The Role of Cattle Grazing Management on Perennial Grass and Woody Vegetation Cover in Semiarid Rangelands: Insights From Two Case Studies in the Botswana Kalahari

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On the Ground

- We assessed the long-term effects of continuous and rotational grazing on grass and tree dynamics on adjacent ranches in the semiarid Kalahari of western Botswana.
- Rotationally grazed ranches had higher grass cover with more perennial grass species, higher grazing value (and capacity), and higher long-term stocking rates than their continuously grazed neighbors. Tree cover tended to be higher on continuously grazed ranches, suggesting that long-term continuous grazing reduced grass production and favored establishment of woody vegetation.
- Improvement in semiarid rangeland health and production is unlikely to be achieved simply by reducing stocking rates; uniform grazing and growing season recovery periods are essential.
- These and other case studies suggest that benefits of grazing strategies likely depend on scale and adaptive management. Future research should be at larger spatial and temporal scales.

Keywords: continuous grazing, grazing capacity, grazing value, rotational grazing, stocking rate.

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Grazing management practices are broadly defined as reoccurring periods of grazing, resting, and deferment of pastures.[1] For simplicity grazing systems are categorized into two broad types: continuous grazing (CG), which involves season-long grazing of the entire management unit, and rotational grazing (RG), which involves moving a herd through multiple pastures within a matrix of paddocks in varying phases of recovery from grazing.[2] Rotational grazing practices are meant to increase grass and animal production, promote more uniform grazing, and maintain favorable grass species composition.[1,3]

Inappropriate grazing practices may result in undesirable vegetation change in rangelands including an increase in woody vegetation and a decrease in perennial grass species leading to reduced carrying capacity.[4] Productive perennial grasses exert strong competitive effects on woody species, thereby greatly retarding their growth.[5] The effects of reduced competition by the grass layer may be exacerbated by reduced fire intensity and frequency, leading to unimpeded woody plant establishment and growth.

Rangeland researchers and managers worldwide continue to debate the efficiency of continuous and rotational grazing practices in maintaining rangeland vegetation and livestock production.[3] Meta-analyses of grazing experimental data have found little or no advantages of RG over CG, with stocking rate rather than grazing system consistently emerging as the most important management factor determining range condition and animal performance.[6] However, Teague and colleagues identified problems associated with small-scale grazing experiments and provided ranch-scale evidence for the benefits of adaptive RG over CG.[3] These authors argued that results from grazing experiments that have relatively small spatial and temporal scales bear little resemblance to the effect of long-term ranch-scale management.

That notwithstanding, small scale experimental research has demonstrated that defoliation of grasses via clipping or grazing reduces their productivity in subsequent years,[7,8] indicating that grasses need periods of non-grazing during the growing season to allow them to recover nutrients lost to grazing. Without sufficient time for recovery, repeatedly grazed perennial grasses will eventually be replaced by ungrazed (less palatable) neighbors and annual grasses[7–9] especially on infertile sandy soils, where recovery of nutrients lost after grazing is more difficult than on fertile soils. These shifts in species composition to plants of lower grazing value, and in dominant life form from perennial to annual, may result in a decline in carrying capacity.[4]

In western and northwestern Botswana, cattle ranching is the main land use practice and an important economic and livelihood strategy in the rangelands.[10] Grazing practices in this area vary from communal areas without a defined system of grazing to commercial ranching in fenced private farms with distinct grazing practices.[11] While there is uncertainty over the efficacy of RG compared with CG,[2,6] both systems (at different levels of intensity) are widely used by ranchers. However, signs of undesirable rangeland conditions have been reported in both commercial cattle ranches and communal areas in this area.[12] In an attempt to monitor and improve rangeland condition in these areas, local government authorities set stocking rates guided by carrying capacities according to the amended grazing policy on agricultural development of 1991.[13]

To acquire more ecological understanding of the dynamics of grasses and woody vegetation between the grazing practices, we conducted two studies on two pairs of adjacent ranches, where in each pair one practiced RG and the other CG, in all cases for many (12-21) years in western and northwestern Botswana. Our objective was to determine the effect of RG vs. CG on perennial grass cover, composition, biomass, and woody vegetation cover. We hypothesized that persistence of perennial grasses and woody vegetation cover would differ with ranches subjected to RG showing significantly higher persistence of perennial grasses and lower woody vegetation cover. We expected to provide insights that would advise policy and ranchers on grazing management strategies in semiarid rangelands particularly on sandy infertile soils.

Study Area

We selected two pairs of adjacent ranches, where in each pair, one practiced RG and the other CG, at two separate sites in the Kalahari ecosystem of Botswana. Both Gantsi and Ngamiland district have a semi-arid climate with cold dry winters and hot wet summers with a mean annual precipitation of 430 mm and 460 mm, respectively.[14] Soils at both study sites are deep Kalahari sands with low nutrients and organic matter content.[15] One site was at Farm 122 and Farm 120-121 in Gantsi District in western Botswana (21°53’42.17”S and 21°49’53.58”E). The other site was at Farm 12 and Farm 11 of the Hainaveld ranches in Ngamiland District in northwestern Botswana (20°26’30.05”S and 23°25’39.9”E).

Gantsi is characterized by open shrub savanna with scattered trees and perennial tufted grasses, dominated by silky bushman grass (*Stipagrostis uniplumis)* and common finger grass (*Digitaria eriantha)*. Vegetation of the Hainaveld ranches is dominated by raisin bush (*Grewia* spp.) and silver terminalia (*Terminalia sericea*) woodland with grass layer characterized by *Digitaria eriantha* and love grasses (*Eragrostis* spp.).[16] The annual recommended stocking rates for Gantsi and Hainaveld, as determined by the Department of Animal Health, and production during the time of survey were 19 ha per livestock unit (LSU, where a LSU is equivalent to a mature cow) and 17 ha/LSU, respectively. However, the recommended stocking rates vary from year to year depending on rainfall and vegetation conditions.

Management Strategies on the Ranches

While some of the ranches we assessed kept detailed records, we acknowledge that information on past management strategies on some of the ranches beyond 15 years was in most cases not available, and as a result we depended on anecdotal information by the ranch owners.

Gantsi – RG

Farm 120-121 (18,800 ha) is a private commercial cattle ranch with a network of fences dividing it into 64 paddocks with eight water points. The water points are located in the center of a wagon wheel pattern of radiating fences of paddocks. It has an advanced intensive grazing system that involves moving multiple herds of cattle (main herd >2,000) to graze each paddock for a week and then allowing the grazed paddock to recover for at least three months. The system is more than just a simple rotation of cattle between paddocks as it also involves pasture assessments in individual paddocks prior to grazing. There were 3,554 mature cattle on the ranch during the study period and this equated to 5.3 ha/LSU, which was more than three times the recommended stocking rate of the region (19 ha/LSU). The stocking rate and the system of grazing had been maintained for 21 years since 1990 (Dudley Barnes–the ranch owner, pers. comm., October 2011).

Gantsi – CG

Farm 122 (15,000 ha) is also a privately owned commercial cattle ranch in Gantsi adjacent to Farm 120-121. The ranch is not divided into any paddocks and it has only one water point located at the northwestern corner. It has been continuously grazed at low stocking densities for at least 15 years since 1996. Information from the Gantsi veterinary department (although it has gaps on some years) indicates that cattle numbers have fluctuated from 745 (20.1 ha/LSU) in 1996 to 582 (25.8 ha/LSU) in 2004. In 2005 ownership of the ranch changed but grazing management remained unchanged until 2011 (time of this survey). During this time, there were 400 head of cattle in the ranch (37.5 ha/LSU), which is about half the recommended stocking rate (19 ha/LSU).

Hainaveld – RG

Farm 12 (5,000 ha) is a commercial cattle ranch at Hainaveld practicing a less intensive system of RG. The ranch is divided into six paddocks where cattle spend two months in each paddock. Three paddocks (half of the ranch) are always grazed in the wet season, and the other three in the dry season. Paddocks that are grazed in the dry season get a full wet season recovery period. Each of the paddocks grazed in the wet season gets at least three months of recovery time either early or late in the growing season depending on when it was grazed, and remains ungrazed throughout the dry season. During the time of survey, there were 450 head of cattle at ca. 11.1 ha/LSU (Sekeletu pers. comm., June 2015). The average stocking density over a 12-year period since 2002 leading up to the study was 13 ha/LSU.

Hainaveld – CG

Farm 11 ranch (5,000 ha) practices CG at ca. 22 ha/LSU. The ranch does not have a defined grazing practice and one herd of cattle graze the entire ranch without paddocks throughout the season. The grazing practice has been maintained for more than 15 years since 1999. Records from the animal health department indicate that the ranch has been stocked at an average of 20 ha/LSU over a period of 15 years (1999–2014).

Vegetation Assessment Methods

We used a fenceline contrast approach to survey vegetation differences between the ranches at both sites. However, we used different vegetation assessment methods at the two sites. For grazing value (palatability) and life form (perennial or annual) of grasses, we followed the classification of van Oudtshoorn. We considered both research and management levels of confidence associated with statistical significance of differences on vegetation dynamics between grazing management types for decision-making purposes.

We conducted the Gantsi contrast in February 2012 along the 7 km eastern boundary of the RG farm and the adjacent CG farm. We assessed grass cover, composition, and standing biomass (live and dead) using the line intercept and quadrat sampling technique in pairs of adjacent transects such that each pair consisted of one transect on the RG and the other on the CG ranch (Fig. 1). We used remotely sensed images of the ranches to compare woody vegetation cover on the two ranches from tree crown areas calculated on 10 paired plots where in each pair one plot was in the RG and the other in the CG ranch (Fig. 1). A full description of the plots and transects layout and treatments is available in the supplemental material (http://dx.doi.org/10.1016/j.rala.2016.07.001).

We carried out the Hainaveld contrast in June 2015, along a section of the RG ranch where the paddock was grazed during the dry season. We surveyed grass and woody vegetation cover along the shared fenceline of the RG and the CG ranch using the variable quadrat method for woody species and the quadrat method for grass species (see online supplemental material). We laid ten pairs of quadrats perpendicular to and 20 m from the fenceline at 500 m intervals.

Refer to the online supplemental material for a full account of the statistical tests and significance levels of differences between the ranches for both research and management decision-making purposes.

Results of Grazing Management

Refer to Table 1 for the response of woody vegetation cover and grass dynamics to grazing management. Total grass cover and perennial grass cover at Gantsi were higher on the RG while annual grass cover was higher on the CG ranch. Similarly, at Hainaveld, total grass cover and perennial grass cover were higher on RG than CG ranch, while annual grass cover did not differ between the ranches. Aboveground biomass (current year and previous years dead) and species diversity did not differ between the RG and CG but species richness was higher on the CG ranch in Gantsi. However, at Hainaveld, the RG ranch had higher grass species diversity than the CG ranch with the same number of species.

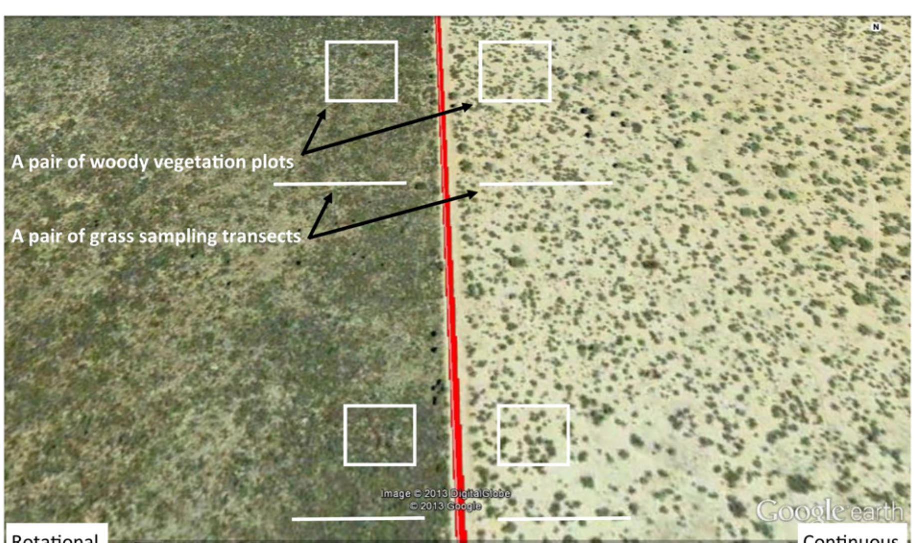

Figure 1. A Google Earth image showing pairs of woody vegetation assessment plots and grass sampling transects drawn along a fenceline (red line) dividing a rotationally grazed and a continuously grazed ranch of Gantsi district in western Botswana. Plots in each pair measure 40 × 40 m, and pairs are 500 m apart.

Table 1. Cover by life form, grass biomass, species richness, and diversity on adjacent ranches practicing continuous or rotational grazing, in two districts of western Botswana

Site	Parameter	Grazing management	
		Rotational	Continuous
Gantsi	Woody plants cover, %	35.9 ± 6.61	43.3 ± 11.24*
	Annual grass cover, %	5.3 ± 2.10	11.5 ± 3.02†
	Perennial grass cover, %	49.0 ± 5.81	27.1 ± 4.54†
	Total grass cover, %	51.8 ± 16.90	35 ± 11.62†
	‡Standing biomass, g^{-2}	41.7 ± 5.12	32.7 ± 6.60
	No. Species	10	12†
	Shannon diversity index, *H*	1.73	1.58
Hainaveld	Woody plants cover, %	37.9 ± 6.45	54.0 ± 11.9*
	Annual grass cover, %	4.08 ± 2.01	2.69 ± 1.23
	Perennial grass cover, %	27.5 ± 5.62	7.28 ± 1.21†
	Total grass cover, %	33.9 ± 6.12	8.83 ± 1.30†
	No. Species	10	10
	Shannon diversity index, *H*	1.29	0.5†

Note. Data are mean per plot and standard error.
* Statistically significant difference ($P < 0.10$).
† Statistically significant difference ($P < 0.05$).
‡ Standing biomass was not measured at Hainaveld ranches.

At the higher confidence level normally used for research (95%), woody vegetation differences between the ranches were not significant, but at the lower and acceptable confidence level associated with management decision-making (90%), there were more woody species on CG ranches at both sites. The aerial view of the Gantsi fenceline contrast also shows larger tree sizes on the CG and more grass cover on the RG grazed ranch (Fig. 2). An extended version of Table 1 showing test statistics is available in the supplemental material (http://dx.doi.org/10.1016/j.rala.2016.07.001).

Refer to Table 2 and Figure 3 for the effects of grazing management on individual grass species of different life forms and grazing value. Cover of high grazing value species was higher on RG than CG ranches at both sites. While cover of

Figure 2. An aerial photograph visualizing the difference in vegetation cover on adjacent ranches practicing continuous and rotational grazing in Gantsi district in western Botswana. (Photo Credits, Dudley Barnes).

Table 2. Cover of grass species of different grazing value on adjacent ranches grazed rotationally or continuously, in two districts of western Botswana

Site	Species	Grazing value*	Life form†	Cover, %	
				Rotational	Continuous
Gantsi	*Aristida congesta*	L	A	0	0.03 ± 0.02
	Aristida meridionalis	L	P	0	1.95 ± 1.19
	Brachiaria nigropedata	H	P	25.4 ± 5.98	1.22 ± 0.72‡
	Digitaria eriantha	H	P	1.64 ± 1.03	2.61 ± 1.52
	Digitaria sanguinalis	L	A	1.93 ± 1.23	4.62 ± 1.43
	Eragrostis lehmanniana	M	P	5.00 ± 1.35	3.72 ± 1.27
	Eragrostis pallens	L	P	1.38 ± 1.09	0.61 ± 0.61
	Eragrostis rigidior	M	P	4.60 ± 4.37	0.31 ± 0.31
	Melinis repens	M	A	2.21 ± 0.91	5.44 ± 1.51‡
	Schmidtia pappophoroides	H	P	2.33 ± 1.53	0.34 ± 0.31
	Stipagrostis uniplumis	M	P	6.32 ± 1.70	17.8 ± 4.89‡
	Urochloa trichopus	H	A	1.12 ± 0.79	1.53 ± 0.80‡
Hainaveld	*Aristida congesta*	L	A	0.24 ± 0.18	0.29 ± 0.18
	Dactyloctenium aegyptium	M	A	0.60 ± 0.60	0.08 ± 0.03
	Digitaria eriantha	H	P	11.69 ± 3.76	1.35 ± 0.55‡
	Eragrostis rigidior	M	P	11.39 ± 1.87	4.71 ± 1.33‡
	Melinis repens	M	A	1.38 ± 0.38	0.91 ± 0.31
	Pogonarthria fleckii	L	A	2.01 ± 1.73	0.06 ± 0.03
	Schmidtia pappophoroides	H	P	3.86 ± 0.94	0.35 ± 0.14‡
	Stipagrostis uniplumis	M	P	0.60 ± 0.28	0.86 ± 0.35
	Tragus racemosa	L	A	0.05 ± 0.03	0.01 ± 0.01
	Urochloa trichopus	H	A	1.80 ± 1.39	1.34 ± 0.46

Note. Data are mean per plot and standard error.
* L = low grazing value; M = medium grazing value; and H = high grazing value.
† A = annual; P = perennial.
‡ Statistically significant difference ($P < 0.10$).

medium grazing value species was not different between RG and CG in Gantsi, it was higher on the RG than CG at Hainaveld. Black-footed grass (*Brachiaria nigropedata*), a high grazing value species, and silky bushman grass (*Stipagrostis uniplumis*), a medium grazing value species, dominated the RG and CG ranch, respectively. Cover of annuals, Natal redtop (*Melinis repens)* and crab finger grass (*Digitaria sanguinalis),* also a low grazing value species, were higher on the CG than RG ranch at Gantsi. Common finger grass (*Digitaria eriantha)* and sand quick (*Schmidtia pappophoroides*), all perennial species of high grazing value, and medium grazing value broad curly leaf (*Eragrostis rigidior*) were higher on the RG than the CG ranch at Hainaveld. A detailed version of Table 2 showing test statistics is available in the supplemental material (http://dx.doi.org/10.1016/j.rala.2016.07.001).

Implications for Grazing Management

In our two case studies, grazing practice changed grass cover and proportion of grass life forms and grazing value. The higher total and palatable perennial grass cover on RG compared with CG ranches, despite the high stocking rates in RG ranches, suggest the importance of recovery periods for grasses to recover nutrients lost to grazing in infertile soils and the benefits of high stocking rates to promote even grazing distribution. At high stocking rates, selectivity is reduced as grazing impacts are evenly distributed over the paddocks, hence both palatable and unpalatable species experience similar grazing levels.[3] However, under similar levels of defoliation, palatable grasses are more tolerant of defoliation than unpalatable grasses.[3,8] While the use of multi-paddock grazing with high stocking rates for short durations, such as

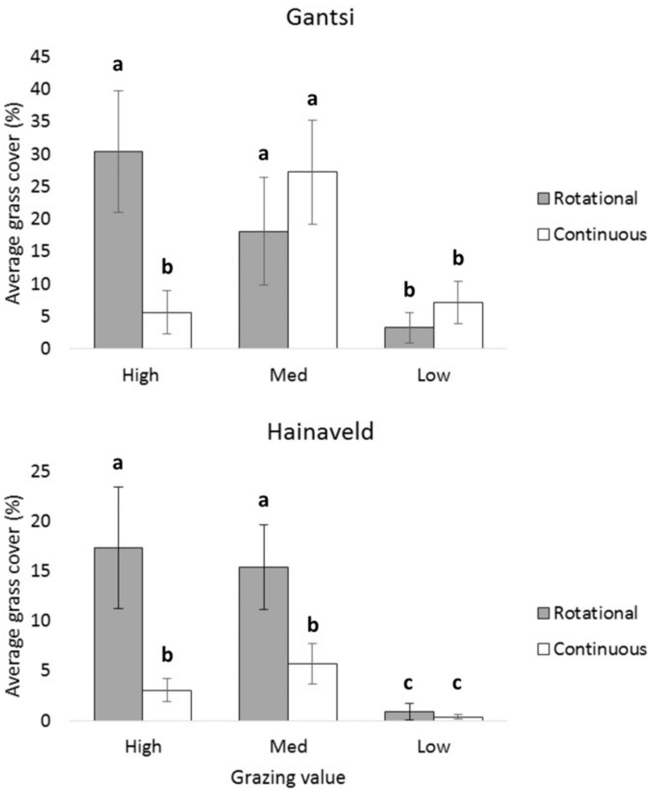

Figure 3. Mean cover (± SE) of grass species of different grazing values on adjacent ranches practicing continuous and rotational grazing in two districts of the Kalahari in western Botswana. Different letters indicate significant differences (Wilcoxons matched pairs test; $P < 0.05$).

the Gantsi RG improves forage resources, it may also be labor and cost intensive. Nonetheless, grazing management that uses few paddocks, such as the Hainaveld RG, may also improve forage resources with less intensive management.

As seen on CG ranches, low stocking rates are not sufficient to promote perennial grass establishment. This is because under CG at low stocking rates, cattle selectively graze the palatable species, which are not afforded adequate recovery, hence promoting uneven grazing distribution.[3,17,18] While continuous grazing at appropriate stocking rates appears to be sustainable in fertile environments,[6] on the infertile Kalahari sands, plant nutrient loss under grazing has much greater consequences for perennial grass persistence than in ecosystems with more fertile soils where nutrients are more easily replaced after removal in grazed tissue.[19] The grazed grasses in these infertile soils would be unable to adequately recover key growth-limiting nutrients such as nitrogen when continuously selectively grazed under a CG strategy. Therefore, while stocking rates form an integral part of grazing management, they must be applied together with management that supports uniform grazing and adequate recovery of the available forage to reduce overgrazing.

In addition to cover, grass species composition changed in response to grazing management. At Hainaveld, while species richness did not differ between grazing management, the diversity was higher on RG perhaps because of the abundance of few dominant species. Similarly, the higher number of species on the CG than the RG ranch at Gantsi suggests an increase of tail-end (minor unabundant) species that result from diminishing dominant species that are continuously selectively grazed.[20] Under appropriate grazing management that promotes uniform grazing and adequate recovery of grazed plants, minor species are out-competed by the dominants and make up a relatively small proportion of cover.[20] On the other hand, grass biomass (not measured at Hainaveld) including moribund material was not different between grazing management perhaps as a result of an accumulation of moribund material from the abundant silky bushman grass that was apparent under CG.

Apart from changes in grass dynamics, grazing management also changed woody vegetation cover. At the 90% confidence level, woody vegetation cover was higher on RG than CG suggesting that grazing management may have affected woody cover. Indeed, this would be expected seeing that continuous grazing has reduced grass cover, which may exert strong competitive effects on trees.[5]

To conclude, we provide a useful insight that grazing management that promotes even grazing distribution at appropriate stocking rates, and adequate recovery periods of grazed paddocks in the growing season, is important for maintaining the cover of palatable perennial grasses in semiarid rangelands. In sandy infertile soils, such grazing management is critical to allow recovery of nutrients lost to grazing and rebuilding of root biomass, which likely is more rapidly achieved in fertile soils. Thus, ranch managers and policy makers should not rely on changing stocking rates as a sole means of improving rangeland productivity and condition, especially in regions with sandy soils.

We recommend future research at larger spatial and temporal scales to determine long-term trends in vegetation responses to different grazing practices in the semiarid rangelands of Botswana. Long-term ranch-based research that combines rancher experience and scientific experiments to assess the effects of grazing management system on local rangelands is lacking.

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Appendix A. Supplementary Data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.rala.2016.07.001.

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