreholes (Lusigi and Glaser, 1984). Studies by Hiernaux and Turner (1996) show that increased grazing pressure may limit the following year's production of annual rangelands through the depletion of seed stock. Dekker (1997) indicated that opening of habitat by tight grazing allows annuals with high seed production to thrive and produce a lot of seed. In Kgatleng District, for example, bare soils, sporadic forb cover and lack of grass cover are increasingly becoming common within 400 m from boreholes (Moleele, 1999). The increase in bare soil, invader species around water sources (boreholes) in communal grazing areas of Botswana is likely to have a negative impact on the seedbank of herbaceous forage plants. Firstly, the reduction in palatable herbaceous plants around boreholes due to increased grazing intensity is likely to weaken (over a long period of time) the process of seedbank replenishment, and in turn a steady increase of invader species seedbank (e.g. forbs) is likely to build up. Secondly, reduction of seeds in the seed bank (due to trampling) is likely to be worse in the sandveld soils (due to loose granules) compared to the hardveld (Buckley *et al*., 1987a).

Viable soil seedbanks contain information about vegetation dynamics that may not be evident in the standing vegetation itself. Soil seed-banks composition can provide insights into plant communities, which previously occupied a site and the changes in species composition that are occurring. Thus knowledge of seedbank status around water points is an essential element for management, conservation and rehabilitation of degraded rangelands (Hopkins *et al*., 1990). The aim of this study was therefore to investigate whether observed herbaceous plant patterns along grazing gradients (in the sandveld and hardveld land zones) were determined by seedbank status.

MATERIALS AND METHODS

Experimental design

The study involved six boreholes (three in the hardveld and another three in the sandveld with 14 (half of which were fenced and the other half unfenced) plots of 10m x 15m at distances 50, 100, 200, 400, 800, 1500 and 3000 m from each borehole. These intervals were located a straight line transect and marked the different grazing gradients along each of the three kilometer transects. Each transect was limited to a 3 km distance to avoid overlap between two or more boreholes (Moleele, 1994). The recommended distance between boreholes in Botswana is 8 km (Ministry of Agriculture, Paper, 1981). It is assumed that changes in vegetation and soil cover along grazing gradients are only due to livestock impacts (Bastin *et al*., 1993). The study sites were utilized by a sizable number of cattle assumed to have an impact on vegetation, soil and plant nutrient status hence their selection. Number of cattle and boreholes in the study areas are given in Table 1.

Table 1. Number of cattle and boreholes in the study areas

	Borehole Name	Cattle Numbers	Date established
Sandveld	Suapan	260	1980
study	Mandlebe	342	1978
sites	Boikinyana	120	1997
	TOTAL	**722**	
-	Ditshwatshwanye	702	1987
	Mamotsatsing	836	1970
Hardveld	Maoka	436	1999
study	TOTAL	**1974**	
sites			

Key: Cattle numbers = average cattle numbers from 1970 – 2001. Source: Department of Animal Health and Production cattle vaccination records, Ministry of Agriculture.

Field sampling

Soil samples were collected after 12 months of fencing from the six boreholes with 2 soil samples per 2 sampling points in each of the fenced and unfenced plots. The samples were extracted from a depth of 20 cm comparable to the rooting zone of grasses, usually 0 - 20 cm (Carter, 1993) and composited before taken to the greenhouse for laboratory analysis.

Pre-lab analysis

Composited soil samples from each of the plots were thoroughly mixed with sterile river sand at the ratio 250 cm^3: 675 cm^3 of soil and sterile sand respectively, replicated 4 times before packaging them in growth trays (10 x 15 x 8 cm^3) and subjecting them to daily watering (about 500mm) for sixty days. The river sand used as a media for growth was sterilized at 70 °C using an electric soil sterilizer for two hours. This was done to discourage unwanted herbaceous plant growths from the sand. The green house temperature was set at 25 °C and 17 °C being the maximum and minimum temperatures (optimum plant growth temperatures) respectively.

Lab analysis

Seedbank analysis was done by counting and recording seedlings of grasses and forbs. The analyses was done daily from each of the growth trays from day one to day 60. Identification of herbaceous species was determined when seedlings were mature enough (about 45 days) to be identified or keyed out by using reference manuals, consultations with National Herbarium experts and personal experience.

Data analysis

Herbaceous plant species diversity was determined by using Simpson's Diversity Index (Bergon *et al.* 1986). Analysis of variance on herbaceous species diversity was determined using the SAS software (Fisher, 1921). A pair-wise comparison of means was done to test differences among distances from the boreholes within treatments (fenced and unfenced). Herbaceous plant community clustering was determined by using TWINSPAN, a FORTRAN programme (ter Braak, 1989; Hill, 1979).

RESULTS AND DISCUSSION

Herbaceous species germination patterns

Significant germination variations ($p = < 0.0001$) were observed along the grazing gradients (Tables 1 and 2). Most grass seedlings recorded germinated from soil samples obtained from fenced plots. For example, out of the eight grass species recorded from the sandveld soil samples, five (*Eleusine coracana, Eragrostis rigidior, Urochloa trichopus, Aristida congesta* and *Setaria verticilata*) had most seedlings germinating from soils obtained from fenced plots (Figure 1a and Figure 1b) while a similar pattern was displayed by the hardveld species where seven out of ten grass species germinated from fenced plots. Other studies blame the species changes as caused by both rainfall and grazing pressure (e.g. McNaughton & Chapin 1985; Jaramilo and Detling 1988; Milchunas & Lauenroth 1993; Hiernaux and Turner 1996). It is clear from the results therefore that given some protection, herbaceous plants can produce to their maximum. The fact that fewer grass seedlings germinated from unfenced plots gives a better picture for future rangeland improvements. It is true that seedbanks are neglected in the land conservation and management, but only because they are difficult to see. If an effort to measure them can be made, then it might be clear as to how certain management actions would affect the quality and condition of the seedbank.

Table 1. Mean grass seedlings along grazing gradients from the sandveld soil samples

		Euco		Urtr		Ergu		Seve	
		Fenced Duncan Grouping	Unfenced Duncan Grouping	Fenced Duncan Grouping	Unfenced Duncan Grouping	Fenced Duncan Grouping	Unfenced Duncan Grouping	Fenced Duncan Grouping	Unfence Duncar Groupin
Dist (m)	N	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
50	36	2.19a	1.08a	0.97a	0.78a	2.14a	2.33a	1.72a	1.68a
100	36	0.56b	0.28b	0.94a	0.50b	1.36b	1.75b	1.06b	1.06b
200	36	0.00c	0.00c	0.72a	0.28cb	0.28c	0.28c	0.00c	0.00c
400	36	0.00c	0.00c	0.69a	0.19c	0.00c	0.00c	0.00c	0.00c
800	36	0.00c	0.00c	0.00b	0.00d	0.00c	0.00c	0.00c	0.00c
1500	36	0.00c	0.00c	0.00b	0.00d	0.00c	0.00c	0.00c	0.00c
3000	36	0.00c	0.00c	0.00b	0.00d	0.00c	0.00c	0.00c	0.00c

		Erri		Seka		Arco		Tragus	
Duncan Grouping		Fenced	Unfenced Duncan Grouping	Fenced Duncan Grouping	Unfenced	Fenced Duncan Grouping	Unfenced Duncan Grouping	Fenced Duncan Grouping	Unfenced Duncan Grouping
Dist (m)	N	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
3000	36	3.47a	2.61a	1.58a	1.75a	2.56a	1.86a	1.22a	1.07a
1500	36	3.44a	2.47a	1.17b	1.64a	1.92b	1.75a	0.28b	0.56b
800	36	2.75b	2.03bc	0.53c	1.00b	1.75b	1.67a	0.00c	0.53b
400	36	1.89c	1.86c	0.25d	0.00c	1.67b	1.25b	0.00c	0.00c
200	36	1.53c	0.94d	0.00e	0.00c	0.50c	0.00c	0.00c	0.00c
100	36	1.47c	0.92d	0.00e	0.00c	0.25c	0.00c	0.00c	0.00c
50	36	0.78d	0.28e	0.00e	0.00c	0.25c	0.00c	0.00c	0.00c

Key: Euco = *Eleusine coracana*; Urtr = *Urochloa trichopus*; Ergu = *Eragrostis gummiflua*; Seve = *Setaria verticilata*; Erri = *Eragrostis rigidi* Seka = *Schimidtia kalaharensis*; Arco = *Aristida congesta*; Tragus = *Tragus berteroianus*. A, b, c and d are Duncan Grouping's Multiple Ra test or pairwise comparison of the means from Statistical Analysis System (SAS, 1999). Means with the same letter within a column are significantly different

Table 2. Distribution of grass species along grazing gradients from hardveld soil samples

		Euco		Urtr		Ergu		Seve	
		Fenced	Unfenced	Fenced	Unfenced	Fenced	Unfenced	Fenced	Unfenced
Dist (m)	N	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
50	36	1.89a	1.47a	1.86a	1.25a	2.53a	2.14a	1.19a	1.39a
100	36	1.22b	0.22b	1.75a	1.22a	1.94b	1.94a	0.97b	0.97b
200	36	0.00c	0.00c	1.61a	1.14a	0.97c	1.08b	0.25c	0.00c
400	36	0.00c	0.00c	0.97b	1.06a	0.28d	0.53c	0.00d	0.00c
800	36	0.00c	0.00c	0.78b	0.53b	0.00d	0.00d	0.00d	0.00c
1500	36	0.00c	0.00c	0.25c	0.00c	0.00d	0.00d	0.00d	0.00c
3000	36	0.00c	0.00c	0.00c	0.00c	0.00d	0.00d	0.00d	0.00c

		Clvi		Para	
		Fenced	Unfenced	Fenced	Unfenced
Dist (m)	N	Mean	Mean	Mean	Mean
50	36	1.53a	0.53a	2.28a	1.56a
100	36	0.97b	0.50a	1.53b	1.03ba
200	36	0.56c	0.44ba	1.25b	1.03ba
400	36	0.33c	0.25bc	1.17b	0.81bc
800	36	0.00d	0.00c	0.97c	0.61bc
1500	36	0.00d	0.00c	0.81c	0.53bc
3000	36	0.00d	0.00c	0.78c	0.25c

		Spio		Tragus		Erri		Arco	
		Fenced	Unfenced	Fenced	Unfenced	Fenced	Unfenced	Fenced	Unfenced
Dist (m)	N	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
3000	36	3.67a	3.14a	1.81a	2.31a	3.69a	3.50a	2.64a	2.47a
1500	36	3.14ba	2.39a	1.72a	1.47b	3.33a	2.78b	2.53a	2.28ba
800	36	2.61bc	2.19b	1.69a	1.19cb	3.31a	1.97c	1.89b	1.97b
400	36	2.22c	2.17b	1.50a	0.97cb	2.58b	0.78d	0.94c	0.89c
200	36	1.19d	1.58c	1.36ba	0.92c	1.56c	0.58d	0.67dc	0.47d
100	36	1.03d	1.03d	1.00bc	0.86c	1.47c	0.50d	0.50dc	0.28d
50	36	0.00e	1.00d	0.86c	0.00d	0.69d	0.50d	0.47d	0.19d

Key: Euco = *Eleusine coracana*; Urtr = *Urochloa trichopus*; Ergu = *Eragrostis gummiflua*; Seve = *Setaria verticilata*; Erri = *Eragrostis rigidior*; Spio = *Sporobolus ioclados*; Pama = *Panicum maximum*; Tragus = *Tragus beteronianus*; Arco = *Aristida congesta*; Clvi = *Chloris virgata*. Means with the same letter within a column are not significantly different.

Four of the eight sandveld (e.g. *E. rigidior*; *A. congesta, S. kalaharensis* and *U. trichopus*) grasses increased significantly with distance from water points (Table 1) while in the hardveld less than 50 % (i.e.). four of the ten grass species e.g. *S. ioclados, T. beteronianus, E. rigidior* and *A. congesta*) showed a similar trend (Table 2). Most of the grass species that decreased with distance were annuals (e.g. *E. coracana, S. verticilata* and *E. gummiflua*

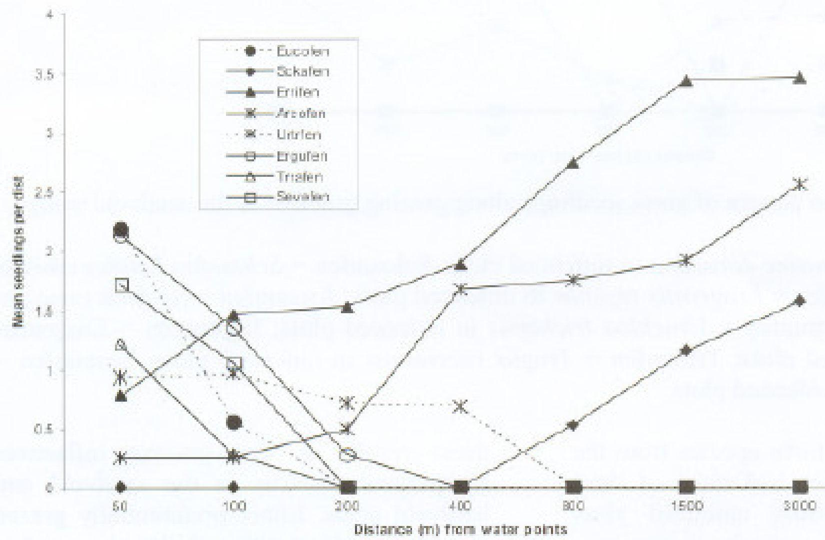

Figure 1a. Germination pattern of grass seedlings along grazing gradient in the sandveld

Key: Eucofen = *Eleusine coracana* in fenced plots; Sckafen = *Schimdtia kalaharensis* in fenced plots; Errifen = *Eragrostis rigidior* in fenced plots; Arcofen = *Aristida congesta* in fenced plots; Urtrfen = *Urochloa trichopus* in fenced plots; Ergufen = *Eragrostis gummiflua* in fenced plots; Trrafen = *Tragus racemosus* in fenced plots; Sevefen = *Setaria verticilata* in fenced plots.

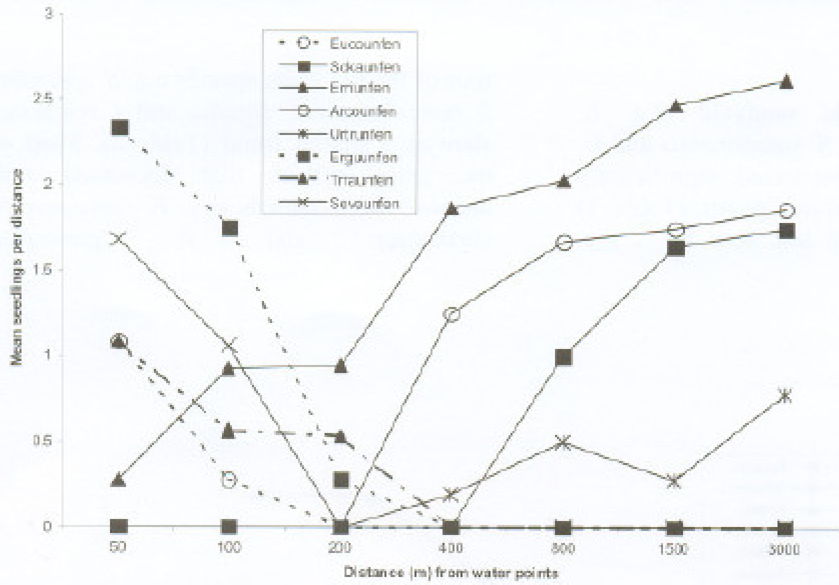

Figure 1b. Germination pattern of grass seedlings along grazing gradient in the sandveld study sites.

Key: Eucounfen = *Eleusine coracana* in unfenced plots; Sckaunfen = *Schimdtia kalaharensis* in unfenced plot; Erriunfen = *Eragrostis rigidior* in unfenced plots; Arcounfen = *Aristida congesta* in unfenced plots; Urtrunfen = *Urochloa trichopus* in unfenced plots; Erguunfen = *Eragrostis gummiflua* in unfenced plots; Trraunfen = *Tragus racemosus* in unfenced plots; Seveunfen = *Setaria verticilata* in unfenced plots.

Nine of the twelve forbs species from the sandveld soils samples had most of their seedlings recorded from unfenced plots while in the hardveld, a similar pattern was shown where sixteen out of the twenty-two forbs germinated from soil samples collected from unfenced plots (Figures 2 and 3). These results suggest that more grass seedlings were found in fenced plots along the grazing gradients compared to forbs. Most grass seedlings were recorded from soil samples collected beyond 400 m from the water points while forbs were between fifty and 400 m. Except for annuals, results show that grass species increased with increasing distance from the boreholes while the forbs did not. The picture emerging from these results is that grazing influences competitive patterns in the sandveld and hardveld areas. Either preferentially grazed species lose competitive ability compared to less grazed ones and subsequently decrease in abundance (Walker and Hodgkinson, 1995) or palatable but grazing-tolerant species remain dominant in preferentially grazed patches. The first effect is common in areas under heavy grazing while the latter is recorded mainly from areas under moderate grazing (Skarpe, 1991). Perhaps the study must be carried out for much longer if one is to determine how seedling recruitment into gaps, created for example by degradation, may influence vegetation change.

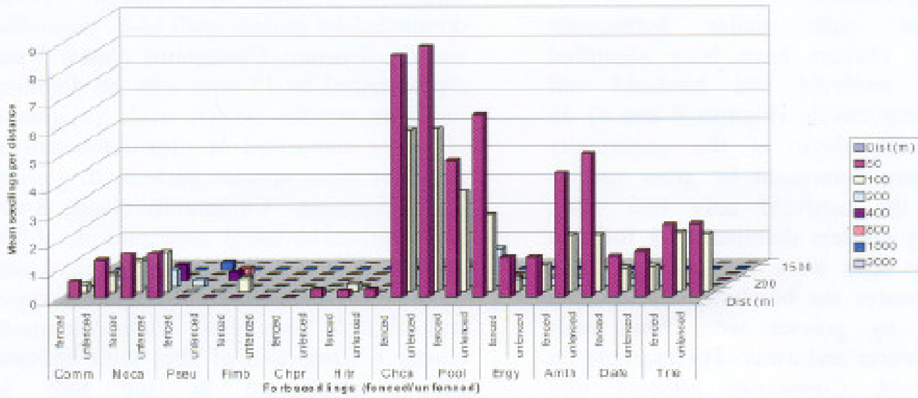

Figure 2. Forbs seedling species in fenced and unfenced plots from the sandveld soil samples
Key: Comm = *Commelina benghalensis*; Moca = *Modiola caroliniana*; Pseu = *Pseudogphalium luteo-album*; Fimb = *Fimbrisylis hispidula*; Chpr = *Chamaesyce proistrata*; *Hibiscuss trionum*; Chca = *Chenopodium carinatum*; Pool = *Portulaca oleraceae*; Hergy = *Helichrysum aergyrosphaerum*; Amth = *Amaranthus thunbergii*; Dafe = *Datura ferox*; Trte = *Tribulos terrestris*.

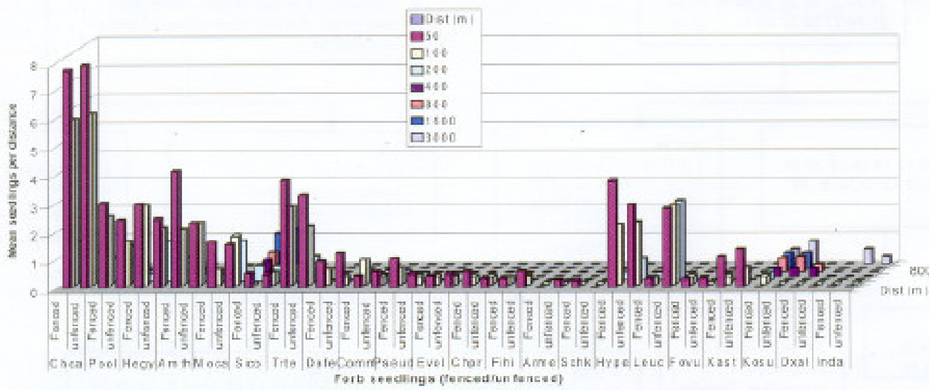

Figure 3. Forbs seedling species from fenced and unfenced soil samples from the hardveld.
Key: Chea = *Chenopodium carinatum*; Pool = *Portulaca oleraceae;* Hergy = *Helichrysum aergyrosphaerum;* Amth = *Amaranthus thunbergii*; Moca = *Modiola caroliniana;* *Sico* = *Sida cordifolia;* *Trte* = *tribulos terristris;* Dafe = *Datura ferox*; Comm = *Commelina benghalensis*; Pseu = *Pseudogphphalium luteo-album*; Evol = *Evolvulus alsinoides*; Chpr = *Chamaesyce protstrata;* Fimb = *Fimbrisylis hispidula*; Arrne = *Argemone mexicana*; Schk =*Schkuhria piñata*; Hype = *Hypertelis bowkeriana*; Leuc = *Lucas martinensis*; Fovu = *Foeniculm vulgare*; Xast = *Xanthium strumarum*; Kosu = *Kouhasita subverticilata*; Oxal = *Oxygonum alatum*; Inda = *Indigofera daleoides*; Dist. = Distance (m) from water points

Classification of major herbaceous community clusters

Six and eight major herbaceous community clusters have been identified from the sandveld and hardveld soil samples, respectively (Figures 4 and 5). In the sandveld, three of the community clusters were dominated by grass species while in the hardveld only two were. Community clusters dominated by forbs in both study sites were mostly from soils collected nearer the boreholes while those dominated by grasses were from soils collected nearer and away. For example, in the sandveld, *Community cluster1* was characterized by a high concentration of *A. congesta* as the major indicator species from a total of 14 samples. Community cluster 2 comprised of sites with indicator species dominated by grasses such as *E. gummiflua* and *E. coracana*. Community cluster 3 was characterized by 15 sites with no dominant indicator species shown while *community cluster 4* comprised of sites dominated by indicator grass species such as *E. rigidior* and *A. congesta*. Community cluster 5 was characterized by a high concentration of forb species such as *Chamaesyce inaequilatera*, *Amaranthus thunbergii*, *Portulaca oleracea* and *Modiola caroliniana* while community cluster 6 comprised of sites with indicator species dominated by the forb *M. caroliniana* from 8 sites.

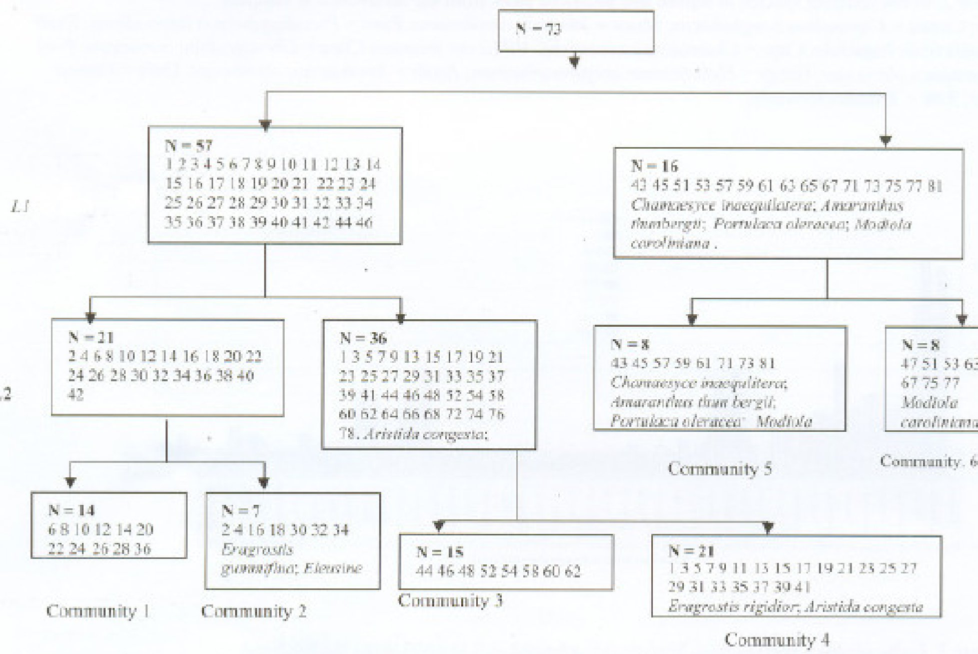

Figure 4. Dendrogram showing TWINSPAN classification of major herbaceous plants community clusters from the sandveld study sites soil samples. Positive and negative signs indicated a particular dichotomy preferred by sites and species while indicator species dominant in each cluster is shown. N = number of samples in each community; f = fenced plots; uf = unfenced plots. L1, L2 and L3 = community cluster levels (L1 being the highest while L3 the least cluster level).

In the hardveld, *Community cluster* 1 was characterized by sites with no indicator species displayed while *Community cluster 2* comprised of sites with indicator species dominated by *E. coracana* grass species. Community cluster 3 composed of sites with indicator species dominated by *E. gummiflua*. Community cluster 4 comprised of 13 sites with no dominant indicator species shown while *community cluster* 5 comprised of 9 sites with *Sida codefolia* as the dominant indicator forb species. Community clusters 6 and 7 (with 10 and 14 sites each respectively) showed no dominant indicator species while *community cluster* 8, which is the smallest, comprised of 6 sites with *Kohaustia subverticilata* as the dominant indicator forbs species.

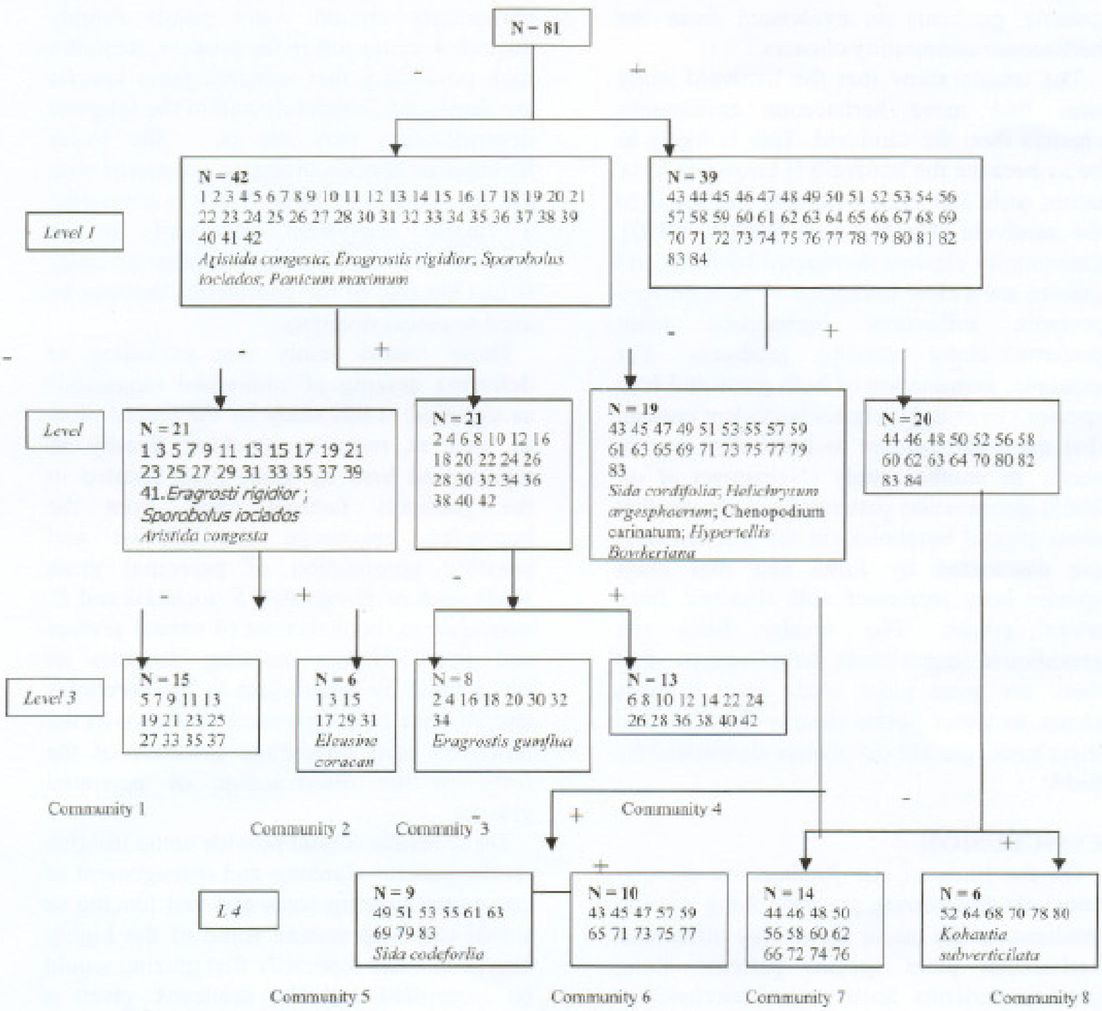

Figure 5. Dendrogram showing TWINSPAN classification of major herbaceous plants community clusters from the hardveld soil samples. Positive and negative signs indicated a particular dichotomy preferred by sites and species while indicator species dominant in each cluster is shown. N = number of samples in each community; f = fenced plots; uf = unfenced plots. L1, L2 and L4 = community cluster levels (L1 being the highest while L4 the least cluster level)

These results show that the majority of the grass seedlings recorded were from soils collected in fenced plots, most of the forbs species were from unfenced plots and closer (within 400 m) to boreholes. Some of the grasses (e.g. *E. gummiflua; E. coracana, S. verticilata, E. rigidior* and *A. congesta*) germinated not only from soils closer to water-points or boreholes but also along all grazing gradients as evidenced from the herbaceous community clusters.

The results show that the hardveld study sites had more herbaceous community clusters than the sandveld. This is likely to be so because the hardveld is known to have better soils and higher rainfall compared to the sandveld (De Wit and Bekker, 1990). Community clusters dominated by forbs and grasses are a clear indication of how grazing pressure influences herbaceous plant patterns along grazing gradients. For example, germination of both grass and forb species closer to boreholes is evident enough that even soils closer to boreholes contain seeds. In another study (Nsinamwa *et al.* 2005) germination patterns have shown that areas around boreholes (in the wet seasons) are dominated by forbs and that grass species only increased with distance from water points. The results from the greenhouse experiment have shown that there are grass plant seeds even in soils closer to water points despite the fact that these areas are almost always dominated by forbs.

CONCLUSION

On the basis of our findings we thereby conclude that grazing pressure along grazing gradients is the major factor that influences herbaceous plant species patterns along grazing gradients. Soils around boreholes or water points (high grazing pressure zones and/or high-nutrient zones) also contain herbaceous plant seeds (particularly grasses) although of low diversity. Forbs constitute most of the herbaceous plants composition, but have largely been ignored in favour of the dominant grasses that are considered important for livestock production. The forbs are likely to widen the bare patches or the areas they temporarily occupy particularly around water points (highly degraded areas) and in the process, there is a high possibility that valuable grass species are displaced completely and in the long run desertification may set in. The lower herbaceous species diversity associated with the sandveld may imply that it is somewhat a fragile ecosystem compared to the hardveld although herbaceous plant diversity is just but one of the parameters that can be used to assess diversity.

These results imply that excluding or deferring grazing of communal rangelands as signified in this study by the fenced plots as well as reducing stocking density as represented here by those plots located in the gradients furthest away from the boreholes, encourage accumulation and possibly germination of perennial grass seeds such as *E. rigidior; S. ioclados* and *P. maximum* at the detriment of annual grasses and forbs. Higher stocking densities as represented by areas close to the boreholes and absence of deferrement as shown in the unfenced plots encourage presence of the forbs to the disadvantage of perennial grasses.

These results should provide some insights on the general planning and management of communal grazing areas and that fencing as a tool can help restore some of the highly degraded areas especially that grazing would be controlled and the seedbank given a chance to express fully its composition.

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