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Research Paper

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

Exclusión en el corto plazo de los impactos del pastoreo en la vegetación graminífera y el suelo y sus implicaciones en la rehabilitación y utilización de pasturas de uso comunal degradadas en una región semi-árida de Sudáfrica

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Abstract

Brush packs from very thorny tree branches were used to simulate grazing exclusions to measure differences in herbaceous vegetation and soil characteristics over 2 years on small ungrazed plots and large continuously grazed communal rangelands on 3 semi-arid soil types [shallow, red stony ground (SRSG); shallow, dark sandy loam (SDSL); and deep, dark clay-loam (DCL)]. Pasture presentation yields within exclusions exceeded those on continuously grazed areas for all soil types by: 98% (SRSG), 128% (SDSL) and 152% (DCL). Herbage samples harvested from the exclusions contained higher acid detergent fiber ($P \leq 0.001$) and acid detergent lignin ($P < 0.05$) concentrations than those from the grazed areas. In SRSG and SDSL soils, herbage samples harvested from the exclusions were deficient in phosphorus (P) for all livestock species. Depending on soil type(s), soil magnesium, organic carbon, nitrogen, P and manganese concentrations were significantly higher within exclusions than in continuously grazed areas ($P \leq 0.05$). Any response from nutrients supplied by leaf drop from the brush packs could not be separated from response due to absence of grazing, and this deserves further investigation. Our results indicate that grazing exclusion for short periods (2 years) on these semi-arid rangelands allowed pastures to produce significant growth, demonstrating that pastures were still productive. Our experiences highlighted the difficulties in erecting and retaining conventional fences to exclude livestock from given areas because of theft. Grazing immediately after vegetation recovery may necessitate judicious nutritional intervention with protein, energy and mineral supplementation to get effective utilization of the available forage.

Keywords: Exclusion; grass biomass; herbage; land degradation; organic carbon; pasture composition.

Resumen

En un estudio de restauración de pastizales nativos degradados, realizado en la provincia de Eastern Cape, Sudáfrica, se usaron ramas ('brush pack') de un árbol muy espinoso para cubrir el suelo en parcelas pequeñas y así protegerlas del pastoreo. Durante 2 años se compararon la vegetación y las características del suelo en estas áreas protegidas con las de las áreas de uso comunal adyacentes y sometidas a pastoreo continuo. El estudio fue realizado en 3 tipos de suelos semiáridos: rojo, pedregoso, poco profundo (SRSG); franco arenoso oscuro poco profundo (SDSL); y franco arcilloso oscuro y profundo (DCL). Las producciones de las gramíneas dentro de las exclusiones fueron más altas que las de las áreas de pastoreo continuo adyacentes para todos los tipos de suelo, así: 98% (SRSG), 128% (SDSL) y 152% (DCL). El forraje muestreado dentro de las exclusiones presentó concentraciones más altas de fibra detergente ácido ($P \leq 0.001$) y lignina detergente ácido ($P < 0.05$) que las de las áreas de pastoreo adyacentes. En los suelos SRSG y SDSL, el forraje

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cosechado dentro de las exclusiones mostró deficiencia en fósforo (P) para todo tipo de ganado. También, dependiendo del tipo de suelo, las concentraciones de magnesio, carbono orgánico, nitrógeno, P y manganeso en el suelo fueron significativamente más altas dentro de las exclusiones que en las áreas de pastoreo continuo ($P \leq 0.05$). No fue posible separar el efecto de la contribución de las hojas caídas de los 'brush packs' en los nutrientes del suelo del efecto de la ausencia de pastoreo; esto requiere una mayor investigación. Los resultados indican que la exclusión del pastoreo por un período corto (2 años) en estas sabanas semiáridas permite una producción significativa de los pastos. Las experiencias también mostraron las dificultades para instalar y mantener, debido al robo de los materiales, cercas convencionales para proteger determinadas áreas del pastoreo. El pastoreo inmediatamente después de la recuperación de la vegetación puede requerir una suplementación nutricional del ganado con proteínas, energía y minerales para obtener una utilización eficaz del forraje disponible.

Palabras clave: Biomasa graminífera, composición de pastura, carbono orgánico, degradación de tierra, encierro, forraje.

Introduction

Rangelands cover around 41% of the terrestrial area of the Earth ([Middleton et al. 2011](#)) and about 43% of the African land surface ([Hoffman and Vogel 2008](#)). If managed properly, rangelands can store enormous amounts of terrestrial carbon (C) stocks. Grazing by livestock is the major land use throughout arid and semi-arid African rangelands with vast areas under communal or public land ownership and without planned grazing management or land rehabilitation practices in place. In these areas, over-grazing, trampling by livestock, soil erosion and climate variation have been reported ([UNCED 1992](#)) as the major causes of land degradation of more than two-thirds of the rangelands.

In southern Africa, semi-arid communal rangelands contain diverse flora and fauna communities on which small-scale livestock holders depend for their livelihoods. Farmers graze mixed livestock species on grazing lands continuously without applying formal grazing land management. Everyone who owns livestock has equal access to resources without temporal or spatial constraints, so vast rangelands have become ecologically fragile, deteriorated or degraded, a situation which is untenable in the long term. Globally, grazing exclusion for certain periods has improved the sustainability of rangelands or restored deteriorated rangelands ([Wang et al. 2016](#); [Qasim et al. 2017](#)) by effectively enhancing grass regrowth and associated ecosystem functions, so may be of benefit in southern Africa.

In the region, while the effects of animal grazing and management practices on grass and soil layers have been well documented ([Nsinamwa et al. 2005](#); [Tefera et al. 2010](#); [Siyabulela et al. 2020](#)), the impacts of short-term grazing deferment on areas normally subject to unrestricted grazing have been poorly documented. Understanding the impacts of grazing deferment on communally used rangelands is vital if these are to

continue to provide economic, socio-cultural and conservation values to the resource-limited communal people.

Ecological indicators, e.g. herbaceous vegetation and soil fertility, are used to measure the efficacy of restoration efforts on ecosystem processes ([Yaynesht et al. 2009](#); [Medina-Roldán et al. 2012](#); [Feyisa et al. 2017](#)). Grass species composition and biomass are the major indicators of rangeland condition and measure of recovery rate, because they provide estimates of changes in grazing capacity and direct feed intake by grazing animals. Herbaceous biomass protects the soil, reduces erosion and enhances nutrient cycling plus efficient soil-water management. Depletion in herbaceous biomass is an early sign of rangeland deterioration before other symptoms emerge, such as shift in species composition, decrease in basal cover and increase in bare soil, as well as woody encroachment. Therefore, any remedial measures to restore herbaceous biomass will help stop development of the aforementioned signs that are more costly to reverse. Concentrations of nutrients in herbage are important indicators of rangeland condition because over-grazing can reduce forage quality, and nutrient flow is critical to animal production. Such information should assist in designing a systematic fodder production/utilization and supplementation program to sustain adequate growth and reproduction of animals in disturbed and restored grazing lands. Unfortunately, no previous grazing exclusion studies have documented effects on the quality of grazeable herbage.

Many ecological studies have also shown soil nutrient levels and their availability to be indicators of rangeland condition. Knowledge of soil fertility trends in different soil types is essential to predict impacts of disturbance and rates of ecosystem recovery in both time and space. In rangeland ecosystems, the majority of nutrients taken up from the soil by plants arise from nutrient cycling by plants rather than from parent material per se ([Charley and Cowling 1968](#)). Factors affecting production and

decomposition of plant material therefore influence nutrient turnover and cycling and, hence, primary forage production. Soil organic carbon (OC) is important because it is vital for maintenance of ecosystem structure and functions (Post and Kwon 2000), by controlling the activity and population of soil micro-organisms directly by supplying C, energy and nutrients and indirectly by controlling soil physical properties, such as aggregate stability, structure, infiltration rate and water availability (Post and Kwon 2000; Dilly 2005), which are critical to soil health and vegetation growth.

The current study sought to document presentation yields and composition of herbaceous vegetation and soil characteristics on areas restricted from grazing using brush packs compared with open-grazed areas in a semi-arid area of South Africa over a 2-year period. The enclosures were established adjacent to open grazed lands in 6 communal areas located on 3 soil types. We tested the hypothesis that short-term grazing deferment of degraded communal rangelands would improve presentation yields and quality of forage as well as soil fertility.

Materials and Methods

Study area

The study was conducted in the savanna of the Eastern Cape province of South Africa (Figure 1). The province comprises the second-largest land mass in the country, making up 13.9% of the total area, and a human population of over 8.5 million (Statistics of South Africa 2011). Vast rangelands in the province are used communally by small-scale livestock holders to raise mixed animal species. The study area is undulating rather than flat and ranges in elevation from 475 to 550 masl. Climate is semi-arid with mean annual rainfall of 586 mm, while mean monthly temperature varies from 13 to 33 °C in summer (wet) and from 3 to 23 °C in winter (dry). The major geology in the study area is homogeneous, dominated by mudstones with subordinate sandstones of the Adelaide subgroup. The vegetation type is Bisho Thornveld and is dominated by a number of grass, tree and shrub species (Mucina and Rutherford 2006).

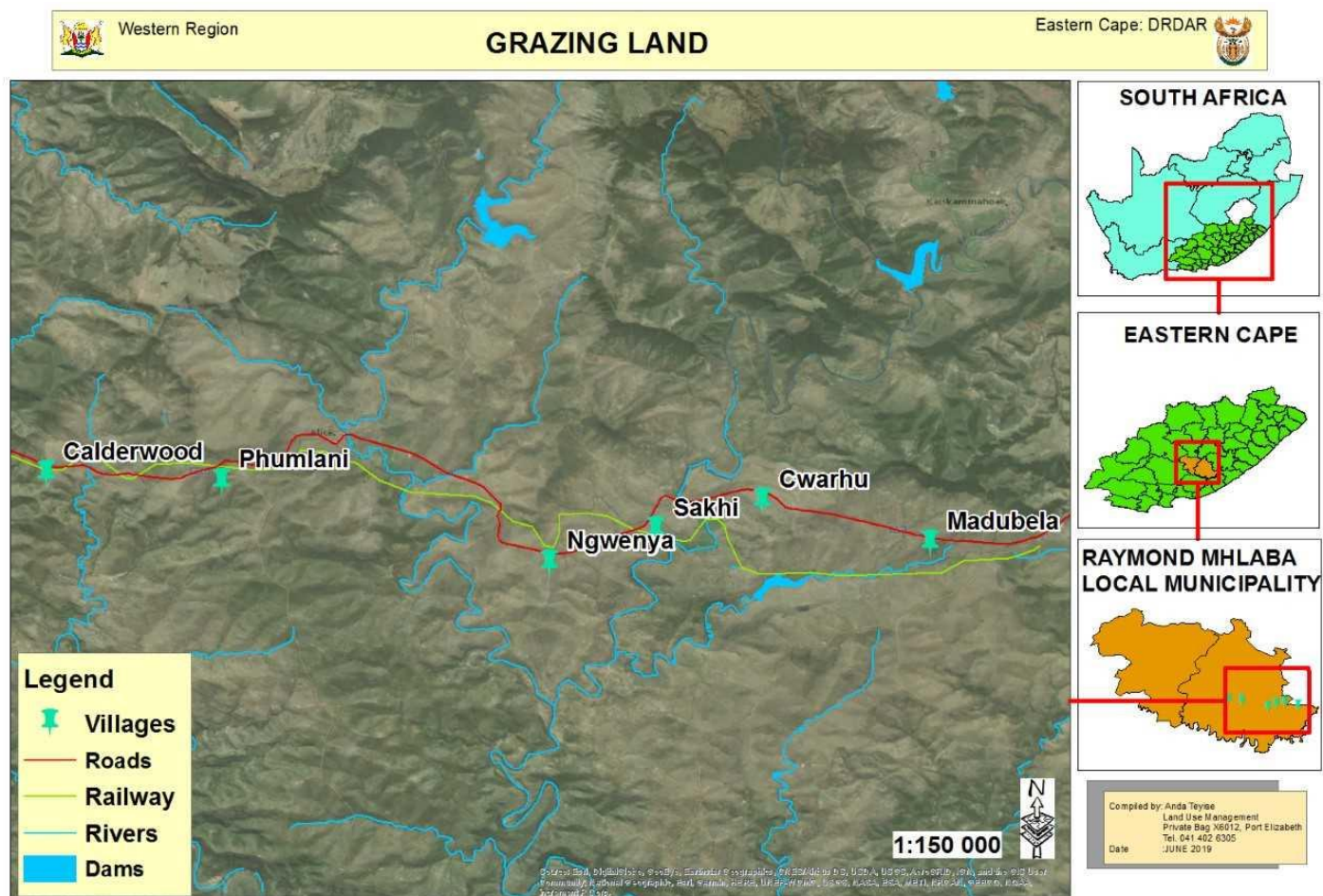


Figure 1. Map of the study area depicting the six communal villages where the study was conducted.

Site selection

Six communal grazing areas distributed along the 80-km-long regional main road from Fort Beaufort to King William's Town were purposely selected for this study because: 1) they show advancing rangeland deterioration and clear signs of degradation; 2) they vary in soil type, and grazing or land-use history; and 3) there is considerable potential to develop the rangeland and livestock sector and improve the communal people's livelihoods by maintaining an appropriate balance between livestock and carrying capacity of the rangelands. The soil types were heterogeneous, but were predominantly: shallow, red stony ground (SRSG); shallow, dark sandy loam (SDSL); and deep, dark clay-loam (DCL). Two communal grazing areas on SRSG (Calderwood and Phumlani), 3 on SDSL (Cwarhu, Ngwenya and Sakhi) and 1 on DCL soils (Madubela) were selected for the study. Communal grazing was practised in SRSG areas during the last 27–32 years, prior to which the lands were private cattle ranches subject to a multi-paddock grazing system and a lighter stocking rate. Most parts of the Ngwenya and Cwarhu communal lands were used as croplands some 3 decades ago, but cropping was abandoned for use as grazing land. Sakhi and Madubela lands have been communally grazed for at least 5 decades. Most communal rangelands in the study area were formerly fenced into camps, but in general only fences along the main road have remained intact. The total grazing area of the communal lands ranged from 350 to 450 ha. Livestock population data for the 3-year study period gathered from individual farmers revealed an average stocking rate of 1.5–3.5 cattle/ha and 1.9–3.9 goats/ha. Table 1 presents the coordinates, elevation and estimated stocking rate for each communal area.

Transect and enclosure layout

In each communal area, 6 transects radiating from the fence line bordering the main road were established (length 1–2 km) to record vegetation and soil data. These fence lines were close to the homesteads. Each transect was divided to form sub-transects: within 100 m (near site); >100 to ≤300 m (middle); and >300 m (far site) from the fence line. Two brush-packed sites with an approximate size of 2 × 2 m (4 m²) were established per sub-transect in each communal area to simulate grazing enclosures (Figures 2 and 3). An enclosure refers to an area of ground that is protected from grazing animals, mainly by fencing or brush packs, to prevent any

disturbance. Enclosures were initially established using posts and fencing wires (Figure 4) but most of these were stolen soon after erection, and were replaced with brush packs composed of branches of the very thorny legume tree, *Vachellia karroo* (Hayne) Banfi & Galasso. The brush packs remained undisturbed for the 2-year study periods. All enclosures were established immediately before the onset of the growing season in August 2015.

Data collection

Species composition and above-ground grass biomass. Initially, composition of the common or dominant grass species was determined from a plot of 100 × 12 m (1,200 m²) in each sub-transect of the 6 transects (total of 108 plots). This was designed to identify the common and dominant grass species in the study areas. The nearest plant and basal strikes were recorded from 200 point observations per plot using the step-point method ([Hardy and Walker 1991](#)). Given the adequate number of sampling plots taken, this size of point observation is acceptable for detailed scientific studies in semi-arid savanna ([Hardy and Walker 1991](#)). Two herbage samples within quadrats measuring 1 × 1 m were harvested within each grazing enclosure and adjacent open grazing lands to a stubble height of 4–5 cm for biomass determination. The harvested materials were bulked, placed in paper bags and dried to constant weight at 65 °C for 48 h. Plants were harvested toward the end of the growing season (February) and dry period (July) over 2 years (2016 and 2017). Before harvesting in February, individual tufts within each quadrat were counted by species when most plants were at the flowering stage, and these data were used to determine species composition in the enclosures and adjacent grazed areas, i.e. percentage of the plant population. 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 (for cattle) – those which develop on rangeland in good condition and decrease with high grazing pressure (decreasers); (ii) moderately palatable species – those which appear in rangeland in good condition and increase with moderate grazing pressure (increasers IIa); and (iii) less palatable and virtually unpalatable species – those which occur in rangeland in good condition and increase with severe utilization (increasers IIb and IIc). In addition, species were grouped into their life forms (annuals or perennials) according to Van Oudtshoorn ([1999](#)) and based on our experience.

Table 1. Soil type, elevation, coordinates and estimated stocking rate (\pm s.e.) of selected study areas based on 3-year (2011–2013) livestock population data.

Communal area	Soil type	Elevation (masl)	Coordinates	Stocking rate (head/ha)	
				Cattle	Goats
Calderwood	SRSG	526	32°48' S, 26°42' E	3.5 \pm 1.8	3.7 \pm 1.1
Phumlani	SRSG	557	32°48' S, 26°47' E	3.1 \pm 1.1	3.9 \pm 1.8
Cwarhu	SDSL	521	32°49' S, 27°02' E	2.7 \pm 1.1	2.9 \pm 1.0
Ngwenya	SDSL	573	32°51' S, 26°56' E	2.1 \pm 0.9	3.0 \pm 1.1
Sakhi	SDSL	475	32°50' S, 26°59' E	2.4 \pm 3.5	3.1 \pm 4.1
Madubela	DCL	544	32°50' S, 27°07' E	1.5 \pm 0.2	1.9 \pm 0.09

SRSG = Shallow, red stony ground; SDSL = Shallow, dark sandy loam; DCL = Deep, dark clay-loam.

**Figure 2.** Exclosures made from brush packs.**Figure 3.** Available biomass at removal of the brush pack.

Forage chemical analysis. Dried forage samples were ground to pass through a 1 mm sieve and stored in air-tight plastic bottles pending chemical analysis. Nitrogen (N) was determined using the Kjeldahl method (AOAC 1999; method number 976.06) and neutral detergent fiber (NDF) and acid detergent fiber (ADF) by the method of Van Soest et al. (1991). Calcium (Ca), magnesium (Mg), potassium (K), copper (Cu), zinc (Zn), manganese (Mn) and iron (Fe) concentrations were determined using the dry-ashing macro- and trace minerals method following the guidelines of the Agri-Laboratory Association of Southern Africa (Palic et al. 1998). Phosphorus (P) was analyzed using an ultraviolet spectrophotometer, K by using a flame photometer and Ca, Mg, Fe, Zn and Cu by using an atomic absorption spectrophotometer (PerkinElmer 1982). Limited funds allowed forage samples collected during only 2017 to be analyzed.

**Figure 4.** Initially used exclosures made from fencing wire.

Soil sampling and chemical analysis. Toward the end of the growing season of 2017, soil samples were collected concurrently with plant sampling. Two topsoil samples (0–20 cm depth) were collected from 1 m² quadrats laid inside the exclosures and adjacent grazed areas. Each set of samples was thoroughly mixed, air-dried and passed through a 2 mm mesh screen pending analysis. Soil texture (particle size) was determined by means of the standard Bouyoucos (hydrometer) method (Day 1965). Soil OC was analyzed using a colorimetric method (Baker 1976) and the Kjeldahl

method was used to determine total N. Potassium was determined by emission spectroscopy and Mg, Ca, Zn and Cu by atomic absorption spectroscopy. Phosphorus was determined using an ultraviolet spectrophotometer (Olsen and Sommers 1982).

Statistical analysis

Analysis of variance was conducted using the General Linear Models (GLM) procedure of SAS (2007) to assess the significance of differences in vegetation and soil variables between the exclosures and grazed areas. For 2 soil types (SRSG and SDSL), the linear model for forage biomass data included exclosure effects, grazing site, distance from the fence line, season and year as well as interaction of exclosure \times any factor. For forage nutrients, samples were harvested over 1 year only, so year effect was excluded from the model. For soil data, season and year effects were excluded because samples were collected only once during the study period. For DCL soil, effect of grazing site was also excluded. Where the main factors and their interactions were statistically significant, multiple comparisons of means

were carried out using the PDIF option of SAS (SAS 2007).

Results

Climate

Medium-term rainfall data (2008–2018) from the nearby weather station show that mean annual rainfall for the area has a range of 408–870 mm, of which about 55% normally falls between November and March. The lowest (24–26 mm) monthly rainfall occurred in September, May and June, and the highest (77 mm) in February (Table 2). Annual rainfalls during the study years were 408 mm (2016) and 558 (2017), which were below the average (588 mm) for the 11-year period. Monthly rainfalls during sampling months of February and July were 85 and 44 mm, respectively, in 2016 and 73 and 4 mm in 2017 (Table 2). Table 3 presents mean monthly temperatures, which reveal that medium-term mean minimum and maximum temperatures fall in the ranges 4–16 °C and 21–29 °C, respectively, compared with 3–17 °C and 20–31 °C for the study years.

Table 2. Monthly and annual rainfall data (mm) for the period 2008–2018.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total annual
2008	63	74	60	63	6.0	19	3.2	60	11	96	59	75	589
2009	58	110	21	59	15	24	38	37	24	62	42	42	532
2010	100	43	31	39	6.0	49	17	13	10	65	58	116	547
2011	130	25	83	56	142	82	77	34	6.6	55	70	109	870
2012	35	111	108	112	16	46	46	27	21	124	21	107	774
2013	42	80	58	65	45	10	15	25	0.3	82	106	78	606
2014	50	69	48	119	14	6.8	1.5	24	17	54	49	50	502
2015	76	124	84	66	7.0	33	92	21	61	18	73	1.8	657
2016	25	85	75	43	7.6	13	44	11	33	18	40	14	408
2017	90	73	34	22	18	2.8	4.3	66	23	85	92	48	558
2018	55	54	57	62	14	4.1	21	16	52	41	32	16	424
Average	66	77	60	64	26	26	33	30	24	64	58	60	588

Table 3. Mean monthly maximum/minimum temperatures (°C) for the period 2008–2018.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2008	28/16	28/16	28/14	25/10	25/9	21/6	23/5	22/6	24/6	24/10	26/13	28/15
2009	28/16	28/16	29/14	27/11	23/8	20/6	21/5	22/6	23/7	23/11	26/12	32/14
2010	29/16	30/17	30/15	26/11	24/9	20/5	22/5	24/6	25/8	23/11	25/13	25/15
2011	28/16	30/18	28/16	23/11	21/8	18/5	17/3	20/5	23/7	24/10	24/11	26/14
2012	30/17	27/16	27/14	24/9	22/8	19/5	19/3	21/6	22/7	21/11	25/11	27/16
2013	27/15	28/14	28/13	24/9	22/7	21/3	20/4	21/6	23/4	25/10	26/12	33/18
2014	30/16	29/17	27/14	25/10	23/7	21/4	22/4	22/8	25/9	24/9	24/19	25/21
2015	30/15	26/14	27/14	22/10	24/8	20/5	18/5	21/7	22/9	26/11	24/11	30/15
2016	31/17	29/16	27/14	27/10	24/7	22/5	20/5	24/7	23/8	25/10	25/13	31/15
2017	28/15	28/16	29/14	25/11	24/9	22/5	21/3	20/6	23/9	23/9	24/11	25/13
2018	29/16	28/15	25/14	24/11	24/6	22/3	22/4	19/4	22/6	26/10	27/11	30/15
Average	29/16	28/16	27/14	25/10	23/8	21/5	21/4	21/6	23/7	24/10	25/11	28/15

Herbaceous layer

A total of 31 grass species were identified in the study sites, of which 28 were perennials and the remaining 3 were annuals, with 11 classified as highly palatable (HP), 7 as moderately palatable (MP), 6 as lowly palatable (LP) and 7 as virtually unpalatable (VUP) species (Van Oudtshoorn 1999). In addition, there was occasionally a very minor and thus insignificant contribution of unpalatable annual forbs, subshrubs and sedges to the herbaceous layer; it was considered negligible.

Abundance of common and dominant grass species

A grass species was considered dominant when its average abundance exceeded 15%, and regarded as common when average abundance was within 5–15%. According to these definitions, the following species occurred as common or dominant in 1 or more soil types: *Cynodon dactylon* (L.) Pers., *Digitaria eriantha* Steud., *Sporobolus fimbriatus* (Trin.) Nees and *Themeda triandra* Forssk. (HP species); *Eragrostis curvula* (Schrad.) Nees (syn. *E. chloromelas* Steud.) (MP species); *Cymbopogon pospischilii* (K. Schum.) C.E. Hubb. [syn. *C. plurinodis* (Stapf) Burt Davy] and *Eragrostis obtusa* Munro ex Ficalho & Hiern (LP species); and *Aristida congesta* Roem. & Schult., *Eragrostis plana* Nees and *Sporobolus indicus* (L.) R. Br. var. *capensis* Engl. [syn. *S. africanus* (Poir.) Robyns & Tournay] (VUP species). The abundances of all species were not significantly ($P > 0.05$)

different between exclosures and open-grazed areas for all soil types. Mean abundance values were as follows: SRSG soil – *D. eriantha* (21%), *S. fimbriatus* (6%), *T. triandra* (8%), *C. pospischilii* (19%) and *E. obtusa* (9%); SDSL soil – *A. congesta* (8%), *C. dactylon* (7%), *D. eriantha* (29%), *E. curvula* (6%), *S. indicus* var. *capensis* (7%) and *T. triandra* (6%); DCL soil – *C. dactylon* (9%), *D. eriantha* (27%), *E. plana* (7%), *S. indicus* var. *capensis* (17%) and *T. triandra* (19%).

Life form and palatability of grasses

The abundances of life forms and palatability groups were not significantly ($P > 0.05$) different between exclosures and open-grazed areas in all soil types. In total, HP and MP species together accounted for the greatest composition of the grass layer, ranging from 63% in DCL to 68% in SRSG soil. All study sites were dominated by perennial grass species with abundance values ranging from 91% (SDSL soil) to 95% (DCL soil).

Grass biomass

For all soil types, grass biomass in the exclosures was significantly greater ($P < 0.0001$) than in the grazed areas (Figure 5). The mean differences in terms of percentage were 98% (SRSG soil), 128% (SDSL) and 152% (DCL soil) over the 2-year study period.

For SDSL soil, a significant interaction between increase in biomass presentation yield in exclosures and

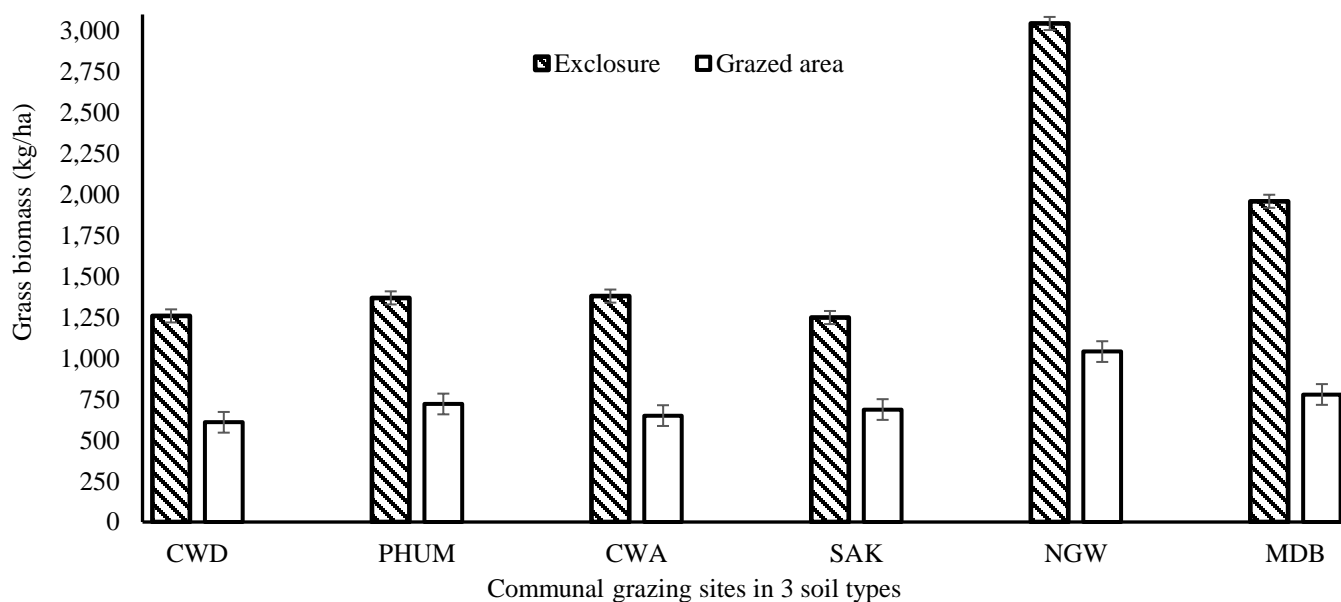


Figure 5. Mean annual dry matter presentation yields of native pastures harvested from exclosures and open-grazed areas on 3 soil types over 2 years. (CWD – Calderwood, PHUM – Phumlani, CWA – Cwarhu, SAK – Sakhi, NGW – Ngwenya and MDB – Madubela).

site was observed ($P < 0.0001$), varying from 193% at Ngwenya to 81% at Sakhi (Figure 5). For all soil types, increases in pasture presentation yields due to grazing exclusion differed significantly with distance from the fence line, but the trend was inconsistent across soil types (Table 4). For SRSG soil, the greatest ($P < 0.01$) increase was at the near (130%) and lowest at the middle (55%) distance from the fence line. On SDSL soil, the largest increase ($P < 0.0001$) was at the far site (192%), while increases at other distances were similar (mean: 108%). On DCL soil, the biomass increase at the middle distance was substantially greater (292%) ($P < 0.0001$) than that at the near (81%) and far (87%) distance points from the fence line (Table 4). For open-grazed areas, presentation yields were not significantly ($P > 0.05$) affected by distance from the fence line.

Table 4. Changes in mean annual dry matter presentation yields (kg DM/ha) of bulked native pastures from exclosures and open-grazed areas with increase in distance from fence line in 3 soil types.

Soil type	Distance from fence line			s.e.
	Near	Mid	Far	
SRSG				
Exclosure	1,556Aa ¹	1,045Ac	1,332Ab	52.3
Grazed area	681Ba	672Ba	641Ba	24.2
SDSL				
Exclosure	1,603Ab	1,646Ab	2,425Aa	92.5
Grazed area	788Ba	762Ba	829Ba	33.7
DCL				
Exclosure	1408Ab	2976Aa	1491Ab	220
Grazed area	778Ba	759Ba	800Ba	46.2

¹Within columns and soil types, means with different upper-case letters differ significantly ($P < 0.05$). Within rows, means with different lower-case letters differ ($P < 0.05$). SRSG – shallow, red stony ground; SDSL – shallow, dark sandy loam; and DCL – deep, dark clay-loam.

On SDSL soil, grass biomass was significantly affected by an exclosure \times season interaction ($P < 0.0001$), with greater biomass increase due to grazing exclusion recorded in the wet season than in the dry season (Table 5). In all soil types, the increase in grass biomass resulting from grazing exclusion was significantly greater ($P < 0.01$) in Year 1 (range: 126% in SRSG to 151% in DCL) than Year 2 (range: 66% in SRSG to 132% in DCL) (Table 6). Overall, presentation yields in Year 1 exceeded those in Year 2.

Herbage chemical composition

For all soil types, no marked differences ($P > 0.05$) in herbage organic matter, CP and NDF concentrations were observed between exclosures and grazed areas. For SRSG and SDSL soils, herbage samples from the exclosures showed higher

ADF ($P < 0.001$) and ADL ($P < 0.05$) concentrations than those of grazed areas (Table 7).

Table 5. Mean seasonal dry matter presentation yields (kg DM/ha) of bulked native pastures from exclosures and open-grazed areas over 2 years in 3 soil types.

Soil type	Season		s.e.
	Dry	Wet	
SRSG			
Exclosure	602Ab ¹	712Aa	26.3
Grazed area	288Bb	377Ba	26.3
SDSL			
Exclosure	744Ab	1148Aa	21.2
Grazed area	353Bb	440Ba	21.2
DCL			
Exclosure	977Aa	982Aa	37.7
Grazed area	374Ba	405Ba	37.7

¹Within columns and soil types, means with different upper-case letters differ significantly ($P < 0.05$). Within rows, means with different lower-case letters differ ($P < 0.05$). SRSG – shallow, red stony ground; SDSL – shallow, dark sandy loam; and DCL – deep, dark clay-loam.

Table 6. Mean annual dry matter presentation yields (kg DM/ha) of bulked native pastures from exclosures and open-grazed areas over 2 years in 3 soil types.

Soil type	Year		s.e.
	Year 1	Year 2	
SRSG			
Exclosure	1,467Aa ¹	962Ab	73
Grazed area	647Ba	580Bb	14
SDSL			
Exclosure	1,725Aa	1,570Ab	117
Grazed area	793Bb	862Ba	49.5
DCL			
Exclosure	1,958Aa	1,315Ab	148
Grazed area	779Ba	552Bb	18

¹Within columns and soil types, means with different upper-case letters differ significantly ($P < 0.05$). Within rows, means with different lower-case letters differ ($P < 0.05$).

SRSG – shallow, red stony ground; SDSL – shallow, dark sandy loam; and DCL – deep, dark clay-loam.

For SRSG soil, grazing exclusion was associated with reductions in forage P ($P < 0.01$) and increase in Fe concentration ($P < 0.05$) compared with the open-grazed area (Table 8). Similarly, for SDSL soil, herbage samples from grazing exclosures showed significantly lower Fe and Mn ($P < 0.05$) concentrations than those from open-grazed areas. For DCL soil, K, Mg and Cu concentrations in herbage samples from the exclosures significantly exceeded ($P < 0.05$) those in samples from the open-grazed areas, where the highest ($P < 0.05$) concentration of Fe was recorded (Table 8).

Table 7. Chemical composition (g/kg DM) of bulked native pastures harvested from exclosures and open-grazed areas in 3 soil types.

Component	SRSG			SDSL			DCL		
	Exclosure	Grazed area	s.e.	Exclosure	Grazed area	s.e.	Exclosure	Grazed area	s.e.
Organic matter	923a ¹	927a	3.33	926a	931a	1.23	928a	934a	1.28
CP	76.2a	83.3a	2.99	72.6a	71.1a	3.02	107a	93.2a	5.98
NDF	708a	697a	5.46	736a	727a	5.22	729a	722a	6.18
ADF	399a	364b	6.34	421a	402b	5.10	388a	384a	6.43
ADL	330a	304b	5.12	342a	328b	4.11	315a	322a	6.44

¹Within rows and soil types, means with different letters differ significantly ($P < 0.05$). SRSG – shallow, red stony ground; SDSL – shallow, dark sandy loam; DCL – deep, dark clay-loam.

Table 8. Mineral concentrations (g/kg DM) in bulked native pastures harvested from exclosures and open-grazed areas in 3 soil types.

Nutrient	SRSG			SDSL			DCL		
	Exclosure	Grazed area	s.e.	Exclosure	Grazed area	s.e.	Exclosure	Grazed area	s.e.
P	1.12b ¹	1.42a	0.06	1.17a	1.23a	0.07	1.67a	1.62a	0.07
Ca	4.22a	4.08a	0.08	3.54a	3.50a	0.11	3.17a	3.23a	0.08
K	14.6a	15.0a	0.61	12.2a	11.8a	0.64	20.4a	15.1b	0.96
Mg	1.32a	1.31a	0.04	1.24a	1.22a	0.04	1.30a	1.02b	0.04
Fe	0.29a	0.28b	0.03	0.34b	0.40a	0.03	259b	335a	0.03
Cu	0.003a	0.003a	0.00	0.003a	0.004a	0.00	0.006a	0.005b	0.00
Zn	0.002a	0.002a	0.00	0.002a	0.002a	0.00	0.003a	0.003a	0.00
Mn	0.07a	0.06a	0.003	0.08b	0.09a	0.006	0.14a	0.15a	0.01

¹Within rows and soil types, means with different letters differ significantly ($P < 0.05$).

SRSG – shallow, red stony ground; SDSL – shallow, dark sandy loam; DCL – deep, dark clay-loam.

Soil physical and chemical properties

The distribution of soil particle size fractions (sand, clay and silt) showed no significant ($P > 0.05$) variations between exclosures and grazed areas for all grazing sites and soil types. Generally, the sand, clay and silt contents of soil samples were in the range of 63–70%, 13–19% and 15.6–19.3%, respectively.

Within exclosures, concentrations of soil P, Mg, K, Mn and OC at the end of the study were greater ($P < 0.05$) than

those in open-grazed areas for all soil types (Table 9). In SRSG and SDSL soils, N concentration was higher ($P < 0.05$) in the exclosures than in the grazed areas. In SDSL soil, soil Cu ($P < 0.05$) was greater in the exclosures than in the open-grazed areas. In DCL soil, soil Ca significantly increased in the exclosures compared with that in the grazed areas (Table 9). All soil mineral concentrations, except Mn, displayed no significant interaction effects of exclosure \times site or distance from the fence line for the studied soil types.

Table 9. Mean macro- and micro-mineral concentrations in soil samples collected from inside exclosures and open-grazed areas in 3 soil types.

Mineral	SRSG			SDSL			DCL		
	Exclosure	Grazed area	s.e.	Exclosure	Grazed area	s.e.	Exclosure	Grazed area	s.e.
P (mg/kg)	9.91a	9.66b	1.11	8.94a	7.51b	0.60	15.3a	11.8b	1.09
Ca (cmol/kg)	4.17a ¹	3.95a	0.23	3.34a	3.07a	0.18	3.01a	2.33b	0.19
K (mg/kg)	258a	235b	24.6	214.1a	203b	16.3	174b	188a	16.7
Mg (cmol/kg)	1.49 a	1.38b	0.07	1.54a	1.31b	0.07	1.16a	0.97b	0.05
Cu (mg/kg)	1.39a	1.39a	0.12	2.23a	2.07b	0.10	2.30a	1.93a	0.14
Zn (mg/kg)	0.74a	0.80a	0.06	0.96a	0.97a	0.23	1.16a	1.55a	0.15
Mn (mg/kg)	173a	149b	10.6	190a	140b	7.59	253a	213b	23.9
OC (%)	1.78a	1.62b	0.11	1.41a	1.25b	0.04	1.48b	1.50a	0.09
N (%)	0.13a	0.10b	0.11	0.11a	0.09b	0.01	0.12a	0.12a	0.01

¹Within rows and soil types, means with different letters differ significantly ($P < 0.05$).

SRSG – shallow, red stony ground; SDSL – shallow, dark sandy loam; DCL – deep, dark clay-loam.

Discussion

Grass species composition and biomass

Our study revealed a significant proportion of palatable as well as strong perennial species in the grass community of all study areas with no significant difference between the enclosures and open-grazed areas. Similar high occurrences of palatable and strong perennial species were recently reported by Siyabulela et al. (2020) in commercial private ranches (mean: 73 and 75%, respectively) and communal grazing lands (mean: 67 and 75%, respectively) found in similar ecology. The current findings are at variance with work of researchers such as Yayneshet et al. (2009) and Rong et al. (2014), who reported variations in species composition between grazed and ungrazed treatments in semi-arid rangelands. The authors reported that, compared with continuously grazed areas, livestock exclusion favored the growth of densely tufted (erect growth) palatable perennial grasses such as *Cenchrus ciliaris*, *Hyparrhenia* spp. and *Sporobolus pellucidus* (Yayneshet et al. 2009) and *Eragrostis collina* and *Stipa glareosa* (Rong et al. 2014). Their reports were based on studies of longer-term enclosure effects (minimum of 5 years) over large grazing areas in contrast to our studies, which focussed on very small enclosure plots for a shorter period. Those authors concluded that the changes in species composition were the result of a long-term evolutionary adaptation to grazing disturbance as well as subsequent periods of grazing exclusion.

Our findings also indicated that excluding livestock from grazing lands using brush pack trees for short periods (2 years) resulted in a significant growth of pasture. Many communal rangelands in South Africa are continuously over-grazed for the entire grazing year without formal rest periods. In the current study areas, which receive an average annual rainfall of 588 mm, the stocking rate for grazing cattle (range: 1.5–3.5 head/ha) was estimated at about 7 times the moderate stocking reported by Fynn and O'Connor (2000) for semi-arid environments. These areas are also characterized by the absence of any efforts to improve the rangeland through rest/rotational grazing, as there are usually no fenced paddocks or herders to control animal movement. Unrestrained access by livestock until growth of forage becomes inadequate to sustain them results in frequent and severe defoliation of the herbaceous layer without sufficient physiological recovery time (Kioko et al. 2012), while grazing exclusion for at least 2 growing seasons may lead to the recovery of the pasture. This finding is therefore of practical significance as pasture presentation yields inside enclosures indicated these pastures are still

capable of producing acceptable DM yields of forage of reasonable quality despite being continuously over-grazed for many years. Adopting a grazing strategy which allowed for periods of rest might help prevent further degradation of pasture. Applying this practice however requires community and resource mobilization as well as dividing the entire grazing lands into camps.

The absence of any shift in species composition within the enclosures suggests that longer periods without grazing may be needed to produce any species changes from seed germination of the existing stand and/or from the soil seed bank. Indeed, the presence of so many palatable species in the grazed areas (18 of 31) suggests that these pastures are still not severely degraded or 'beyond reclamation' threshold.

Based on our results, we assume that, in semi-arid or arid rangelands, decline in herbaceous (forage) biomass is the first and early symptom of rangeland deterioration. Many communal rangelands in South Africa show low forage biomass, although the desirable and perennial grass species still dominate, accounting for up to 67% of the grass layer (Yonela 2017; Siyabulela et al. 2020). Such rangelands, including the current study areas, may not be beyond reclamation, but classified as being in a transition state from good to poor health condition, while others containing >40% undesirable species are considered moderately degraded (Yonela 2017). When decreased biomass is not reversed, loss continues with advance in degradation, and may reach a threshold (a point at which disturbance should be limited or controlled to prevent drastic changes in other ecosystem components). Biomass decline beyond a threshold may inevitably accompany other long-lasting symptoms, such as shift in species composition, decreased basal cover, increased bush encroachment and soil erosion. Certainly, empirical data are required to distinguish processes of rangeland degradation and link symptoms with various degradation stages.

In the present study, the increase in standing biomass in the enclosures compared with open-grazed areas was substantially greater than that reported previously from long-term studies, such as 65% increase after 8 years of exclusion in arid rangelands of Tunisia (Jeddi and Chaieb 2010), 29% increase after 12 years of exclusion in northwest China (Rong et al. 2014), 100% increase in Pakistan within 8–15 years of exclusion (Qasim et al. 2017) and 54–75% increase after 16 years of exclusion in semi-arid rangelands in northern Ethiopia (Yayneshet et al. 2009). Such differences may be ascribed to variations in stocking pressure, climate, soil, design and duration of the experiments plus stage of degradation of soil and pasture and presence of seed to allow regeneration.

While increases in herbaceous biomass as a result of grazing exclusion varied with distance from the fence line in our study, there was no consistent pattern. Such spatial variation may reflect patchy characteristics of the semi-arid environments in terms of soil, micro-climate and grazing disturbance. Further examination of the areas involved could provide possible reasons for the differing patterns. In SDSL soil, the increase in herbaceous biomass as a result of grazing exclusion varied between communal grazing areas, suggesting that the recovery potential of rangelands may be influenced by previous land-use history. Additional forage on areas subject to long-term cropping in the past and later abandoned for a period prior to grazing was superior to that on areas that have been continuously grazed for their entire history.

The difference in biomass between the exclosures and grazed areas measured towards the end of the wet (growing) season provides an indication of the minimum amount of forage utilized by grazing animals. In the current study, this amount was equivalent to 47% (SRSG soil), 59% (DCL soil) and 62% (SDSL soil), which is consistent with the off-take range of 30–90% reported by McNaughton (1985) and the utilization of 60% reported by Yayneshet et al. (2009) for East African semi-arid rangelands. If compensatory growth occurred after grazing, the amount removed would be higher than our current values. Such a utilization level may be considered severe based on the 25–30% recommendation for semi-arid rangelands (Holechek et al. 2003) and may lead to severe degradation if sustained for a long term without restorative measures.

Annual presentation yields (range: 609–1,041 kg DM/ha) recorded in the open-grazed lands in the present study were generally lower than those reported in similar ecologies, e.g. Yonela (2017); Siyabulela et al. (2020). On the other hand, the annual biomass yields (range: 1,059–3,042 kg DM/ha) recorded in the exclosures were generally similar to those reported for good rangelands (Siyabulela et al. 2020) under commercial ranch systems or game reserves.

Forage chemical composition

For pasture-based feeds, DM intake of livestock decreases as CP concentration decreases below 70 g/kg DM (Minson and Milford 1967). The CP% in bulk forage samples harvested from the exclosures and grazed areas met the minimum level of 75 g/kg DM required for effective rumen function (Van Soest 1994), except for forage samples harvested from SDSL soil (range: 71–73 g/kg DM). On the other hand, a minimum CP concentration of 150 g/kg DM is required to supply adequate

nutrients for lactation and adequate growth of cattle (Norton 1982), and all forages harvested from the study areas had CP% below this recommended level.

The higher ADF and ADL concentrations in herbage from the exclosures than those of the grazed areas is characteristic of mature tropical grass species. The NDF% recorded in the exclosures in all soil types (range: 708–736 g/kg DM) and in grazed areas (range: 698–728 g/kg DM) were above the average value of 662 g/kg DM for tropical grasses (Van Soest 1994; McDonald et al. 2002). This may affect the intake of forages by ruminants under small-holder conditions, and would ultimately limit the production and productivity of livestock. According to Meissner et al. (1991), the threshold NDF concentration in tropical grasses beyond which DM intake of cattle is affected is 600 g/kg DM.

Based on estimated ruminant requirements (NRC 1996; McDowell 1997), the K, Fe and Mn concentrations of all herbage samples harvested from the exclosures and grazed areas exceed the required levels, while being non-detrimental to the performance of all livestock species. However, herbage P (from grazing exclosures on SRSG and SDSL soils) and Cu (on all soil types) concentrations were below the levels required for satisfactory production of all livestock species. On SRSG soil, the significantly lower concentration of P in forage harvested from exclosures compared with that from grazed areas is of particular concern because this amplifies an already existing P deficiency and, therefore, P supplementation of animals grazing the enclosed areas should be a priority.

The absence of interaction effects of enclosure × grazing site, distance or season on the concentrations of some forage minerals, CP and fiber fractions shows that normal factors like stage of maturity and forage type were the over-riding factors determining forage quality.

Soil properties

The absence of significant variation in soil texture between the exclosures and grazed areas confirms that soil texture is more influenced by the inherent characteristics of the soil parent material than by grazing management practices in the short term. However, mismanagement that promotes depletion of herbaceous vegetation cover and accelerated soil erosion over the long term may increase the sand fraction by lowering the silt or clay proportion. In general, arid and semi-arid rangelands in Africa are characterized by high sand fractions in soil (Tefera 2013; Feyisa et al. 2017).

The observation that concentrations of several soil macro- and micro-elements were higher inside the exclosures than in the open-grazed areas corresponds with

the findings of Angassa et al. (2012) and Feyisa et al. (2017) in East African semi-arid rangelands and suggests that soils in exclosures may attain higher cation exchange capacity and P concentrations than those of continuously grazed areas. In the present study, relatively higher soil OC and N concentrations (except for DCL soil) in the exclosures than in the grazed areas was possibly the result of increased organic matter inputs to the soil (litter, dead roots, mycorrhizae and exudates) through annual production of biomass following grazing deferment as well as litter inputs from the brush pack trees (Qasim et al. 2017). Conversely, grazing reduces OC and N inputs into the soil as a result of greater removal of the herbaceous layer, which is the major source of litter-fall and organic matter, and export of nutrients through urine and faeces when animals are kraaled at night. In addition, while repeated grazing may tend to increase biomass and N flow to the animals, it reduces the energy and nutrient flow to roots and crowns of plants, resulting in a significant decline in the reserves of soil OC and other nutrients (Naeth et al. 1991). Year-long continuous grazing depletes herbaceous vegetation, which leads to increased areas of bare ground and accelerated erosion, causing further depletion of soil nutrients. It is also likely that increased soil aggregation (although not measured in the current study) in the grazing exclosures over the study period may have physically protected the organic matter from microbial mineralization and its subsequent losses (Steffens et al. 2008), and facilitated OC accumulation in the soil. The significant increase in concentrations of soil OC and N as a result of grazing restriction reported in the present study is consistent with similar findings for arid and semi-arid rangelands (Angassa et al. 2012; Sousa et al. 2012). Those studies, however, reported improved OC and N concentrations following a minimum of 6 years grazing protection, whereas the present results hinted at possible increase in soil C and N concentrations in semi-arid rangelands after only 2 years of grazing protection.

The improvement in soil conditions in such a short time was possibly impacted largely by leaf fall from the brush pack trees. In contrast, many other studies (Medina-Roldán et al. 2012; Raiesi and Riahi 2014; Aynekulu et al. 2017) have shown that, despite changes in plant communities, both soil OC and N storage appear to be unaffected by grazing exclosure in upland grasslands and arid or semi-arid rangelands. Certainly, such variation in the response to grazing exclusion could be attributed to differences in exclusion methods used, climatic conditions, soil properties and depth, topographic position, vegetation community composition and/or pasture management practices, such as stocking rate and grazing intensity or frequency. In the current study, soil

bulk density was not measured to calculate the total OC and N pools in the soil, but based on the C and N concentrations, we may anticipate greater OC and N stocks in the grazing exclosures compared with those in the continuously grazed areas.

Conclusions

In conclusion, short-term exclosure from grazing using brush pack trees resulted in increased above-ground presentation yields of grass, soil nutrients, C and N storage in communal rangelands characterized by a current state of low herbage biomass, which was to be expected. However, exclosure did not significantly change the species composition of grasses as compared with grazed areas. To restore the low state of forage biomass in those communal rangelands, and indeed prevent further advance in deterioration, periodic rest-rotate grazing practices may be recommended. Applying such practices requires planning, plus community and resource mobilization. This also needs a strategy to divide the entire grazing lands into camps, using either fence lines or imaginary borders as well as trained herdsmen to control animal movements. Preferably, this would need to be done by taking groups of villages together rather than on a single village basis. Grazing exclusion may lower the nutritive value and intake of available forage immediately after herbaceous recovery. Therefore, grazing immediately after vegetation recovery may demand judicious nutritional interventions, such as supplementation with protein and energy sources and certain minerals such as P. We recommend undertaking additional studies on larger sampling areas to expand on these conclusions, given that responses of biomass, soil OC, N and other soil physical properties (e.g. bulk density) to grazing are highly variable across macro- and micro-climates, and across other ecosystem variables, such as soil depth and period of exclosure.

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