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Full Length Research Paper

Soil seed bank dynamics in relation to land management and soil types in the semi-arid savannas of Swaziland

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In the semi-arid savannas of Swaziland, communal grazing, commercial ranches and game reserves are the main land management systems for animal production. These land uses can have different ecological effects on the rangelands. This study was conducted to investigate the differences in soil seed bank characteristics between three land management systems having high (communal land), low (government ranch) and medium (game reserve) stocking rates, and soil types (lithosol and vertisol or raw mineral). Two grazing areas (Bigbend and Simunye) each with the three land management systems and soil types were selected for this study. A total of 40 plant species were identified in the seed bank of both grazing areas. *Panicum maximum* dominated both grazing areas. *Cenchrus ciliaris* was dominant in Bigbend area, while *Digitaria eriantha* was dominant in Simunye area. Seedling density varied (P<0.05) among the land management systems and soil types. The difference in past and recent grazing pressure may be the primary cause of the observed differences. In all study sites, the soil seed bank was a poor reflection of the aboveground vegetation as revealed by weak similarity. In Bigbend, *P. maximum* and *Urochloa mosambicensis* were well represented in the seed bank. In Simunye, however, these two species were comparatively under-represented. Whereas the regeneration of the aforementioned two species from the seed bank may be high and have a profound effect in restoration of rangelands after disturbance, this may be affected by spatial differences in terms of rainfall and soil. Valuable species under-represented in the seed bank can be prone to extinction under heavy utilization and therefore, *in situ* conservation within certain localities should receive high priority.

Key words: Grazing pressure, greenhouse, herbaceous layer, rangeland, seedling.

INTRODUCTION

Southern Africa savanna ecosystems represent species rich plant communities, containing a large diversity of both herbaceous and woody plants. Savannas have been used for many centuries as extensive rangelands for livestock production, with communal grazing and commercial ranching being the dominant forms of land use and management. In recent years, game ranching and reserve ventures have been growing mainly as an alternative land use in response to changes of these ecosystems. Furthermore, large areas of savannas are being used for agricultural activities, urban development and industrialization (Annika, 2000). Consequently, the total area of the savanna ecosystem for animal production has declined dramatically. Therefore, the sustainable use of the remaining land should depend not only on understanding how grazing interacts with the underlying biotic and abiotic factors as well as the ecological processes, but also on understanding the extent and degree of its deterioration and ways of restoration (Solomon et al., 2007). Many studies have demonstrated that vegetation restoration partly depends on the ability of viable seeds to persist in the soil seed bank as a remnant of the past or present plant community (Bekker et al., 1997; Solomon et al., 2006).

A soil seed bank is defined as the optimal pool of seeds potentially present on or beneath the soil that is capable of germination (Vércin et al., 2007). Most of the seeds in the seed bank come from the nearby parent plants, while the remaining seeds are contributed by plant communities a long distance away from the parent plants. Soil seed banks are important in savanna ecosystems where grasses dominate the herbaceous layer. Seeds in the seed bank can remain stored in the soil for various lengths of time and then later germinate with the return of favorable seasonal conditions.

Storage of viable seeds in the soil and the subsequent establishment are functions of the soil. Seedling recruitment from the seed bank is restricted to periods of favorable soil conditions that may control seed survival and germination. One of the most important conditions is soil moisture (Snyman, 1998), while other factors include soil pH (Snyman, 2005) and light. All these factors in turn are affected by the type of the soil. Seed bank production and recruitment are also functions of disturbance factors. Grazing in particular influences the vegetation and seed bank dynamics in a variety ways. Most importantly, grazing has direct effects on plant community and seed bank by reducing biomass and seed production.

Disturbance gradients that occur at different land management systems (types) have been extensively studied to determine the level of vegetation response to intensity of use. Many studies provided evidence of significant changes in species composition at more intensively grazed areas (Friedel, 1997; Solomon, 2003). Others found that vegetation disturbance is a product of a complex interaction that existed between grazing, soil type, rainfall and/or landscape characteristics (for example, Van Rooyen et al., 1994).

Seed bank dynamics of arid and semi-arid savanna ecosystems have been intensively studied. Important topics covered in these studies included density and composition, spatial patterns (Marone et al., 1998), age structure (Moriuchi et al., 2000), and relationships between seed bank and existing plant communities (Solomon et al., 2006; Vércin et al., 2007). Attempts have also been made to appraise the contribution seed banks can make to population dynamics and viability (Cabin et al., 1998; Turelli et al., 2001).

Regeneration from seed banks is an important process in maintaining the above ground plant community of the savanna ecosystems of Swaziland, and its pattern and diversity could vary in relation to land management and/or edaphic factors. Some studies dealing with vegetation in savannas of Swaziland are restricted to the above ground plant community (Sweet and Khumalo, 1994; Dlamini et al., 2000) and knowledge of seed bank structure and composition is still scanty.

The three land management types (communal, government ranch and game reserve) found in the study areas differ in terms of animal composition, stocking rate and season of grazing, and this variation allowed me to assess the impacts of management types on seed bank population and dynamics. Two major soil types common to the three land management systems in each study area were found, and their effect on the seed bank was also studied. The current study also assessed the similarity of grass composition between the seed bank and above ground plant community of the various land management and soil types.

MATERIALS AND METHODS

Site description

The study area is located in the Lowveld of Swaziland which covers about 31% of the country (Remmelzwaal, 1993). The landscape comprises mainly of gentle undulating terrain, and ranges in altitude between 250 to 400 m above sea level. The area has arid to semi-arid climate with annual rainfall ranging from 400 to 600 mm, mostly occurring between October and March (Monadjem and David, 2005; Solomon et al., 2008). The mean annual temperature varies from 18 to 26°C. The geology is dominantly basalt and sandstone-claystone complexes, and the major soil types include lithosol, vertisol and raw mineral (Murdoch, 1970). Three vegetation types were described in the Lowveld savannas (Sweet and Khumalo, 1994), namely broad leaved woodland savannas, microphyllus (*Acacia*) savannas and riverine forests.

Site selection and layout

Two grazing areas, namely Bigbend and Simunye, were selected for this study. The two areas were approximately 90 km apart, and not considered as spatial replicates because they differ in the distribution of dominant soil types, landscape as well as rainfall patterns. Bigbend area is dominated by vertisol and lithosol types whereas raw mineral soil and lithosol represent the dominant soil types in Simunye (Figure 1). In each grazing area, three land management types having high (communal grazing land), low (government ranch) and medium (game reserve) stocking rates located adjacent to each other were identified. Unfortunately, grazing history of these land management types has not been well documented. However, it is well known that the communal lands have been heavily grazed with an estimated stocking rate between 2 ha LSU^{-1} (Sweet and Khumalo, 1994) and 0.94 ha LSU^{-1} (Dlamini et al., 2000). The government ranches had estimated stocking rate of ≥ 6 ha LSU^{-1}, and is mainly used as cattle breeding center. The stocking rate of the game reserves fell between the communal and the government ranches. Prior to establishment (before 1986), the game reserve in Simunye area was utilized as cattle ranches with an estimated average stocking rate of <4.4 ha LSU^{-1}, but it has only been sparsely stocked in recent time. Six sites were selected, one on each of the two common dominant soil types in the three land management types of the two grazing areas. Three 100 m transects were laid out randomly on each site, giving a total of 36 transects in the two grazing areas, with each area having equal number of transects. The minimum and maximum distance between two transects were 30 and 50 m, respectively. Each transect was divided equally into 10 m sub-transects. All study sites were georeferenced.

Soil sampling

Soil sampling was done towards the end of May 2006, after most

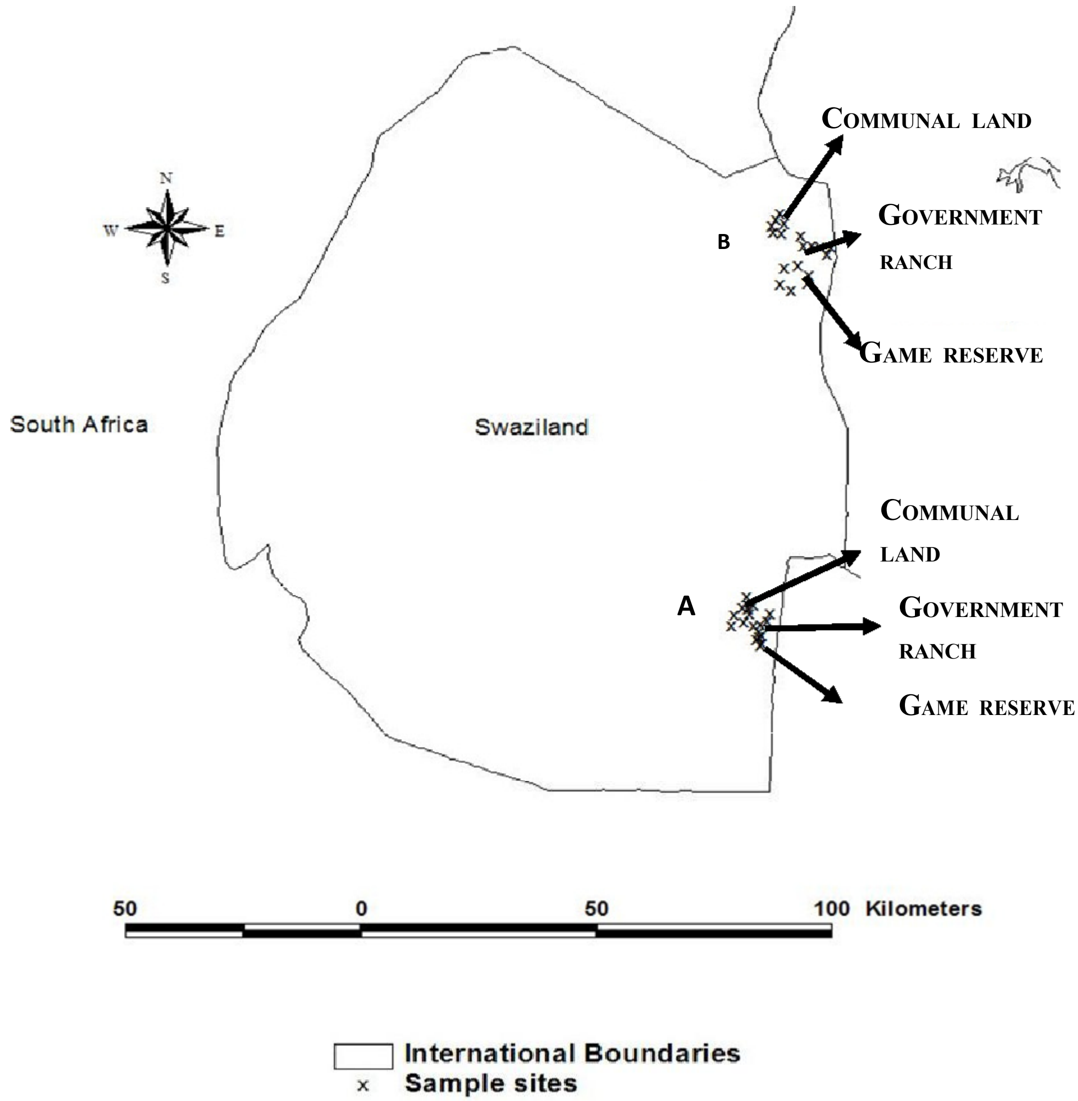


Figure 1. Map of the study sites in the Lowveld of Swaziland: Bigbend (A) and Simunye (B).

seeds had been shed prior to winter (dry and cold). Ten soil samples with a depth of 30 mm were collected from an area of 0.25 m^2 quadrat per sample per transect. According to Chields and Goodall (1973), the first 20 mm accumulates most of the seed bank in arid and semi-arid ecosystems. The soil samples were collected from the field in plastic bags and then immediately transferred into paper bags for storage. The samples were stored for one month at room temperature. Germination of seeds did not occur during the storage period in all the soil samples.

Green house experiment

In the green house, labeled plastic pots with a depth and diameter of 220 mm were filled with a sterile composite to a depth of approximately 180 mm, and were placed at random on shelves. The soil samples were then spread out in a thin layer of 20 mm in each plastic pot. Prior to spreading, each sample was thoroughly mixed after removal of all roots and debris. Eight control pots filled with the sterile composite were also placed randomly on the shelves to test for contamination. The temperature in the green house was controlled, and varied between 18 and 25°C during the day and 10 and 12°C during the night. All seedlings from germinated seeds were counted every week up to 6 months period after which further emergence of seedlings decreased remarkably. Each pot was hand-watered and regularly fertilized with urea to allow continued growth of the seedlings. The first seedlings in the green house appeared three weeks after the start of the experiment. At seedling stage it was possible to clearly distinguish between grasses, forbs and trees/shrubs, and in a few cases to species level. Seedlings identified to species level were removed immediately. Otherwise, seedlings were allowed to grow until identification was possible. The grasses and forbs started flowering in the 10 weeks of the experiment. Trees and shrubs did not show flowering throughout the experimental period. To determine botanical composition, floristic data was taken from every species as flowering occurred. The flowering plants were then removed gently without disturbing the soil. The duration of the green house experiment lasted 12 months.

Above ground grass species composition

Grass species composition was estimated from a belt transect of 100 x 6 m with step point method (Solomon et al., 2007). The nearest plant and basal strikes were recorded from 300 point observations per belt transect. This sample size has been reported to be adequate for reliable results (Hardy and Walker, 1991). Point observations were spaced by approximately 2 m intervals and records were made over the length of transect in six straight parallel lines with approximately 1 m distance between them. Vegetation surveys were done late in the growing season (March to April 2006).

Species identification and classification

Grasses were classified into three groups based on the succession theory described by Dyksterhuis (1949) and on ecological information for the arid to semi-arid regions of South Africa (Tainton et al., 1980; Vorster, 1982). Accordingly, the species were grouped into (1) highly desirable species: those which occur in rangeland under good condition and decrease with overgrazing or under grazing (decreasers), (2) desirable species: those which occur in rangeland under good condition and increase with moderate overgrazing (increaser IIa), and (3) less desirable species: those which occur in rangeland under good condition and increase with severe/extreme overgrazing (increasers IIb and IIc).

Data analysis

The main interest in this study was to determine the status of the seed bank in the three land management types and two soil types. In each grazing area, sampling sites were chosen within a small area where the three land management types occurred adjacent to one another. This closeness did not allow the transects to comprise independent samples of a particular soil type for the separate land management type (Annika, 2000). Therefore, the study was based on an approximate field experiment with six treatment combinations and three replicates within each grazing area. The transects established under each soil type of the land management systems were spatial pseudoreplicates. The risk of pseudoreplication in the present study was expected because the sample area was smaller or more restricted to infer about the land management and soil effects. Moreover, true replication of the land management and soil effects was not possible because the geology and landscapes differ over a short distance. It was also assumed that limitations associated with pseudoreplication were less compared to those of the non-representativeness of taking samples from a large area. Pseudreplication should not be as related to sampling design and procedure, as to the application of inappropriate statistical analysis, or to the use of unallowable generalizations (Annika 2000). Most rangeland research that covers extensive areas of grazing systems and landscape features is inferential and inductive, but discussions and conclusions drawn from such research should not be of less interest or value.

Data of the 10 sub-transect within each transect was pooled together to give the replicate values. Since data on seedling density were not normally distributed and replicates inadequate, the non-parametric Whitney U-test for two independent samples was used (Kent and Coker, 1992). The significance levels were not compared to priori requirements, but used as semi qualitative ‘relevance indicators’ for individual differences. Similarity between seed bank samples and above ground vegetation was determined using Sorensen’s Index:

$$S = 2c/(a+b+2c),$$

where a is the number of species present only in the seed banks, b is the number of species present only in above ground vegetation and c, the number of species present in vegetation and seed bank samples (Sorensen, 1948). Forbs were rarely presented in the above ground vegetation and therefore, similarity was calculated only for grass species. For data that did not require analysis, simple descriptive statistics were employed where appropriate.

RESULTS

Seedling density of grasses and forbs

In Bigbend grazing area, the mean seedling density of grasses differed significantly ($P<0.05$) among the three land management systems with the greatest value observed at the low stocking rate (141 seedlings m^{-2}). Mean seedling density of forbs did not differ significantly among the land management systems and ranged from 88 to 164 seedlings m^{-2}. Soil type did not affect ($P>0.05$) seedling density of grasses or forbs.

In Simunye grazing area, the maximum number of grass seedling obtained at the low stocking rate (148 seedlings m^{-2}) was significantly higher ($P<0.05$) than the moderate and high stocking rates. Seedling density of forbs was greater ($P<0.05$) at the medium stocking rate than the low or high stocking rate. Considering the soil types of this area, lithosol had significantly more seedling density (125 seedlings m^{-2}) than the raw mineral soil (68 seedlings m^{-2}) (Table 1).

Species composition of the herbaceous and woody vegetation

A total of 39 species were identified of which 21 were forbs, 15 were grasses and 3 were trees or shrubs. In Bigbend area, *Flavis bidentis*, *inds145* (Unidentified species) and *Euphorbia sp* are forb species that occurred commonly though their frequencies varied between the land management and the soil types. In Simunye area, *Cenia turbinate* was a forb species that dominated the medium stocking rate, while *Dichrostachys cinerea* and *Chromolaena odorata* represented the dominant woody species and were more abundant on the high stocking rate. The last two species were more frequent on the raw mineral (Table 2) than the lithosol soil type. The forb species identified in this study were predominantly annuals.

Out of the 15 grass species recorded in the soil seed bank, three were identified as highly desirable or less desirable, and nine- as desirable. In both grazing areas, the dominant grass species in the seed bank were

Table 1. Seed bank seedling density (mean ± SE seedlings m^{-2}) of grasses and forbs under three land management and soil types in the two grazing areas.

Land management (stocking rate)	Bigbend area	
	Grasses	**Forbs**
High	127.8^{b} ± 25.7	87.5^{a} ± 80.4
Low	140.6^{a} ± 24.5	89.7^{a} ± 68.9
Medium	89.6^{b} ± 24.5	164.4^{a} ± 65.7
Soil types		
lithosol	122.0^{a} ± 19.9	75.7^{a} ± 59.5
vertisol	116.7^{a} ± 20.7	152.1^{a} ± 57.9
Land management (stocking rate)	**Simunye area Seedling density**	
	Grasses	**Forbs**
High	61.7^{b} ± 25.4	47.7^{b} ± 45.1
Low	147.5^{a} ± 25.4	115.4^{ab} ± 27.6
Medium	79.6^{b} ± 25.4	136.6^{a} ± 29.8
Soil types		
lithosol	124.7^{a} ± 20.8	132.6^{a} ± 31.9
Raw mineral soil	67.6^{b} ± 20.8	67.2^{b} ± 24.9

Mean values in the same column with different superscript letters differ significantly (P<0.05).

Table 2. Botanical composition (%) of the germeable soil seed bank under three land management and soil types in the two grazing areas.

Grasses	Bigbend area[a]					Simunye area[a]				
	Land management (Stocking rate)			Soil type		Land management (Stocking rate)			Soil type	
	High[b]	Low	Medium	Litho	Verti	High	Low	Medium	Litho	Raw
Aristida stipitata								2.70	1.28	
Arundinella nepalensis	2.94			1.75				2.70		9.09
Brachiaria eruciformis	5.88			1.75	2.22					
Cenchrus ciliaris		20.0	3.39	6.88	8.11					
Chloris virgata								8.11	3.85	
Cymbopogon excavates		5.45			2.70					
Cynodon nlemfuensis	2.94	3.64		1.75	1.80					
Digitaria eriantha			1.69	1.59		13.3	65.4	13.5	24.2	40.1
Eleusine coracana			1.69	3.17		6.67			3.03	
Eragrostis superba	2.94			1.75	1.71					
Lolium perenne	5.88				4.44					
Melinis repens								2.70		9.09
Panicum deustem		7.28		1.85	2.70					
Panicum maximum	14.6	49.1	5.08	32.2	16.6	20.0		2.70	10.4	
Urochloa mosambicensis	29.4	1.82	3.39	14.1	6.67	6.67			3.03	
Forbs										
Alternanthera pungens			1.69	1.59						
Cenia turbinata								32.4	17.8	

Table 2. Contd.

Chenopodium album		5.45	1.69	5.56	0.85					
Cleome rubella						13.3			6.07	
Euphorbia helicoscopia	+		+							
Euphorbia peplus		+						+		
Flavis bidentis		5.46	44.1	1.59	24.1					
Gnaplalum Sp								2.07		9.09
Ind[1]			1.69	1.59						
Euphorbia sp	8.82		16.9	15.9	6.67		3.85			12.5
Ind[11(201)]								5.4	1.28	
Ind[2(51d)]		1.82	1.69		1.76					
Zaleye pentandra	2.94				2.22					
Ind[5(s140)]	2.94				2.22					
Ind[145]			15.3		7.69					
Ind[8]								2.70		
Corbichronica decumbens								2.70		
Smelter's bush	+									
Solanum nigrum							3.85		1.52	
Tail fleabane	+									
Xantium spinosum			1.69		0.85					
Shrubs/trees										
Siba rhombifolia	8.82			5.26	2.22			2.70	1.28	
Dichrostchys cinerea	11.8			5.26	4.44	20.0	15.4	8.11	13.2	10.0
Chromolaena odorata						20.0	11.5	10.8	11.7	10.4

[a] high = communal, low = government ranch, medium = game reserve, litho = Lithosol; verti = Vertisol; raw = Raw mineral soil, Ind = unidentified species, [b] + = <0.05%.

perennials and included *Cencrhus ciliaris* (Bigbend area), *Digitaria eriantha* (Simunye area), and *P. maximum* (in both areas) (Table 3). Few annual grass species, such as *Arundinella nepalensis*, *Brachiaria eruciformis*, *Eleusine coracana*, *Aristida stipitata* and *Melinis ripens* also formed the seed bank of the studied areas in varied proportions.

In Bigbend grazing area, highly desirable species had the greatest proportion in the low stocking rate (84.3%) followed by the moderate stocking rate (60%). In respect to soil type, lithosol had a greater proportion of highly desirable species (62.7%) compared to vertisol (32.5%). In contrast, desirable species had the greatest proportion (77.5%) at the high stocking rate and the lowest (15.5%) at low stocking rate. This plant group was more copious on the vertisol soil (Table 3). In Simunye grazing area, the low stocking rate had greatest frequency of highly desirable species followed by the high stocking rate. No desirable species was recorded in the low stocking rate. In the comparative soil types, raw mineral had the greatest and lowest proportions of highly desirable and desirable species, respectively. Less desirable species were rarely recorded in all the stocking rate levels of both grazing areas (Table 3).

Grass similarity between seed bank and above ground vegetation

In Bigbend grazing area, the mean Sorensen's similarity index comparison showed that the low stocking rate (45.7%) presented a higher 'above ground and seed bank' grass similarity than the high (30.3%) and medium (33.3%) stocking rate. Soil types presented little variation in similarity index (lithosl-35.9% and vertisol-29.6%).

In Simunye grazing area, Sorensen index showed the absence of similarity in the low stocking rate, while the values for the high (13.3%) and medium (12.1%) stocking rate revealed low similarity. The results in the raw mineral soil indicated the absence of similarity (Figure 2). In all the study sites, the number of grass species present in the above ground vegetation (Table 4) was considerably greater than that of the seed bank. However, few grass species (*A. stipitata*, *A. nepalensis* and *Lolium perenne*)

Table 3. Relative proportion of grasses (%) in the soil seed bank grass under three land management and soil types in the two grazing areas.

Species[C]	Bigbend					Simunye				
	Land management (Stocking rate)			Soil type		Land management (Stocking rate)			Soil type	
	High	Low	Medium	Litho	Verti	High	Low	Medium	Litho	Raw
Highly desirable(Decreasers)										
Cenchrus ciliaris		24.4	20.0	12.8	10.0					
Digitaria eriantha			10.0	4.17		28.6	100	41.7	33.3	86.9
Panicum maximum	22.7	59.9	30.0	45.7	22.5	42.9		8.33	6.67	
Desirable (Increasers IIa)										
Arundinella nepalensis	4.6			2.22				8.33		6.55
*Brachiaria eruciformis**	9.1			2.22	4.76					
Chloris virgata								25.0	20.0	
Cynodon nlemfuensis	4.6	4.44		2.22	2.22					
*Eleusin coracana**			20.0	8.34		14.3			6.67	
Eragrostis superba	4.55			2.22						
Lolium perenne	9.09				9.52					
Panicum deustem		8.82		2.22	3.33					
Urochloa mosambicensis	45.5	2.22	20.0	17.8	47.6	14.3			6.67	
Less desirable (Increasers IIc)										
*Aristida stipitata**								8.33	6.67	
Cymbopogon excavatus	+	+		0.09	1.21					
*Melinis repens**								8.33		6.55

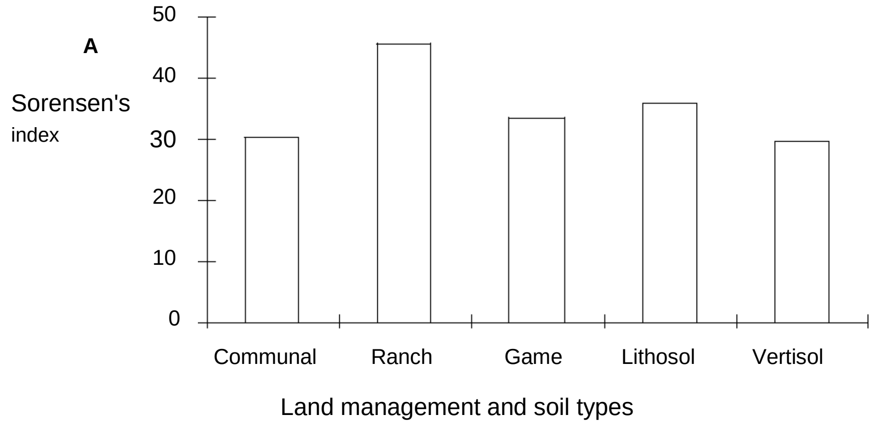
[c], *Annual species.

present in the seed bank of the two grazing areas were absent in the above ground vegetation

DISCUSSION

Seedling density

Assessment of seedling density of grasses in the seed banks of both grazing areas showed a significantly greater seedling density in the low stocking rates compared to the high or medium stocking rates. This suggests that differences in the past and present grazing pressure may be the primary cause of the observed variations. Solomon et al. (2008) reported in similar study areas that grazing at the low stocking area resulted in lower above ground grass cover than grazing at medium and high stocking rate. Consequently, this may reduce the production capacity of grasses and decreased seed densities in the seed bank confirming the observation made by Solomon et al. (2006) in the east African rangelands. Several studies in southern Africa and European grasslands have also reported the importance of increased grazing pressure on the reduction of the herbaceous seed bank size (O'Connor and Pickett, 1992; Bekker et al., 1997). In contrast, Meissner and Facelli (1999) conferred the insignificant effect of grazing on the seed bank germinable seed density and composition. In Simunye grazing area, the significantly lower seedling density of grass on the raw mineral than the lithosol soil was expected because the former is characterized by possessing outcrops with discontinuous soil cover and occasionally buried soil sandwiched between stone mantle and consolidated rock which might not favor abundant grass production. The overall results in the current study showed that the average total seedling densities (range 110 to 269 m^{-2}) were extremely lower than those reported by the previous studies (Meissner and Facelli (1999) (270 to 13,350 m^{-2}), Kinloch and Friedel (2005) (286 to 1403 m^{-2}), Solomon et al. (2006) (390 to 905 m^{-2}), Verćin et al. (2007) (3892 to 11,333 m^{-2}), but comparable to the result found in the semi-arid southern Africa savannas (Snyman, 2004) (58 to 350 m^{-2}). Several factors may contribute to the small seed bank size recorded in the current study. This includes rapid germination of dispersed seeds (Davy and Smith, 1998), high mortality of seeds (Ungar, 1978), and removal of seed



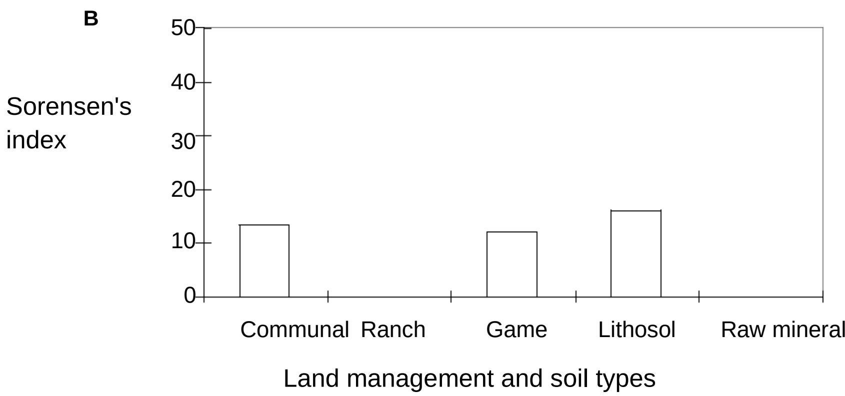


Figure 2. Similarity in grass flora between seed bank and above ground vegetation under three land management and soil types in Bigbend (A) and Simunye (B) grazing areas.

by wind, water and/or predation (Mayor et al., 2003). Regardless of the management systems, visual observation in the study areas attested to the presence of huge colonies of ants, and seed predation on the grass species which begins on the plant even prior to maturity and dispersion. This process could have a decisive influence on the seed production and seed bank as well as their germeability (Mayor et al., 2003). Low seed bank density can also be partly explained by the limited soil depth (30 mm) that was sampled in the current study. According to Bekker et al. (1998), a large proportion of herbaceous seeds remain within the depth of up to 50 mm, and thereafter, seed density sharply declines. Low seed production could also be due to a grazing event that may occur before seed production, while the time of soil sample collection could also impact the size of seed bank size.

Seed bank composition

The three land management systems and the two soil types under the two grazing areas were clearly distinguished by their species composition more than the seedling densities. Indeed, a few forb and grass species dominated the seed bank, and in most cases, the composition of the seed bank did not form a unique pattern of variation across the land management and soil types.

In the Bigbend grazing area, at least 75% of the total seed bank composition in the medium stocking rate was due to three annual forb species: *Flavis bidentis*, Ind 145 and *Euphorbia* sp. About 70% of the total seed bank in the low stocking rate was composed of two grass species: *P. maximum* and *C. ciliaris* that were also dominant in the above ground herbaceous layer. *Cenchrus ciliaris*, although common in the above ground vegetation in the high stocking area, was completely absent in the seed bank. In contrast, *P. maximum* was dominant (15%) in the seed bank but was relatively rare (2%) in the above ground herbaceous layer which suggests that only few individuals would have been needed to produce numerous persistent seeds that accumulated in the soil seed bank.

Table 4. Percentage frequency (%) of above ground grass species under three land management and soil types in the two grazing areas.

Grasses	Life[e] forms	Bigbend area					Simunye area				
		Land management			Soil type		Land management			Soil type	
		High	Low	Medium	Litho	Verti	High	Low	Medium	Litho	Raw
Aristida bipartite	P	3.98	0.21	2.90	4.66	0.06	3.59		5.75	3.55	2.68
Aristida Sciurus	P	3.70	0.34	0.42	1.20	1.77	2.39	1.75	3.13	2.33	2.52
Bothricloa insculpta	P	4.68	1.32	0.12	0.58	3.51	1.30		4.90	3.65	0.49
Bothriochloa radicans	P						0.27	0.11	1.45		1.22
Brachiara eruciformis	A	7.17	3.60	2.94	3.04	6.10	1.09			0.54	0.18
Brachiaria nigropedata	P								0.21		0.14
Cenchrus ciliaris	P	11.0	25.8	12.3	21.4	11.3	1.99	0.11	2.43	1.91	1.11
Chloris virgata	A	4.60	1.44	23.8	6.45	13.5	1.81		3.24	2.08	1.29
Cympopogon excavates	P		3.61		2.41		0.08	0.29	0.20	0.38	
Cynodon nlemfuensis	P		1.00			0.67					
Dactyloctenium aegypticum	A						1.88		3.98	3.17	0.73
Dactyloctenium austral	A								0.13		0.08
Digitaria longiflora	A						2.28	0.19		0.73	0.92
Digitaria scalarum	A	3.37	0.14	1.87	3.58		0.28				0.19
Digitaria sp	P							3.49		1.17	1.15
Digitaria velutina	A						1.52	0.46		0.73	0.59
Diplachne eleusine	P		1.23		0.82		3.01		2.32	0.17	3.39
Eleusine coracana	A								0.29		0.20
Enneapogon cenchroides	A		0.06			+			3.77	2.08	0.43
Enneapogon scoparius	P	0.88				0.59					
Eragrostis spp	P	0.24				0.16			0.43	0.28	
Eragrostis cilianensis	A	0.20	0.50		0.41	0.05					
Eragrostis lehmanniana	P							0.46			0.30
Eragrostis plana	A						0.31		0.47	0.21	0.32
Eragrostis pseudoxsclerantha	P			0.38	0.25						
Eragrostis rigidior	P								0.40	0.26	
Eragrostis rotifer	P	0.68	0.23		0.51	0.09	0.54		0.45	0.30	0.36
Eragrostis superb	P	3.90		3.57	4.98		2.52	2.71	1.56	3.89	0.64
Eustachys paspaloides	P			0.21	0.14		0.92	1.41		0.47	1.08
Fingerhuthia africana	P	1.32			0.88						
Helictotrichon sp	P	2.03		2.03	2.70						
Helictotrichon turgidulum	P		11.3	0.08	1.14	6.47					
Heteropogon contortus	P		0.98	0.13	0.65	0.09	2.43	16.84	6.11	5.42	11.5
Hyparrhenia cymbaria	P			0.79	0.53		0.84	4.08	0.12	0.70	2.65
Panicum coloratum	P	+									
Panicum deustum	P		0.21		0.14		20.4	15.7	11.9	8.4	23.6
Panicum dregeanum	P			4.98	0.37	2.95					
Panicum maximum	P	2.32	22.1	9.32	5.18	17.3	16.3	28.8	17.1	28.4	13.2
Panicum natalense	P							0.38			0.25
Panicum stapfianum	P	0.42			0.28						
Sehima galpinii	P		5.18		3.10	0.36	0.46			0.16	0.15
Setaria nigrirostris	P		0.39		0.26			0.11			0.08
Sorghum versicolor	A/P		0.13			0.08		0.31		0.21	
Sporobulus consimillis	P							0.44	0.15	0.29	0.10
Tragus berteronianus	A	11.7	3.86	3.60	11.6	1.19	6.16	0.13	11.84	7.95	4.12
Urochloa mosambicensis	P	33.5	10.6	28.4	21.6	26.6	15.4	14.4	6.59	16.2	8.00

[e-] P – Perennial, A- annual.

In Simunye grazing area, *Digitaria eriantha* was the dominant seed bank species although it was not recorded in the above ground vegetation. *U. mosambicensis* was abundant in the vegetation but rare in the seed bank. *Panicum deustum* was one of the dominant above ground species but completely absent in the seed bank. Similarly, *H. contortus* and *Tragus berteronianus* were recorded as common above ground species but were not present as seed bank species. Moreover, *Cenia turbinata*, an annual forb species, represented the most important species in the low stocking rate. Several studies have consistently reported that grazing changes the relative abundance of species in the seed bank as it does in the above ground vegetation (Bekker et al., 1997; Meissner and Facelli, 1999; Solomon et al., 2006). Kinloch and Friedel (2005) found that the size and composition of germinable seed bank in arid grazing lands of Australia were changed over continuous heavy grazing, but not when grazing was lighter. Forbs and woody plants in the present study were particularly more abundant in the seed bank of the medium and high stocking rate, respectively, which experienced a history of heavier grazing pressure than the low stocking area. Similarly, these species were reported to increase in rangelands subject to heavy grazing pressure and absence of fire (Distel and Bóo, 1995).

The relative seed bank dominance of *C. ciliaris* and *P. maximum* at low stocking rate and *U. mosambicensis* at high stocking rate (Bigbend area) and *D. eriantha* at low stocking rate (Simunye area) may indicate their ability to produce a high turnover of germinable seeds, while their small abundance in the other sites confers their low status and production capacity in the above ground vegetation, which in turn produced small amount of germinable seeds. On the other hand, in spite of their high abundance in the above ground vegetation, the small seed bank size of *P. maximum* and *U. mosambicensis* in Simunye grazing area suggests that their ability to form a persistent seed bank could also be affected by climatic and edaphic factors. The most abundant perennial forage grasses as found in this study have been cited as good forage species, highly preferred by cattle and only abundant under light grazing pressure (Solomon et al., 2006), but tend to disappear under continuous heavy grazing (Distel and Bóo, 1995). Similar to the finding of Solomon et al. (2006), the current study indicates that depending on the climate and soil factors, few valuable perennial grasses can form a good proportion of persistent seed bank in the savanna rangelands, and this could imply their potential recovery after disturbance. In contrast, Coffin and Lauenroth (1989) reported that seeds of perennial grasses are usually scarce in the soil and this would explain, in part, the slow recovery of disturbed perennial rangelands.

In all the study sites, nearly all annual grass species present in the above ground vegetation were completely absent in the seed bank, and this may be related to their low abundance in the above ground vegetation and/or the low production of viable seeds. Contrary to this, the observation made by Mayor et al. (2003) suggested that most annual grass species produce copious number of viable seeds ready to germinate and establish when adequate conditions occur. On the other hand, three annual species (*Aristida stipitata, Arundinella nepalensis* and *Lolium perenne*) found in the seed bank were completely absent in the above ground herbaceous layer. The low frequency of the former two species in the seed bank where mature above ground stands did not occur, indicated that seeds were dispersed through wind, water or animals from adjacent rangelands, while the later species may be introduced from the cultivated pasture close to the green house where the experiment was conducted. In total, the results of our seed bank study indicated that highly desirable species had greatest frequency in the low stocking rate management of both grazing areas.

Comparison of seed bank and corresponding vegetation

Generally, land management and soil types showed weak Sorensen's similarity (<50%) between the seed bank and corresponding vegetation in the two grazing areas. This is mainly reflected by the absence or poor representation of many above ground grass species in the seed bank. Seeds of 39 grass species present in the above ground vegetation were not found in the seed bank. When the two grazing areas are compared, Bigbend area showed relatively higher Sorensen's similarity than Simunye grazing area. In Bigbend area, Sorensen's similarity was greatest (45.7%) at the low stocking rate. On the other hand, few grass species were well represented in the seed bank, and this observation concurs with that of Bilquees and Darell (2001). The general poor reflection of the grass community in the seed bank in all land management and soil types suggests that the recovery of many grass species may be slow after disturbance. Several studies concluded that grass species typical of the established vegetation are under represented in the seed bank compared to their abundance in the vegetation (Solomon et al., 2006; Vércin et al., 2007). Undoubtly, poor representation is partly due to the inherent sampling limitations of seed bank studies. Since soil sampling is time consuming, and there is always limited space for green house experiments, the number of samples taken has always been small in comparison to the area covered. However, the area sampled in the current study (0.25 m^2 with 10 samples per transect) is greater than other studies (Mayor et al., 2003; Vércin et al., 2007). It also appears that Sorensen's similarity index can be affected by the diversity of seasonal conditions over sampling periods (Solomon et al., 2006) as well as the duration of the green house experiment. Unfortunately, soil sampling in this study was carried out only once over the dry period. Further, the duration of the green house experiment may not be enough to allow the germination of dormant seeds although conditions were set to favor the growth and germination requirements.

In other arid and semi-arid environments for which Sorensen's similarity was calculated, a wide range of value has been reported. Henderson et al. (1988) reported 88.9% for three sampling periods in less than 6 months, but appeared to have included only those species occurring at frequencies >5%. Solomon et al. (2006) reported similarity of 16 to 40% in Borana rangelands in southern Ethiopia, and Vércin et al. (2007) reported 35 to 47% in northern France alluvial meadows. It is important, however, to be cautious when comparing studies of soil seed banks because of the different methods used including sample size, depth, time and number of germination cycle (Snyman, 2004).

Conclusion

The study concluded that the differences in grass seedling densities among the land management systems were substantial, and the past and present grazing pressure may be the primary cause. Any disparity in the results concerning the soil types was attributed to the inherent soil nature which affects plant productivity and distribution. Land management and soil types also showed prominent differences in seed bank composition. Seed bank composition in the current study was a poor reflection of the above ground vegetation. Only few species made up the bulk of seed bank composition.

Grass species (*P. maximum, C. ciliaris, U. mosambicensis*), highly preferred by cattle, and showed signs of high frequency in the soil seed bank as an indicator of a high recovery from overgrazing. Other grass species widespread in the above ground vegetation were poorly represented or completely absent in the seed bank which suggests that the species are insufficient to restore degraded rangelands. Such species are more prone to extinction under continuous heavy utilization (high stocking) as experienced on the communal lands in particular, and hence are of concern for *in situ* conservation. This study was conducted over one season and with few replicates. Consequently, the results showed the risk of drawing certain conclusions in regard to grazing impacts, land management or soil type effects. Therefore, future experiments will be necessary to elucidate the results. Moreover, whilst spatial variation in seed bank appears to play a vital part in the maintenance of diversity in the herbaceous vegetation in semi-arid savannas, effects of temporal variations (seasonal variations) would deserve future investigation.

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