Spatio-temporal status of vegetation, soil and cattle serum minerals in degraded communal rangelands of the Eastern Cape, South Africa: Implications for livestock sustainability and management interventions

***Nangamso Mlaza*[1], *Solomon Tefera*[1*], *and Abubeker Hassen*[2]**

[1]*Livestock and Pasture Department, University of Fort Hare, Alice, South Africa*
[2]*Department of Animal and Wildlife Sciences, University of Pretoria, Pretoria, South Africa*
[*]*Correspondence author email, email: teferabeyenesolomon@yahoo.com*

ABSTRACT

In this study, we examined the forage, soil and cattle serum status in severely (SD) and less severely (LSD) degraded semi-arid rangelands of South Africa. Such evidence is essential to inform rangeland policies and interventions. In each degraded area, three villages were identified, and grazing sites near, at intermediate (middle) and far distance from homesteads were selected. Soil from LSD rangelands had generally greater macro and microelement levels than soil from SD rangelands. Soil elements (i.e. N,P, Mg and Cu) displayed variations at local scale (between villages or distance points from the homestead) depending on degradation conditions. Degradation level significantly influenced the local abundance of graces between the distance points from the homestead (*Themeda triandra* Forssk and *Aristida conjesta Roem. & Schult.*) between villages (*Digitaria. Eriantha steud.*, *Eragrostis. Curvula (schrad.)*, and Nees, *T. triandra*). Forage biomass was low (range:45-223kg ha^{-1}) in both degraded conditions. During the dry periods, cattle grazing SD rangelands had most serum minerals below a critical level, but pastures shwed Cu and N deficiencies only. We conclude that the low forage yield may limit animal mineral intake. On the other hand, the great abundance of perennial grasses with high forage values (60–76 %) indicates that degraded areas may be regenerated. In SD rangelands, complete mineral supplementation of cattle is recommended during the dry period.

Key words: forage value, macro-minerals, micro-minerals, native grasses, ruminants.

Introduction

Southern Africa has vast rangelands commonly used by small-scale farmers for livestock production (Nowers et al. 2013). In these rangelands, grasses contribute to the bulk of ruminant feed, and provide all essential minerals and other nutrients. However, even under good pasture conditions, intake native grasses and browses alone will not supply nutrients that meet the requirements for a mature animal, especially during dry periods and drought (Gwelo et al. 2015).

Large areas of communal grazing lands in the region are degraded, driven essentially by the effects of climate change, population growth and livestock overgrazing (Palmer and Bennet 2013; Kwaza et al. 2020). Rangeland degradation is often associated with a decline in the productivity and functionality of the vegetation and soil (Palmer and Bennett 2013; Dlamini et al. 2014; Kwaza et al. 2020)**.** These changes can adversely affect a range of ecosystem processes (Han et al. 2008), and services (Stringham and Krueger 2001; Briske 2017). In particular, shortages in forage supply and quality in degraded rangelands, and accompanying mineral-deficiencies retard the growth and development of animals due reduced intake, nutrient absorption, and lower immunity, which increase their susceptibility to contagious diseases (Ndebele et al. 2005; Radwińska and Żarczyńska 2014; Gwelo et al. 2015).

The Eastern Cape is the second largest province in South Africa. Livestock production in the province is mostly small scale, but have proven capable of supporting the livelihoods of resource-limited rural communities. However, similar to many parts of the southern African region, massive tracts of South African communal rangelands are degraded (Hoffman and Ashwell 2001: Kwaza et al. 2020). Gwelo et al. (2015) investigated the temporal and spatial scales of the pasture condition and mineral in the central Eastern Cape rangelands by taking various distances from homesteads comprising different topography. The authors concluded that biotic and abiotic factors may influence the distribution of soil and forage elements, but their effects may vary between the two areas. However, no comprehensive studies have collectively examined the forage, soil, and animal blood serum mineral status of cattle grazing degraded rangelands.

Understanding the status of the grazing resources and nutrient dynamics of the soil, forage and animals across degradation levels is essential for developing interventions for sustainable livestock production in degraded communal areas. The objectives of this study were 1) to investigate the composition and dry matter yield of grasses in selected degraded rangelands, and 2) to examine interrelations of soil, forage and cattle blood serum mineral concentrations.

Materials and Methods

Study areas

The study was carried out in communally grazed areas of Raymond Mhlaba local Municipality, located in the centre Eastern Cape, South Africa. The landscape is characterised by the presence of valleys, as well as gentle slopes, with a combination of undulating and flat lands ranging in altitude from 550–623 m above mean sea level (amsl). Long-term (200-2009) meteorological data from the nearby weather station (ID: 30284, University of Fort Hare; 32º47′24.8″ S 26º50′47.3″ E) showed that the climate is semi-arid, with long-term mean annual rainfall of 586 mm. The mean monthly temperature varied from 13 to 33 °C in summer (wet) and from 3 to 23 °C in winter (dry) season. Soils are heterogeneous and underlain by sedimentary sandstone and mudstone, with some igneous rock (doleritic dykes and sheets) (Mucina and Rutherford 2011). The vegetation has been described as Thornveld savanna, which consists of open to dense woody vegetation that is dominated by *Vachellia karroo* (Hayne) Banfi & Galasso.

Site selection and plot establishment

Few days before data collection, we had a focus group meeting with selected local farmers, extension officers and elders to provide information about the study, and discuss the status of the rangelands and the history of grazing. On other days, we drove around villages with selected extension officers and local elders (a total of eight) to conduct rapid visual rangeland assessment, and selected areas representing two degradation conditions, namely less severely (LSD) and severely degraded (SD) rangelands. We focused on these rangelands because these areas are critical to examine and give prior attention of management, restoration and fodder flow planning. Together with the selected informants, four additional individuals (a rangeland ecologist, an experienced field technicians and two students) also participated in visual assessment. We walked approximately 500 m, recorded the vegetation and the soil condition at 100 m intervals and gave ratings (poor to excellent). Based on the combined results, we described the two degraded rangelands as follows. The LSD rangeland was estimated to affect nearly 20–40% of the municipality (total area of approximately 6 300km^2). The grazing land was characterised by the occurrence of frequent small to moderated sized bare patches (50 cm to 1 m diameter), an abundance of short-lived perennial grass species, and a fair presence of strong perennial grass species with high grazing value. The area was encroached lightly by woody plants mainly *Vachellia karroo*. The presence of sheet erosion, pedestals, rifts and rills indicated moderate soil losses (Fig. 1a) and that confirmed the degradation status. The severely degraded (SD) rangeland covered nearly 10–40% of the total area of the Municipality, and consisted of large bare patches, an abundance of mature *V. karroo* plants, short-lived pereinnal and annual grass species. This rangeland was also characterized by rills and gullies with evidence of small-to medium-sized gravels on the soil surface (Figure 1b). Three communal grazing sites (villages) were selected in each degraded condition. The villages in the LSD rangeland were Nonzwakazi, Lenge and Gaga Skolweni with the villages in the SD rangeland, represented by Kwezana, KwaMemela and eSiginqini (Table1). The selection criteria of the villages in each degraded condition included access to roads, and uniformity in landscape, soil, vegetation distribution and livestock population. The estimated size of grazing lands in each village ranged from 4000 to 4500 ha in LSD, and 3400 to 3700 ha in SD rangelands. Data from livestock census during the study period indicated that estimated stocking rate for cattle and small stock differed between LSD and SD rangelands (Table 1). In each village, grazing land around a homestead was identified for vegetation and soil sampling, and divided into three main grazing sub-sites including near (0–100 m), middle (> 100–200 m), and far distance (> 300 m) sites from the homestead. At each sub-site, three 100 x 20 m plots were established in three directions to cover the whole grazing area, parallel with the direction of grazing activity as explained by the cattle owners.

Figure 1. An example of less severely degraded (LSD) (A) and severely degraded (SD) (B) rangelands in the study area.

Table 1. Altitude, coordinates and estimated stocking rate in the study areas based on one year (2017) household livestock inventory.

	Village	**Altitudes (m)**	**Coordinates**	**Stocking rate**	
				Cattle ha lsu^{-1}	**Goats ha lsu^{-1}**
LSD	Nonzwakazi	612	32º46′29.47″S, 26º48′13.61″E	4.2	2.8
	Lenge	617	32º46′32.35″S, 26º47′02.24″E	6.2	2.6
	Gaga Skolweni	623	32º45′48.84″S, 26º47′13.59″E	4.03	2.4
SD	Kwezana	592	32º48′06.07″S, 26º45′41.03″E	3.17	2.5
	Memela	562	32º47′54.06″S, 26º44′12.62″E	2.75	2.2
	Esiginqini	555	32º47′53.29″S, 26º42′21.96″E	5.17	2.3

Vegetation and soil sampling

Grass species composition was estimated from each plot using a step point method (Hardy and Walker 1991). The nearest plant and basal strikes were recorded from 250 point observations per plot. When the distance was more than 20 cm from the marked step point, it was recorded as a bare area. The point observations were placed at 2 m intervals and records were made over a length of the plot in five straight parallel lines with a distance of 4 m between them. Grasses were classified based on the succession and ecological information for the arid and semi-arid regions of South Africa (Tainton et al. 1980; Vorster 1982) as follows: (i) highly palatable species; those that develop on rangeland in good condition and decrease with high grazing pressure (decreaser), (ii) palatable species; those that appear in rangeland in good condition and increase with moderate grazing pressure (increaser IIa), and (iii) less palatable species; those that occur in rangeland in good condition and increase with severe utilization (increaser IIb and IIc). In addition, species were grouped into their life forms (annuals or perennials) and abundance (dominant, common or present). A vegetation survey to determine botanical composition was conducted during the growing season (end of November 2017–January 2018) when inflorescence development of grasses was optimal for identification. Many grasses were identified in the field using a field guide book (van Oudtshoorn 2014). Those grasses that were not identified were collected with full inflorescences and sent to South African National Biodiversity Institute (SANBI) Herbarium in Pretoria for identification.

In each plot, four 0.25 m^2 quadrants were randomly placed for above ground grass biomass sampling, giving a total of 12 per sub-site and 36 per communal area. Forages within each quadrant were harvested at stubble height, bulked and oven-dried for 48 h at 60 °C. Dried samples were weighed to measure the dry matter (DM) yield, and milled through a 1 mm sieve for chemical analysis. Soil samples to a depth of 20 cm were randomly collected from five locations per plot using soil auger. The five samples were bulked, thoroughly mixed, air-dried and passed through a 2 mm mesh screen for chemical analysis. Forage biomass and soil samples were collected towards the end of the growing (warm wet) season (March-April 2018).

Chemical analysis

Forage and soil samples were analysed for nitrogen (N), calcium (Ca) phosphorus (P), potassium (K), magnesium (Mg), copper (Cu), zinc (Zn) and manganese (Mn). Forage samples were also analysed for iron (Fe). Forage P, K, Ca, Mg, Cu, Zn, Mn and Fe were measured using the dry ashing macro- and micro-minerals method for feeds and plants (ALASA 1998). For soil samples, available P and extractable Ca, Mg and K were measured by inductively coupled plasma (ICP) analysis of extracts of soil with 1% citric acid (ALASA 1998). Soil Cu, Zn and Mn were determined using the same procedure in 0.02 M di-ammonium EDTA soil extracts. The Standard Kjeldahl method was used to analyse the total N contents of both forage (ALASA 1998) and soil samples (Bremner and Breitenbeck 1983).

Nguni cattle selection and blood sample collection

In each degraded rangeland, blood samples were collected for the wet (April) and winter (dry cold) (July 2018) seasons from a total of eight Nguni cattle (6 heifers and 2 steers) aged 2.5–3 years. The same animals were used across the two seasons. Great number of animals than the current study could have been used to increase representativeness, but it was not possible to obtain animals with the same gender or age. In addition, many farmers were not willing to give their animals for blood sampling. Blood samples were collected by restraining the cattle in a race to hold their heads in a head gate. An ethical clearance certificate was obtained from the University of Fort Hare Research Ethics Committee to obtain permission for the use of animals. The samples were collected into 10 ml vacutainer tubes using a tail bleeding method. Immediately after collection, the samples were transported in a portable cooler box with ice packs to the Pathcare Lab in East London, South Africa, to determine the mineral concentrations. Following collection, the serum was separated by centrifuging the samples at about 3 220 rpm for 20 min and frozen pending analysis. Calcium, Fe and Mg were determined by AU5800 using the colorimetric assay (colour reaction with Arsenazo) method (Beckman Coulter USA). Potassium was determined by the same instrument using an indirect ion-selective electrode (ISE) method (Goce et al. 2010). Inorganic P was measured by photometric UV (Pathcare Lab, East London, SA). Zinc was determined by mass spectroscopy using quantitative inductively coupled plasma-mass spectrometry. Copper was measured in a Varian AA using an atomic absorption Spectrometer. Iron concentration was measured from the deproteinised serum with 12 % trichloroacetic acid in a 1:1 dilution (Pathcare Lab, East London, SA).

Statistical Analysis

High spatial heterogeneity is always expected in rangeland studies when carried out at a large spatial scales. To reduce the spatial heterogeneity, the six villages were selected based on their location in similar environment, including vegetation, soil and topography as these were the major spatial variables. Therefore, the study followed a natural approximation of field experiment with two degradation conditions (LSD and SD), replicated three times (villages or blocks) with three distances from homestead, each replicated three times, being nested within each village. All data were analysed using the general linear model (GLM) procedure of SAS (2007).

For the vegetation and soil, the statistical model used was

$Y_{ijk} = \mu + R_i + V_j + D_k + (R \times V)_{ij} + (R \times D)_{ik}\ (R \times V \times D)ijk + \varepsilon_{ijk}$

where Y_{ijk} = dependent variable, μ = the overall mean, R_i = the effect of rangeland condition (two degradation levels), V_j = the effect of village (three villages per degradation level), D_k = the effect of distance, (three distance levels), ij = the interaction between degradation and village, ik = the interaction between degradation and distance, ijk = the interaction between degradation, village and distance, and ε_{ijk} = the random error. The relationship between soil and forage minerals in each degradation level was investigated using the PROC REGGR procedure of SAS (2007).

Table 2. pH, temperature, nitrogen, macro and micro-mineral status of soils (mean ± SE) sampled from less severely (LSD) and severely degraded (SD) rangelands (N = 27 per degradation level).

Elements	**LSD**	**SD**	**Critical level for pasture growth[1,2,3]**
N (%)	$0.2^{A} \pm 0.01$	$0.1^{B} \pm 0.01$	< 0.1
P (ppm)	$36.4^{A} \pm 2.3$	$28.3^{B} \pm 2.3$	< 10
K (Cmol/kg)	$0.40^{A} \pm 0.03$	$0.41^{A} \pm 0.03$	< 0.15
Ca (Cmol/kg)	$4.8^{A} \pm 0.5$	$5.1^{A} \pm 0.5$	< 0.35
Mg (Cmol/kg)	$2.5^{A} \pm 0.2$	$2.2^{B} \pm 0.2$	< 0.07
Zn (ppm)	$1.6^{A} \pm 0.3$	$1.1^{B} \pm 0.3$	2.5
Cu (ppm)	$4.2^{A} \pm 0.3$	$2.1^{B} \pm 0.3$	0.3
Mn (ppm)	$330.2^{A} \pm 23.7$	$231.4^{B} \pm 23.7$	2.0
Soil pH	$6.2^{A} \pm 0.08$	$6.1^{A} \pm 0.08$	
Soil temperature	$24.5^{A} \pm 0.11$	$24.7^{A} \pm 0.11$	

Means in the same row with different superscripts are significantly different ($P \leq 0.05$).

[1]Mtimuni (1982) and McDowell (1985) (macro-element critical levels for pasture and crop).

[2]Rhue and kidder (1983) (Cu and Zn critical levels for grasses).

[3]Katyal and Randhawa (1983) (Mn critical level for crops).

For blood samples, effect of sex was not included in the model because the preliminary data analysis showed no significant differences between the heifers and steers in all mineral concentrations. Therefore, the statistical model used was:

$$Y_{ij} = \mu + R_i + S_j + (R \times S)_{ij} + \varepsilon_{ij}$$

Where, R_i= effect of rangeland condition (two degradation levels), S_j = the effect of season (two seasons), ij = the interaction between degradation and season, and ε_{ij} = the random error.

Results

Soil pH, temperature and mineral status

Mean values for soil pH and temperature did not differ significantly between LSD and SD rangelands (Table 2). In the SD rangelands, distance from homesteads had a significant ($p < 0.01$) effect on soil pH being highest in the middle (mean: 6.7) and lowest in the sites near (mean: 5.9) the homestead. A similar trend was observed in the LSD rangelands, although the difference was not statistically significant. soil pH showed marked ($p < 0.001$) variations between villages within each degraded area, varying from 5.5–6.6 in SD, and from 5.7–6.4 in SD rangelands. Soil from LSD rangelands had greater ($p < 0.05$) concentrations of Mg, N, P, Cu, Mn and Zn than SD rangelands (Table 2). For some minerals, spatial variations between distance points from the homestead or between villages interacted with degradation condition (Table 3). For instance, in LSD rangelands, soil from the farthest site had greater ($p < 0.05$) N concentration (0.22%) than the middle and near (0.16%) points from the homestead, but in SD rangelands, there was no significant difference, though soil from the far site had slightly lower N (0.11%) compared to the middle and near (0.14%) sites. In LSD rangelands, soil from the farthest site had greater ($p < 0.01$) P concentration (67.7 ppm), followed by the middle (28.7 ppm) and the near (12.7 ppm) sites from the homestead. In SD rangelands, soil samples from the far sites had greater ($p < 0.01$) P concentration (32.1 ppm) than the middle (24.9 ppm) and near (27.8 ppm) sites. Soil N, Mg and Cu concentrations showed significant differences between villages in LSD rangelands (range: N, 0.15–0.27 %; Mg, 1.6–3.8 Cmol kg^{-1}; Cu, 3.3–5.9 ppm), but these variations were absent in SD rangelands (range: N, 0.11–0.14%; Mg, 2.1–2.5 Cmol kg^{-1}; Cu, 1.8–2.5 ppm).

Table 3. Analysis of forage and soil minerals between distance from homesteads (sites) and between villages within degraded rangelands. F = F ratio, *P* = probability value (*N* = 27 per degradation level).

	Dis		Dis x Deg		Vil		Vl x Deg	
Soil	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**
N	4.31	0.02	3.14	0.05	3.48	0.04	9.29	0.0005
P	8.61	0.02	0.70	0.05	1.17	0.31	0.94	0.39
K	0.20	0.82	2.31	0.11	0.11	0.89	0.8	0.10
Ca	0.86	0.43	0.03	0.97	0.81	0.45	0.05	0.61
Mg	0.31	0.73	0.37	0.69	4.31	0.02	6.23	0.004
Cu	0.06	0.19	0.82	0.06	4.08	0.02	7.69	0.001
Zn	1.05	0.36	1.09	0.34	1.78	0.18	2.83	0.07
Mn	0.03	0.97	0.43	0.65	2.37	0.10	2.37	0.11
Forage								
N	0.97	0.38	0.23	0.79	5.22	0.01	3.69	0.03
P	0.40	0.67	3.40	0.05	0.41	0.66	6.78	0.20
K	1.42	0.25	0.00	0.99	5.29	0.009	3.54	0.03
Ca	0.90	0.41	1.06	0.35	2.98	0.06	0.83	0.44
Mg	1.33	0.27	0.85	0.43	0.48	0.61	0.68	0.51
Fe	0.54	0.58	0.40	0.67	2.61	0.08	0.38	0.68
Cu	0.23	0.79	1.35	0.27	0.58	0.56	1.63	0.21
Zn	0.18	0.83	0.33	0.72	0.83	0.44	0.31	0.86
Mn	0.66	0.52	0.01	0.98	1.84	0.17	0.40	0.38

Dis-distance from homestead within village; Vil- village within degradation level; Deg-degradation level; significant difference is at $p \leq 0.05$.

Herbaceous layer

A total of 20 grasses were identified in the two degraded areas, of which 16 were long-lived perennials, three were short-lived perennial and one species was an annual (Table 4). In terms of palatability, 45% were highly palatable (HP), 25% were moderately palatable (MP), and 30% were less palatable (LP). In terms ecological grouping, 35% of the grass species were classified as decreasers, 5% as increaser I, 4 % as increaser II, 10% as increaser III and 5% as invader species. A total of six grass species were identified as commonly occurring species in both degradation areas, namely: *Aristida conjesta Roem*, *Cynodon dactylon (L) Pers*, *Digitaria eriantha steud*, *Eragrostis chloromelas (Schrad) Nees*, *Sporobolus fimbriatus (Nees ex Trin.) Nees* and *Themeda triandra* Forssk (Table 4).

Table 4. Life forms, palatability, ecological value and abundance (%) of grass species in severely and less severely degraded rangelands (N = 27 per degradation level).

Species	Life forms[2]	Palatability[3]	Ecological-value[4]	LSD[1]	SD[1]
Aristida conjesta	An	LP	IncII	C	C
Cynodon dactylon	SP	HP	IncII	C	C
Cymbopogon pospischilii	LLP	LP	IncI	C	R
Chloris gayana	SP	HP	De	+	R
Digitaria eriantha	LLP	HP	De	C	C
Eragrostis capensis	LLP	MP	IncII	R	R
Eragrostis chloromelas	LLP	MP	IncII	C	C
Eragrostis plana	LLP	LP	IncII	C	R
Eragrostis obtusa	SP	MP	IncII	R	R
Eustachys paspaloides	LLP	HP	De	-	+
Heteropogon contortus	LLP	MP	IncII	R	+
Hyparrhenia hirta	LLP	MP	IncI	R	R
Panicum maximum	LLP	HP	De	R	-
Panicum stapfianum	LLP	HP	De	-	+
Paspalum dilatatum	SP	HP	Inv	C	R
Melica decumbens	LLP	LP	IncIII	+	+
Microchloa caffra	LLP	LP	IncII	R	C
Sporobolus africanus	LLP	LP	IncIII	C	R
Sporobolus fimbriatus	LLP	HP	De	C	C
Themeda triandra	LLP	HP	De	C	C

[1]C, common (> 5–15%); R, rare (> 1–5 %) +, present (≤ 1 %); -, absent.

[2]An, annual; LLP, long-lived perennial; SP, short-lived perennial.

[3]HP, Highly palatable; MP, moderately palatable; LP, less palatable.

[4]De, decreaser; Inc, increaser; Inv, invader.

Table 5. Relative abundance (%) (mean ± SE) of common grass species, ecological and palatability groups in severely and less severely degraded rangelands ($N = 27$ per degradation level).

Grass species	**LSD[1]**	**SD[1]**
Aristida conjesta	$9^{A} \pm 1.4$	$6^{B} \pm 1.4$
Cynodon dactylon	$14^{A} \pm 1.6$	$10^{B} \pm 1.6$
Digitaria eriantha	$13^{A} \pm 1.4$	$6^{B} \pm 1.4$
Eragrostis chloromelas	$12^{A} \pm 2.3$	$6^{B} \pm 2.3$
Sporobolus fimbriatus	$6^{B} \pm 1.6$	$9^{A} \pm 1.6$
Themeda triandra	$14^{A} \pm 3.0$	$9^{B} \pm 3.0$
Ecological groups		
Decreasers	$46.3^{A} \pm 1.5$	$32.4^{B} \pm 1.5$
Increaser I	$1.3^{A} \pm 0.08$	$1.3^{A} \pm 0.1$
Increaser II	$38^{A} \pm 1.4$	$41^{A} \pm 1.4$
Increaser III	$6.2^{A} \pm 0.7$	$6.8^{A} \pm 0.7$
Invaders	$4.4^{A} \pm 0.3$	$2.4^{A} \pm 0.3$
Palatability groups		
Highly palatable	$59^{A} \pm 1.6$	$44^{B} \pm 1.6$
Moderately palatable	$17^{A} \pm 1.2$	$16^{A} \pm 1.2$
Less palatable	$20^{A} \pm 1.2$	$23^{A} \pm 1.2$
Virtually unpalatable (forbs)	$3^{B} \pm 0.8$	$12^{A} \pm 0.8$
Bare soil frequency	$2^{B} \pm 0.9$	$6.6^{A} \pm 4.0$

[1]LSD = less severely degraded; SD = severely degraded.

Means in the same row with different superscript are significantly different ($p \leq 0.05$).

Occurrence of common grass species and dry matter yield

All common grass species except *S. fimbriatus* were more ($p < 0.05$) abundant in the LSD than in the SD rangelands (Table 5). In terms of palatability and ecological groups, HP species and decreasers were more frequent ($p < 0.001$) in the LSD rangelands than in SD (Table 5). Degradation had also significant ($p < 0.05$) effect on grass DM yield with SD (76 kg ha^{-1}) having lower yield than LSD (193 kg ha^{-1}) rangelands (Fig. 2).

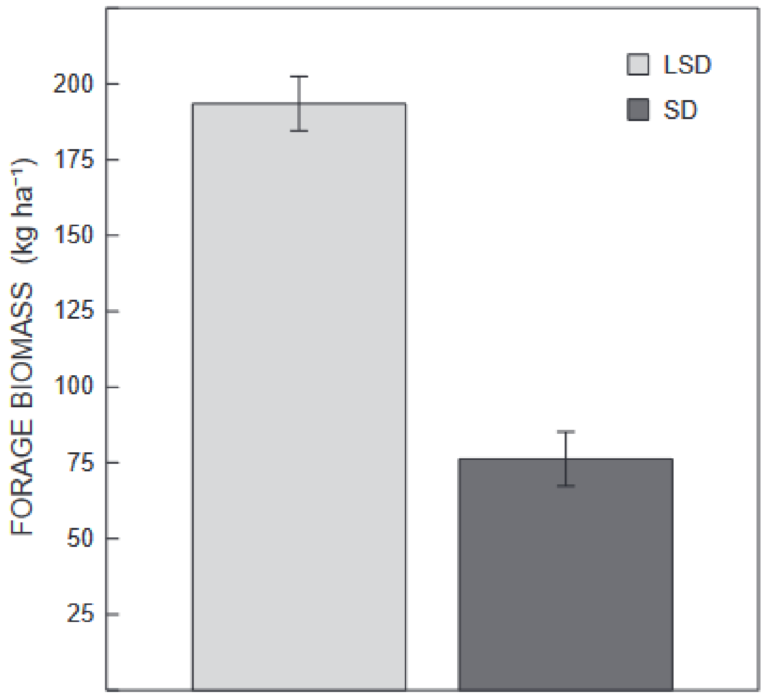

Figure 2. Mean forage biomass production (kg ha^{-1}) in severely degraded (SD) and less severely degraded (LSD) rangelands.

Degradation condition interacted significantly ($p < 0.05$) with distance from homestead to influenced the local variation in the abundance of *T. triandra* and *A. conjesta*. In LSD rangelands, *T. triandra* showed greater ($p < 0.01$) frequency at the far (27%) and lowest (9%) at the near site from the homestead. In the same rangelands, *A. conjesta* was more abundant ($p \leq 0.05$) in the middle (13%) than the near and farthest distance (8%) from the homestead. Similarly, trends in the local abundance of HP species group along distance points from the homestead was not the same to both degraded areas. In LSD rangelands, HP species occurred more abundantly ($p \leq 0.05$) in the far (63%) than the near (59%) or middle (54%) sites from homestead, whereas in SD rangelands, near sites to homestead were characterised by greater abundance of HP (49%) compared to the far and middle (41%) sites. In both degraded conditions, LP species had greatest abundance in the middle (24%) and lowest in the far (18 %) distance from the homestead. Of the ecological groups, only Increaser II species showed significant differences between distance points from homestead being higher in the middle or near sites (42%) than the far (35%) site from the homestead.

Degradation influenced ($p < 0.01$) the local distribution of *D. eriantha*, *E. curvula*, and *T. triandra* between villages. In SD rangelands, the aforementioned grasses varied significantly between village sites (range: 7–15%, 4–12% and 1–21%, respectively), but these variations were absent in the SD rangelands. The abundance of the remaining grass species, MP, and ecological species groups (except Increaser II and III) showed significant ($p < 0.05$) differences between villages within each degradation level (Table 6).

Table 6. Analysis of abundance (%) of common grass species, ecological and palatability groups between distance from homesteads (sites) and villages within degraded rangelands. *F* = F ratio, *P* = probability value (*N* = 27 per degradation level).

Grass species	**Dis**		**Dis x Deg**		**Vil**		**Vl x Deg**	
	F	***P***	***F***	***P***	***F***	***P***	***F***	***P***
Aristida conjesta	2.30	0.05	3.54	0.03	5.71	0.001	5.10	<0.01
Cynodon dactylon	0.81	0.45	0.36	0.69	7.91	<0.01	4.96	<0.01
Digitaria eriantha	1.41	0.26	2.06	0.14	5.08	0.002	5.01	<0.01
Eragrostis chloromelas	0.51	0.60	0.32	0.71	2.03	0.11	6.1	<0.01
Sporobolus fimbriatus	1.91	0.16	0.66	0.52	7.57	<0.01	5.3	<0.01
Themeda triandra	5.07	0.01	5.2	<0.01	6.79	<0.01	6.90	<0.01
Palatability								
Highly palatable	3.48	0.04	3.11	0.05	2.30	0.11	8.86	<0.001
Moderately palatable	0.31	0.73	2.04	1.44	3.74	0.03	2.47	0.09
Less palatable	4.29	0.02	0.35	0.71	0.01	0.99	3.41	0.04
Virtually unpalatable (forbs)	0.92	0.40	0.11	0.89	0.87	0.49	0.84	0.43
Ecological groups								
Decreasers	2.64	0.08	1.12	0.33	2.48	0.09	13.8	<0.001
Increaser I	2.31	0.11	3.00	0.06	8.97	0.001	1.36	0.27
Increaser II	5.32	0.01	0.14	0.86	0.75	0.45	5.64	<0.01
Increaser III	0.57	0.57	0.13	0.87	1.06	0.36	4.04	0.02
Invaders	1.02	0.37	0.11	0.89	3.07	0.05	6.05	<0.01
Bare soil frequency	0.39	0.67	0.50	0.60	3.2	0.02	1.1	0.40

Dis-distance from homestead within village; Vil- village within degradation level; Deg-degradation level; significant difference is at $p \leq 0.05$.

Table 7. Nitrogen, macro and micro mineral status of bulk forage (mean ± SE) sampled from severely degraded and less severely degraded rangelands (N = 27 per degradation level).

	LSD[1]	**SD[1]**	**SE**	**Recommended levels for individual livestock species[2, 3]**
N (g kg^{-1} DM)	11^{A}	11^{A}	0.4	< 11.2
P (g kg^{-1} DM)	1.5^{A}	1.4^{A}	0.1	1.2 – 4.8
K (g kg^{-1} DM)	9.1^{B}	11.0^{A}	0.4	5.0 – 11
Ca (g kg^{-1} DM)	3.2^{B}	4.1^{A}	0.1	1.9 – 8.2
Mg (g kg^{-1} DM)	1.0^{A}	1.0^{A}	0.2	1.0 – 2.5
Fe (ppm)	838^{A}	745^{A}	70.6	30 – 50
Cu (ppm)	3.6^{A}	3.6^{A}	0.20	6 – 13
Zn (ppm)	33.5^{A}	31.7^{B}	1.80	20 – 40
Mn (ppm)	109.6^{A}	87.4^{B}	9.30	20 – 40

Means in the same row with different superscript are significantly different ($p \leq 0.05$).

[1]LSD-less severely degraded; SD-severely degraded.

[2] Recommended mineral requirements for all classes of ruminants suggest by National Research Council (1996) and summarised by McDowell (1997).

[3]DM intake of livestock decreases as the N contents fall below 11.2 g kg^{-1} DM (Minson and Milford, 1967).

Forage mineral concentration

Forage (mixture of grass species sampled) K and Ca concentrations showed higher ($p \leq 0.05$) values in samples harvested from SD, whereas forage Zn and Mn had greater values for samples harvested from LSD rangelands (Table 7).

Forage N showed differences ($p < 0.01$) between villages in SD (range: 9.6–13 g kg^{-1} DM) and LSD (range: 10 – 12 g kg^{-1} DM) rangelands, while forage K showed significant differences between villages only in SD rangelands (range 8.0–13 g kg^{-1} DM). all forage minerals did not show significant difference between distance points from the homestead.

Table 8. Correlation coefficients (r^2) between soil and forage minerals for severely (27 samples) and less severely degraded rangelands in samples collected during late summer (N = 27 per degradation level)

	LSD		**SD**	
Elements	**r^2-value**	**P-value**	**r^2-value**	**P-value**
N	0.21	0.02	0.004	0.75
P	0.32	0.002	0.03	0.36
K	0.03	0.37	0.08	0.16
Ca	0.16	0.04	0.03	0.39
Mg	0.00004	0.99	0.002	0.80
Zn	0.23	0.01	0.05	0.25
Cu	0.30	0.003	0.003	0.78
Mn	0.028	0.40	0.23	0.01

Relationship between soil and forage nutrients

A summary of the correlation analysis between soil and forage samples is provided in Table 8. The results showed different patterns for the two levels of degradation. In LSD rangelands, there were strong ($p < 0.05$) relationships for N, P, Ca, Zn and Cu levels between the soil and forage samples. In SD rangelands, except for Mn, relationships were not significant ($p > 0.05$).

Cattle blood serum mineral status

Table 9 presents serum mineral concentrations of Nguni cattle that grazed SD and LSD rangelands during the wet and dry seasons. Results showed significant interaction effects of degradation x season. In summer, the concentrations of all serum minerals did not show($p >$ 0.05) significant difference between degradation conditions, though slightly lower K and Mg and higher Ca and P levels were found in the serum collected from LSD rangelands than SD (Table 9). In winter, however, all minerals had higher ($p < 0.05$) levels in cattle serum collected from LSD rangelands. Each degraded condition showed different seasonal characteristics for some serum minerals. For instance, serum K, Ca, Mg, P and Fe concentrations had higher ($p <$ 0.05) values in summer than winter season in SD rangelands, but these variations were absent in LSD rangelands. In both degraded rangelands, serum Cu and Zn were higher ($p < 0.05$) in summer than winter season.

	Macro minerals							
	K		Mg		Ca		P	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
SD	$2.27^{Bb*} \pm 0.45$	$4.54^{Aa} \pm 0.45$	$0.40^{Bb*} \pm 0.08$	$0.92^{Aa} \pm 0.08$	$1.12^{Bb*} \pm 0.21$	$2.33^{Aa} \pm 0.21$	$0.93^{Bb*} \pm 0.29$	$1.21^{aA} \pm 0.29$
LSD	$4.68^{Aa} \pm 0.45$	$4.35^{Aa} \pm 0.45$	$0.81^{Aa} \pm 0.08$	$0.86^{Aa} \pm 0.08$	$2.26^{Aa} \pm 0.21$	$2.38^{Aa} \pm 0.21$	$1.81^{Aa} \pm 0.29$	$1.68^{Aa} \pm 0.29$
Recommended level[1]	4.3 − 5.7		0.74 – 1.3		2.20 – 2.70		1.10 – 2.10	
	Micro minerals							
	Fe		Zn		Cu			
	Winter	Summer	Winter	Summer	Winter	Summer		
SD	$10.3^{Bb**} \pm 2.63$	$17.8^{Aa**} \pm 2.60$	$0.58^{bB*} \pm 0.15$	$1.42^{Aa} \pm 0.10$	$0.30^{Bb*} \pm 0.07$	$0.66^{Aa*} \pm 0.06$		
LSD	$19.9^{Aa**} \pm 2.63$	$19.1^{Aa**} \pm 2.60$	$0.96^{Ab} \pm 0.15$	$1.38^{Aa**} \pm 0.10$	$0.46^{Ab*} \pm 0.07$	$0.66^{Aa*} \pm 0.06$		
Recommended level[1]	1.30 – 2.50		0.7 – 1.3		0.7 – 1.6			

Table 9. Blood serum macro (mmol L^{-1}) and micro (ug/ml) mineral levels (mean ± SE) of Nguni cattle collected from severely and less severely degraded rangelands in the summer and winter seasons (*N* = 8 cattle per degradation level).

*Values are below the recommended level; **Values above the recommended level.

[1] Puls (1994); De Waal (1999).

Means in the same row with different lower-case superscripts show significant difference ($p \leq 0.05$) between seasons within degradation level.

Means in the same column with different upper-case superscripts show significant difference ($p < 0.05$) between degradation levels within season.

Discussion

Soil elements

The current study showed an overall decrease in most soil nutrient levels (except Ca and K) with increased degradation. Depleted plant cover and litter, the formation of a hard soil surface and leaching associated with degradation are likely to be the major causes of a decrease in soil nutrients (Snyman and du Preez 2005). The significant reduction of soil N in SD rangelands Supports similar results reported for degraded semi-arid thicket (Mills and Fey 2004; Lechmere-Oertel et al. 2005; Rutherford et al. 2014) and savannas biomes (Snyman and Du Preez 2005; Yonela 2017) in South Africa. Researchers such as Feller and Beare (1997) attributed a decrease in soil N with degradation to a significant decline in soil organic matter, which provides physical protection to the soil from erosion. Water erosion (surface runoff) could be relatively high in SD rangelands and hence could enhance removal of nutrients from the A horizon, including of soil N (Dlamini et al. 2014), although some researchers (Snyman and Du Preez 2005) have suggested that erosion may account a small proportion (< 3.5 %) of the total soil nutrients loss. Although this was not investigated, we anticipate that SD rangelands might have lower soil-water content than LSD rangelands, therefore a lower rate of decomposition organic of matter, and hence a lower amount of nutrients returned into the soil. The decrease in soil Mg with increased degradation agreed with the findings of Mills and Cowling (2010); Rutherford et al. (2014) from semi-arid thicket biome of South Africa. Furthermore, the insignificant change in soil Ca and K with increased degradation corresponds with the findings of Mills and Cowling (2010) from semi-arid South Africa. Other studies carried out in the savanna (Yonela 2017) and grassland (Dlamini et al. 2014) biomes reported that severe degradation reduced soil Ca and K concentrations by 67% and 56% respectively. The relatively low levels of soil P found in SD rangelands agreed with the findings of Yonela (2017), but was inconsistent with those of Lechmere-Oertel et al. (2005) who reported a greater value at severely degraded rangelands, and Rutherford et al. (2014) who reported absence of change.

Patchy differences in soil N and P with distance may be related to livestock concentration and distribution, which are likely to be altered by degradation. In LSD rangelands, these two key elements showed greater soil levels with an increase in distance from the homestead, whereas in SD rangelands, this trend was only observed for soil P level. In disturbance gradients, animals spend more time grazing and resting in places where forage resources are more accessible. In the current study, increased soil N and/or P in the farthest sites may be the results of i) transport of nutrients by cattle from the surrounding grazing sites; ii) local deposition of nutrients (via dung and urine), iii) leaf litter from leaf fall, stem flow and through leaf fall, and iv) nitrogen fixation by the abundant leguminous woody plants. Higher soil P levels in farthest grazing sites contradicts the findings of Gwelo et al. (2015), who reported greater soil P in the sites nearest to the homesteads.

Local variations in the concentrations of few soil elements (N, Mg and Cu) between village grazing sites were limited to LSD rangelands. The characteristic patchiness of certain soil nutrients necessary for plant growth and community establishment is normal in healthy and moderately degraded rangelands, but these characteristics may disappear as the state of rangelands deteriorate. Certainly, the identification of the key factors in spatial differences of soil elements and interaction effects merits further study. In SD rangelands, uniform depletion of plant cover, scattered distribution of animals to search for limited forage resources and widespread soil erosion may have decreased the heterogeneity of soil nutrients across village sites. The patchy characteristic of key soil nutrient distributions should be considered when planning restoration of degraded rangelands, at least for priority and immediate responses.

Localized nutrient-rich areas may form an important nutrient source for the restoration of plant communities and seed banks.

In all studied areas, soil P, Ca, K, Mg, Cu and Mn were generally above the required amounts for plant growth (Mtimuni 1982; Rhue and kidder; Katyal and Randhawa 1983; McDowell 1985; Tefera et al. 2010). Overabundance of soil nutrients, such as Mn is unhealthy for plant growth, and may threaten biodiversity. In the current study, Zn was deficient in most soils which was consistent with the results reported by Gwelo et al. (2015) for a similar environment. Low soil Zn and P are common in many southern African semi-arid rangelands (Ndebele et al. 2005; Nsinamwa et al. 2005; Tefera et al. 2010; Gwelo et al. 2015).

Herbaceous species composition and biomass

The abundances of some grass species, such as *D. eriantha, T. triandra, E. Curvula*, and *C. dactylon* decreased with increased in the level of degradation. Similarly, the abundance of decreasers and HP species, and forage biomass decreased with increased degradation. In contrast, the abundance of virtually unpalatable forbs and bare soil increased with degradation. The apparent decline of good forage grasses and increase in abundance of unpalatable forbs with degradation, might result from sustained heavier grazing pressure, coupled with poor soil moisture conditions, which prevail on SD rangelands relative to LSD (Rutherford et al. 2014). Densely tufted perennial species, such as *D. eriantha* and *T. triandra* were reported as common grass species in the central Eastern Cape communal rangelands (Magandana 2016; Yonela 2017; Siyabulela et al. 2020), in agreement with the present results, which showed they have a combined average frequency of 15–27 %. These grass species are the most important forage plants in the eastern (Tefera et al. 2007) and southern (Tefera 2013) African communal rangelands.

Variation in the abundance of some key grass species and functional groups with distance from the homestead or villages confirms the presence of floristic patchiness of herbaceous on small to moderate spatial scales, depending on degradation level. Long-term rainfall, soil (e.g. texture) and topographic heterogeneity within short distances may have an effect on patchiness at fine spatial scale. In addition, forage scarcity and uneven distribution in degraded or deteriorating rangelands may induce patch selection and overgrazing that contribute to heterogeneity in plant community species composition. The current findings supported the study of Hoffman and Cowling (1990), who reported small-scale vegetation heterogeneity, but contradicts Rutherford et al. (2014) who confirmed greater homogenization of species on small spatial scales in the degraded thicket savannas of South Africa. Characteristic patchiness of plant communities may adversely affect the forage nutrient intake by grazing animals, and ultimately their production, by altering duration of grazing, resting, and energy spent in search of feed.

Forage biomass did not show differences on small or moderate spatial scale, and is generally low in both degradation conditions, which is an issue of concern, that is likely to be caused by long-term heavy and continuous grazing. In addition, rainfall variability may be a determining factor. In the present study, forage biomass data was collected in March-April (2018). The rainfall in the preceding months of January (55 mm) and February (54 mm) was below the long-term average rainfall of 66 and 77 mm, respectively. In 2017, the rainfall during these months (90 and 73 mm, respectively) was far above the long-term averages or slightly below (Kwaza et al. 2020). Resource-limited rural people in communally managed rangelands depend on domestic herbivores to meet their socio-economic and cultural needs. The declining condition of the forage resource means reduced animal production, which leads to a loss in food security and rural income, to poverty and weakening social and cultural cohesion. If this trend of low biomass is not reversed, the ongoing practice of continuous and heavy grazing, may turn vast rangelands to denuded areas or desert lands in the medium term. Low grass biomass suggests low soil cover and great vulnerability of the soil to erosion and fragility of the ecosystem. On the other hand, the abundance of functional groups that comprise long-lived perennial species with high forage values (HP and MP species together) in LSD (76 %) and SD (60 %) rangelands suggests that the areas may be restored effectively. Livestock exclusion for some growing seasons may promote recovery (Kwaza et al. 2020) if combined with successful practices of soil water conservation. These practices may improve seed production and dispersal, germination and seedling establishment of the desirable species improving their recruitments, vigour and biomass production.

Spatial variations in forage minerals and relations to animal requirements

The inconsistent variations in the concentration forage elements with degradation suggests that forage quality may not reflect land degradation. Nevertheless, the anticipated low forage production in degraded areas is likely to reduce mineral intake limit herbivore production. Forage N or K are the only elements that showed local variations at moderate land scale between village sites.

All the grasses harvested from both degraded rangelands had amounts of P, K, Ca, Mg and Zn that were adequate to meet the needs of grazing animals, provided that availability and intake are not limiting. This may be a reflection of the forage botanical composition in which MP and HP grass species account for the major portion of the bulk forage. All forage samples harvested from both areas showed deficiency in Cu and N in several grazing sites. In addition, the reduced forage intake owing to low availability may worsen the deficits. Forage Cu and P deficiencies in native pastures have been reported for many African rangelands (Ndebele et al. 2005;

Beyene and Mlambo 2012; Gwelo et al. 2015). Forage Fe and Mn were above the normal requirements of grazing animals. High forage Fe level may be associated with soil contamination, which is common in heavily stocked grazing areas, such as in a communal system. Indeed, the excess forage Fe was not above the maximum tolerable level of 1000 ppm, and hence not high enough to cause toxicity in grazing cattle (NRC 1996; Gizachew et al. 2002). Forage Mn levels in both degraded rangelands was much higher than the recommended levels for grazing livestock (NRC 1996), but was considered below the maximum tolerable level of 2000 ppm (Tefera and Mlambo 2017).

Relationship between soil and plant nutrients

In LSD rangelands, significant positive correlations between several elements in forage and soil samples were established, but this was absent in SD rangelands. Most elements (N, P, Ca, Cu, Zn) had significantly lower levels in soils from the SD than the LSD rangelands. It is difficult to explain these trends, but the lower soil elements concentration (except Ca) in SD rangelands, coupled with foreseeable limited soil water and absorption might result in absence of significant correlations. Indeed, a large number of soil and forage samples from several heterogeneous sites and seasons would be needed to validate the accuracy of the current observation. The absence of relationships between all elements (except Mn) in the soil and forage samples is not consistent with the findings of other studies carried out in African rangelands (Gizachew and Smit 2012; Beyene and Mlambo 2012; Gwelo et al. 2015). The slightly low N, high Ca and Mn soil concentrations were reflected in the corresponding forage samples harvested, whereas the high soil Cu level recorded in the soil was below the critical levels in the forage samples (Table 6).

Spatio-temporal variations in mineral status of Nguni cattle blood serum

Drastic decrease of several serum minerals in animals that graze degraded rangelands during the dry season may indicate the changes in the forage mineral contents within seasons. In the current study, the mineral status in the dry season was not determined. Serum samples collected during summer showed optimal K, Ca, Mg, P and Zn concentrations in both types of degraded rangelands. All serum samples collected during winter from SD rangelands had a mineral status (except for Fe) below the critical levels. This may be related to the low quality and quantity of nutrient intake. Serum Fe and Cu were respectively above and below the minimum critical values and reflect concentrations in the grazing pastures. High Fe intake by animals may worsen the limited pasture Cu availability, particularly when the S concentrations in the pasture is high (Gizachew et al. 2002). However, in the current study forage S was not determined. A high Fe intake has been associated with the reduction of liver and plasma Cu concentration. Copper deficiency can lead to low growth rates and change the texture and colour of hair in cattle (Phillippoo et al. 1987; Gizachew et al. 2002). Under these circumstances, Cu supplementation may be recommended throughout the year in degraded rangelands.

Conclusion

This study observed an overall decrease in soil mineral concentrations with degradation, except soil Ca and K levels. Patchy distribution of soil N and P in grazing lands around the homestead may be altered by degradation. All common grass species, except *S. fimbriatus*, decreasers and HP groups, had greater abundance in LSD rangelands than SD rangelands. The current results also highlighted that degradation caused patchiness in the composition of herbaceous vegetation on small or moderate spatial scales. Forage biomass was low in both degradation conditions, which is of great concern. Low forage production may lead to reduced animal production and loss in food security, rural income, poverty and social or cultural cohesion for communal farmers. On the other hand, the great abundance of perennial grasses with high forage values indicates that areas may be restored successfully. Forage mineral concentration was not affected by degradation, but the low pasture biomass may reduce mineral intake by grazing ruminants. Based on our study, we recommend, rangeland restoration and supplementation programmes as urgent research priorities and strategies to sustain rangeland resources and animal production. In SD rangelands in particular, complete mineral supplementation of cattle is recommended for the dry period. We also recommend studies to quantify levels of supplementation needed based on the mineral status of the animal serum and forages.

Acknowledgement

We express our appreciation to communal elders and people of the study areas for their active participation and willingness to use their grazing camps and animals.

Funding

This publication is an output from a research project funded by the Govan Mbeki Research and Development Center of the University of Fort Hare and National Research Foundation of South Africa.

References

ALASA (Agric Laboratory Association of Southern Africa), 1998. Handbook of feeds and plant analysis. Palic D, Classens AS, Collier J, Look A, Hattingh D (eds). Pretoria: ALASA.

Beyene, S.T., Mlambo, V., 2012. Botanical and chemical composition of common grass species around dip-tank areas in semi-arid communal rangelands of Swaziland. Tropical & Subtropical Agroecosystems 15, 143–142.

Bremner, J.M., Breitenbeck, G.A., 1983. A simple method for determination of ammonium in semi–micro Kjedahl analysis of soil and plant material using a block digester. Communications in Soil Sciences & Plant Analysis 14, 905–913.

Briske, D.D., 2017. Rangeland Systems. Processes, management and challenges. Briske DD (Ed). Springer, USA

Dlamini, P., Chivenge, P., Manson, A., Chaplot, V., 2014. Land degradation impact on soil organic carbon and nitrogen stocks of sub-tropical humid grasslands in South Africa. Geoderma 235, 372−381. doi: 10.1016/j.geoderma.2014.07.016

Feller, C., Beare, M.H., 1997. Physical control of soil organic matter dynamics in the tropics. Geoderma 79, 69–116**.**

Gizachew, L., Hirpha, A., Jalata, F., Smith, G.N., 2002. Mineral element status of soils, native pastures and cattle blood serum in the mid-altitude of western Ethiopia. African Journal of Range & Forage Science 19, 147−155.

Gizachew, L., Smit, G.N., 2012. The status and importance of crude protein and macro minerals in native pastures growing on vertisols of the central highlands of Ethiopia. Journal of Environmental Management 93, 177−184.

Dimeski G, Badrick T, John AS. 2010. Ion Selective Electrodes (ISEs) and interferences--a review. Clinica Chimica Acta 411: 309−317. https://doi.org/10.1016/j.cca.2009.12.005.

Gwelo, A.F., Tefera, S.B., Muchenje, V., 2015. Temporal and spatial dynamics of minerals of forage, soil, and cattle blood serum in two semi-arid savannas of South Africa. African Journal of Range and Forage Science 32, 279–287.

Han JG, Zhang YJ, Wang CJ, Bai WM, Wang YR, Han GD, Li LH. 2008. Rangeland degradation and restoration management in China. The Rangeland Journal 30: 233−239. https://doi. org/10.1071/RJ08009

Hardy, M.B., Walker, L.S., 1991. Determining sample size for assessing species composition in grassland. Journal of the Grassland Society of Southern Africa 8, 70–73.

Hoffman, M.T., Cowling, R.M., 1990. Desertification in the lower Sundays River Valley, South Africa. Journal of Arid Environments 19, 105–117.

Hoffman, M.T., Ashwell, A., 2001. Nature Divided, Land degradation in South Africa. University of Cape Town press, Cape Town, 1– 68.

Katyal, J. C., Randhawa, N.S., 1983. Micronutrients. FAO Fertilizer and Plant Nutrition Bulletin No. 7. FAO, Rome.

Kwaza A., Tefera S.B., Mlambo V, Mopipi K., 2020. Short-term grazing exclusion impacts using brush packs on soil and grass layers in degraded communal rangelands of semi-arid South

Africa and implications for restoration and pasture utilization. Tropical Grasslands-Forrajes Tropicales 8 (3), 220–233.

Lechmere-Oertel, R.G., Cowling, R.M., Kerley, G.I.H., 2005. Landscape dysfunction and reduced spatial heterogeneity in soil resources and fertility in semi-arid succulent thicket, South Africa. Austral Ecology 30, 615–624.

Magandana, T.P., 2016. Effect of acacia karoo encroachment on grass production in the semi-arid savannas of the Eastern Cape, South Africa: MSc Agriculture (Pasture Science) thesis. University of Fort Hare, South Africa.

McDowell, L. R., 1985. Nutrition of grazing ruminants in warm climates. Orlando: Academic Press.

Mills, A., Fey, M., 2004. Transformation of thicket to savanna reduces soil quality in the Eastern Cape, South Africa. Plant & Soil 265, 153–163.

Mills, A.J., Cowling, R.M., 2010. Below-ground carbon stocks in intact and transformed subtropical thicket landscapes in semi-arid South Africa. Journal of Arid Environments 74, 93–100, DOI: 10.1016/j. jaridenv.2009.07.002.

Mtimuni, J.P., 1982. Identification of mineral deficiencies in soil, plant and animal tissues as constraints to cattle production in Malawi: PhD thesis, University of Florida, USA.

Mucina, L., Rutherford, M.C., (eds). Reprint., 2011. The vegetation of South Africa, Lesotho and Swaziland. *Strelizia* 19. South African National Biodiversity Institute, Pretoria.

National Research Council., 1996. Nutrient requirements for beef cattle. 7th edn. National Academy Press, Washington, DC, USA.

Ndebele, N., Mtumuni, J.P., Mpofu, I.D.T., Makuza, S., Mumba, P., 2005. The status of selected minerals in soil, forage and beef cattle tissues in a semi-arid region of Zimbabwe. Tropical Animal Health & Production 37, 381–393.

Nowers, C.B., Nombula, L.M., Welgemoed, J., 2013. Reproduction and production potential of communal cattle on sourveld in the Eastern Cape, South Africa. Applied Animal Husbandry and Rural Development 6, 48 − 54.

Palmer, A.R., Bennett, J.E., 2013. Degradation of communal rangelands in South Africa, towards an improved understanding to inform policy. Journal of Range and Forage Science 30, 57 – 63.

Phillippoo, M., Humphries, W.R., Garthwaite, P.H., 1987. The effect of dietary molybdenum, and iron on copper status and growth in cattle. Journal of Agricultural Science 109, 315–320.

Radwińska J, Żarczyńska K., 2014. Effects of mineral deficiency on the health of young ruminants. Journal of Elementology 915–928

Rhue, R.D., Kidder, G., 1983. Analytical procedures used by the IFAS extension soil laboratory and the interpretation of results. Gainesville: Soil Science Department, University of Florida, USA.

Rutherford, M.C., Powrie, L.W., Husted, L.B., 2014. Herbivore-driven land degradation: consequences for plant diversity and soil in arid subtropical thicket in South-eastern Africa. Land Degradation & Development 25, 541-553.

SAS Institute. 2007. User's guide: statistics, SAS version 9.1.3. Cary: SAS Institute.

Siyabulela, S., Tefera, S., Wakindiki, I.S., Keletso, M., 2020. Comparison of grass and soil conditions around water points in different land use systems in semiarid South African rangelands and implications for management and current rangeland paradigms. Arid Land Research & Management 34, 207–230. doi: 10.1080/15324982.2019.1670279.

Snyman, H.A., du Preez, C.C., 2005. Rangeland degradation in a semi-arid South Africa-II: influence on soil quality. Journal of Arid Environments 60, 483–507.

Stringham, T.K., Krueger, W., 2001. Application of non-equilibrium ecology to rangeland riparian zones. Journal of Range Management 54, 210−217.

Tainton, N.M., Edwards, P.J., Mentis, M.T., 1980. A revised method for assessing veld condition. Proceedings of the Grassland Society of Southern Africa 15, 37–42.

Tefera, S.B., Snyman, H.A. Smith, G.N., 2007**.** Rangeland dynamics in South Ethiopia: Botanic composition of grasses and soil characteristics in relation to land-use and distance from water in semi-arid Borana rangelands. Journal of Environmental Management 85, 429−442.

Tefera, S., Dlamini, B., Dlamini, A.M., 2010. Soil nutrients and grass species structure in relation to land management systems and soil classes in the semi-arid low veld rangelands. Journal of Arid Environments 74, 675−684.

Tefera, S., 2013. Rangeland degradation in semi-arid Swaziland: effects of dip-tanks on herbaceous vegetation and soil properties. African Journal of Range and Forage Science 30, 127−140.

Tefera, S., Mlambo, V., 2017. Macro and trace elements of 26 browse species growing in semi-arid grazing lands of Eastern Cape, South Africa. African Journal of Range & Forage Science 34, 209–217.

van Oudtshoorn FP. 2014. Guide to grasses of South Africa. Pretoria: Briza Publications

Vorster, M., 1982. The development of the ecological index method for assessing veld condition in the Karoo. Proceedings of the Grassland Society of Southern Africa 17, 84–89.

Yonela, M., 2017**.** The impact of rangeland degradation on vegetation cover and soil quality in the semi-arid communal rangelands of the Eastern Cape Province South Africa: MSc Agriculture (Pasture Science) thesis. University of Fort Hare, South Africa.