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Response of Soil Chemical Attributes Under Cattle and Goats Mixed-Species Grazing System in Semi-Arid Botswana

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ABSTRACT: The effects of cattle alone (1:0), goats alone (0:1) and different cattle and goats combinations (1:1, 2:1 and 3:1) on soil chemical properties under Mixed Mopane veld paddocks stocked at 12ha/LSU (1 livestock unit, LSU = 450kg) were investigated. Using the piosphere approach, topsoil cores were collected and analyzed at 0, 50, 150, 300 and 500m from water points along 2 randomly-placed transects in each respective treatment. Overall, there was limited uniformity in responses of soil chemical attributes to the different grazing ratios. However, there was a centripetal flow of soil cation exchange capacity, phosphorus, potassium, magnesium and organic carbon as well as pH with increasing distance from water points. It is likely that the conservative stocking rate of 12ha/LSU was not sufficient to induce significant changes in soil chemistry, thus more robust tests can be attempted under a wider range of stocking densities.

Key words: Botswana, *Colophospermum mopane*, mixed-species grazing, piosphere, soil spatial variability, Tswana cattle-goat ratio

INTRODUCTION

Utilization of natural rangelands by two or more animal species with different grazing habits may be one of the most biologically and economically viable systems available to producers, especially on landscapes that support heterogeneous plant communities (Anderson *et al.* 2012). Mixed-species grazing studies over the years involving domesticated animals like cattle, sheep and goats have demonstrated beneficial effects for both quality of forage and animal performance (Boswell and Cranshaw 1978; Donaldson 1979; Collins 1989; Sikosana and Gambiza1993; Abaye *et al.* 1994; Del Pozo *et al.*1998; Animut *et al.* 2005; Celaya *et al.* 2007; Allred *et al.* 2012; Monametsi *et al.* 2012) and consequently suggests a 'win-win' solution for farmers and conservationists alike (Fraser et al. 2014).

However, the focus of such studies has largely neglected the effect of mixed-species grazing on soil properties, despite the recognized importance of incorporating soil information into rangeland management planning (Klemmedson 1970)**.** The soil base is often our most underrated resource, but a valuable resource nonetheless - supporting vegetation and the grazing animals humanity depends on.

Grazing can enhance or be detrimental to soil physical and chemical properties (Lodge 1954; Beebe and Hoffman 1968; Johnston *et al.* 1971; Dormaar *et al.* 1977; Tolsma *et al.* 1987; Hiernaux *et al.* 1999; Mapfumo *et al.* 1999; Neff *et al.* 2005; Li *et al.* 2012; Kotze *et al.* 2013) and therefore there is need to continuously monitor or measure different soil properties so as to ascertain whether these properties are improving, staying constant or degrading with time.

In semi arid Botswana where livestock plays a pivotal role in the lives of communities and is often blamed for degradation of communal rangelands, very few mixed-species grazing studies have been conducted (e.g. Monametsi *et al.* 2012). Instead, previous studies (Moleele and Perkins 1998; Mphinyane *et al.* 2001; Nsinamwa *et al.* 2005) with a bearing on grazing-soil interfaces were restricted to cattle only or failed to objectively account for other animals like goats, sheep and equines concurrently utilizing the same rangelands with cattle and would rather simply bulk animals together as 'livestock'. This is often overlooked despite the common practice by communal pastoral communities to concurrently keep both cattle and small stock like goats and sheep as well as occasionally watering these animals at shared water points.

Understanding the effects grazing animals have on different soil attributes would lead to better design and timely implementation of soil conservation efforts such as proper density and distribution of artificial water points in semi arid environments of southern Africa and elsewhere. This would not only maintain healthy soil moisture and fertility conditions, but ultimately enhance pasture production and in the same breath, drive sustainable livestock productivity and secure multiple livelihoods dependent on the these rangelands. This study therefore sought to determine the influence of different combinations of cattle and goats on chemical properties of soil around permanent water points.

MATERIALS AND METHODS

A. Study site

The trial was conducted at Impala Ranch (21°08' - 21°11' S, 21°35' - 27°37' E), an area dominated by *Colophospermum mopane* tree vegetation within the North East District approximately 7km east of Francistown, Botswana. The semi arid area receives about 630mm of rainfall annually, with high temporal and spatial variation. The rainfall pattern is uni-modal and rain events are restricted mainly between December and March. The soils are classified as haplic lixisol, a typical sodic type and characterized by clay (FAO 1991). The same site has previously been described by Monametsi et al. (2012).

The current reported trial was part of an ongoing long-term study on mixed-species grazing started in 2007, utilizing six paddocks at a stocking rate of 12 hectares per livestock unit (LSU) where 1 LSU is equivalent to 1.667 steers or 6 goats as recommended for Mopane veld vegetation. The total area covered by the study was 812ha and the indigenous, hardy and well-adapted Tswana cattle and goat breeds were used. The treatments were Tswana cattle only, Tswana goats only, Tswana cattle and goats at 1:1, Tswana cattle and goats at 2:1, Tswana cattle and goats at 3:1 and lastly a non-grazed paddock as the control (Table 1). The data on animal and vegetation response has been reported by Monametsi *et al*. (2012).

Table 1: Grazing ratio treatments and actual animal numbers used.

Treatment ratio (LSU*)		Animal numbers	
Cattle	Goats	Cattle	Goats
1	0	23	0
1	1	8	30
0	1	0	15
2	1	9	17
3	1	11	13
0	0	0	0

*1 LSU taken to be an animal that weighs 450kg

B. Soil sampling procedure

Soil sampling was done at the end of the active vegetation growth season (March 2011, 5 years after the initiation of the mixed-species grazing study) at sampling points along randomly-placed line transects. Because water is often a limiting factor for livestock production in arid and semi arid environments like Botswana, the artificial water points (borehole filled-troughs) serve as important foci around which livestock congregate for longer periods. Therefore, following the piosphere approach (Lange 1969), 2 line transects were set up radiating away from the artificial water point in each paddock. Topsoil cores (0-7.5cm) were then taken using a standard MAF core sampler, 2.54cm in diameter at 0, 50, 150, 300 and 500 metres from the water point along the transects. The distance intervals were selected arbitrarily, but the total length of the transect was also designed to fit within the smallest of all the paddocks. At each sampling point, litter was removed if present and 2 core soil samples were taken, bulked together, thoroughly mixed and the final subsample for analysis taken from the composite. The same sampling technique was applied in the non-grazed paddock (control).

After drying, the soil samples were analyzed for chemical properties at the Soil and Plant Analytical Laboratory in Sebele, Botswana. Exchangeable bases Calcium (Ca), Magnesium (Mg) and Potassium (K) were determined using Ammonium Acetate as described by Thomas (1982). The Walkley and Black method (Walkley 1935) was used to determine the organic carbon (OC) content in the soil samples, while the Bray II method (Bray and Kurtz 1945) was followed in determining Phosphorous (P) amounts. Soil pH was measured in a 1:2.5 soil water relation extraction method.

Data were subjected to Statistical Analysis System (SAS) software. Statistical analysis methods applied were the analysis of variance (ANOVA) using the General Linear Model (GLM) procedure for testing the statistical significance using the F-test of the main effects (Cattle-Goat Ratio and Distance from water source) and their interaction, the orthogonal polynomials for the linear and quadratic effect of the factor Distance. Dunnett's test was used to compare the control (0:0) to the other cattle-goat ratios, and the LSD for the mean separation of the main effect means. Due to high variability (CVs > 20%) for the variables Cation Exchange Capacity (CEC), OC, P, Ca, Mg, K and Na, the logarithmic transformation was used to stabilize the variances. Statistical significance was declared at the 5% probability level.

RESULTS

A. Spatial variability of soil chemical properties along grazing piosphere

With the exception of Ca and Na, all the measured soil properties tended to be highest at the water point, after which they declined and further away at 300 and 500m they slightly increased. Several parameters like OC, CEC, Ca and Mg tended to drop to their lowest point at 150m from the water point. However, there was no distinct and consistent pattern for all measured parameters throughout the grazed paddocks.

Table 2: Means of soil chemical and mineral elements at varying distances from water point.

Distance from water point (m)	pH	OC (%)	P (mg/kg)	CEC (cmol/kg)	Ca (cmol/kg)	Mg (cmol/kg)	K (cmol/kg)	Na (cmol/kg)
0	6.236^{a}	0.651^{a}	3.023	2.017^{a}	1.866^{a}	1.071^{a}	0.803^{a}	0.153
50	5.926^{ab}	0.425^{b}	2.476	1.906^{ab}	1.788^{ab}	0.955a^{b}	0.385^{b}	0.067
150	5.716^{b}	0.349^{b}	2.511	1.648^{b}	1.429^{b}	0.720^{b}	0.311^{bc}	0.168
300	5.682^{b}	0.414^{b}	2.461	1.807^{ab}	1.618^{ab}	1.000^{ab}	0.307^{bc}	0.102
500	5.687^{b}	0.445^{b}	2.642	1.930^{ab}	1.895^{a}	0.993^{ab}	0.259^{c}	0.188

[a,b] Means within a column followed by different letters differ significantly (P<0.05)

B. Cattle-goat ratio impact on soil chemical properties

Again, no distinct pattern was observed on response of soil chemical attributes to the various cattle: goat combinations. However, the soil CEC under grazing ratios 3:1, 1:1 and the control were significantly higher than that under grazing ratios 0:1 and 2:1 (Table 3), but not significantly different from grazing ratio 1:0. Also Na and P values did not show significant differences (P>0.05) with varying grazing ratios. Though the values were not significant, soils under the non-grazed paddock had the highest P and the second highest CEC, Ca and Mg while Na was the lowest in this paddock.

Table 3: Means of soil chemical and mineral elements at different grazing ratios.

Cattle:goat ratio	pH	OC (%)	P (mg/kg)	CEC	Ca	Mg	K	Na
				(cmol/kg)				
0:0	5.766[ab]	0.444[ab]	3.035	2.008[a]	1.938[ab]	1.034[ab]	0.358[ab]	0.068
0:1	6.269[a]	0.482[ab]	2.690	1.592[b]	2.061[a]	1.206[a]	0.420[ab]	0.166
1:0	5.670[b]	0.397[b]	2.501	1.799[ab]	1.391[c]	0.719[c]	0.427[ab]	0.190
1:1	5.846[ab]	0.457[ab]	2.322	2.103[a]	1.662[abc]	0.887[bc]	0.493[a]	0.095
2:1	5.699[b]	0.425[b]	2.564	1.542[b]	1.530[bc]	0.894[bc]	0.315[b]	0.203
3:1	5.725[b]	0.541[a]	2.626	2.074[a]	1.731[abc]	0.948[abc]	0.462[a]	0.092

[a,b] Means within a column followed by different letters differ significantly ($P<0.05$)

Table 4: P-values for interaction between grazing ratio and distance from water point on soil attributes.

Source	**pH**	**OC (%)**	**P (mg/kg)**	**CEC**	**Ca**	**Mg**	**K**	**Na**
						(cmol/kg)		
Paddock	0.187	0.174	0.588	0.000	0.025	0.071	0.121	0.651
Distance	0.056	0.001	0.485	0.095	0.146	0.146	0.000	0.660
Interaction	0.159	0.169	0.920	0.293	0.284	0.284	0.012*	0.440

*significant at $P<0.05$

C. Interactions between distance and cattle-goat ratio on soil chemical properties

Potassium was significantly affected by the interaction between grazing ratio and the distance from the water point (Table 4). All other chemical elements and mineral elements were not significantly affected.

DISCUSSION

A. Spatial variability of soil nutrients along grazing biosphere

Water points, whether artificial or natural, are characterised by higher density of livestock in the semi arid Kalahari ecosystem of Botswana and tend to create a 'grazing pressure gradient' radiating outwards. Water points thus serve as important ecological reference points in such settings. In this study, soil chemical properties did not show a consistent pattern along the grazing biosphere, particularly Na which reflected very high spatial variability. Nonetheless, pH, CEC, P, K, Mg and OC tended to be highest closer to the water point. Then from the water point radiating outwards there was a sharp decline in these same soil parameters and as one progressively moved away then they slightly increased to amounts generally not beyond those observed at the water points. This trend of soil nutrient centripetal flow is consistent with findings from other studies elsewhere (Tolsma *et al.*1987; Mphinyane 2001; Shahriary *et al*. 2012). This can be attributed to increased redistribution of nutrients through urine and faecal deposition by grazing animals closer to water points (Sasaki *et al.* 2008; Shahriary *et al.* 2012). The relatively high P concentration closer to the water points could also be explained by low uptake by vegetation as these areas are mostly denuded of vegetation cover as suggested in other studies (Biro et al. 2011). Phosphorus is generally limited in Botswana soils and thus it is not surprising that amounts recorded away from the water point were relatively lower.

However, Moussa *et al.* (2008) found no significant differences on soil phosphorus between grazed and ungrazed rangelands, and this could partly explain the weak phosphorus response to change in grazing pressure as distance increase from water point.

The relatively high soil K near water points could be due to nearness of parent rock to the surface as it largely results from mineral weathering of the rocks. Also, urine is the primary excretory path for K, which could accumulate due to livestock congregating around water points either drinking or resting. According to Cui *et al.* (2005), soil OC response to grazing pressure is highly varied and thus it is still characterised by discrepancies. In the present study, soil OC was also observed to be significantly higher at the water points also due to fecal deposition, which then declines until the 150m point. At 300m and beyond, there is possibly more carbon restored in the soil through decomposition of vegetation as the grazing pressure declines (Steffens *et al.* 2008) and less vegetation biomass is consumed as observed by Savadogo *et al.* (2007). Also, Bauer *et al.* (1987) have shown reduction in soil OC under grazed native grasslands. In fact, most significant soil properties and nutrient changes have been observed within the radius of 100m from boreholes (Shahriary *et al.* 2012) while Mphinyane (1991) reported a radius of 150m. The density of livestock concentrated at the water point, among other factors has an influence on the extent of this radius. It should be noted that the accumulation of nutrients close to water points does not necessarily contribute much to vegetation productivity because higher density of livestock exert relentless pressure on these areas and thus they are normally bare except for a few annual plants during the rainy season.

B. Cattle-goat ratio impact on soil chemical properties

Grazing can and does alter soil properties. However, in this study there were marginal changes observed. The grazing ratio 3:1 exhibited the highest soil OC, K and the second highest CEC values, with the latter being significantly different from grazing ratios 0:1 and 2:1. Previous findings have demonstrated superior animal performance (in terms of weight gain) and an increase in herbaceous cover under grazing ratio 3:1 (Monametsi *et al.* 2012). It is thus likely that the increased vegetation cover contributed to soil OC accumulation, especially through the belowground parts of vegetation as reported by Cui *et al*. (2005). Both goat and cattle manure can increase soil pH as well as increase exchangeable Ca and Mg, although some studies have found goat faecal material to be more effective (Ano and Agwu 2005) – a likely scenario reflected under grazing ratio 0:1 with goats only. Overall, different grazing ratios of cattle and goats did not strongly influence soil chemical properties and this could be attributed to the conservative stocking rate used in this study which is recommended for the mixed Mopane veld. It is therefore not surprising that at this stocking rate, no deleterious effects on soil properties were detected. However, it will be interesting to monitor soil quality over longer periods of time to observe any significant changes due to varying grazing ratios. Also, other factors not measured in the present study like soil texture may have had an influence.

On the other hand, the non-grazed paddock displayed the highest P as well as relatively higher CEC values. Soil CEC is an indicator of nutrient cycling and storage potential (Liebig *et al.* 2006), and its high level under non-grazed land could suggest high nutrient retention as standing biomass is decomposed and nutrients recycled locally with limited redistribution across the rangeland. Hence, grazing removal could facilitate recovery of soil nutrients as observed in previous studies (Gass and Binkley 2011). However, it is widely accepted that light or moderate grazing intensity as used in this study generally benefits biodiversity as well as aboveground biomass production (McNaughton 1979). Thus it may not be desirable to continuously exclude disturbances like grazing from highly productive grassland ecosystems.

C. Interactions between distance and cattle-goat ratio on soil nutrients

Multivariate analysis did not detect a distinct and consistent response of soil properties in relation to the grazing piosphere and cattle-goat combinations, with exception of K concentration which showed significant interaction of grazing distance and mixed-grazing. Grazing pressure, reflected through distance from water source, affects several soil properties even under mixed grazing, which indicates that grazing intensity does affect soil properties as suggested in other studies (Smet and Ward 2006). Therefore, rotational grazing, where water source is shifted across grazing areas, could create nutrient hotspots in the grazing land and in turn, boost primary productivity and grazing land patchiness (Muchiuru *et al.* 2009).

CONCLUSION

Soils under paddocks grazed by cattle alone or goats alone or different combinations of the two livestock species did not show any overall deleterious effects.

However, there was a centripetal flow of certain nutrients with increasing distance from the permanent water points particularly CEC, P, K, Mg and OC as well as soil pH. The non-grazed paddock had relatively higher P values *vis-a-vis* grazed paddocks. It is highly likely that the conservative stocking rate of 12ha/LSU used in this study and the duration were not sufficient to induce significant changes in soil chemistry, thus a more robust test can be attempted under a wider range of stocking densities before practical soil fertility management implications are inferred. Livestock herd behaviour under such settings can also be investigated further.

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