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Rangeland management effects on soil properties in the savanna biome, South Africa: A case study along grazing gradients in communal and commercial farms

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ABSTRACT

Although the savanna biome of South Africa is a major resource for rangeland management, little is known about how differences in rangeland management systems affect soil properties in such biomes. Near to Kuruman, commercial farms have practiced rotational grazing for decades. In communal areas of former homeland Bophuthatswana, similar strategies were used prior to 1994. Nowadays, a continuous grazing system is common. We hypothesized that these changes in management affected soil properties. To test this, we sampled soils at communal and commercial land along a gradient with increasing distance to water points. The results revealed that communal systems with continuous grazing showed enlarged spatial gradients. The soils were depleted in most nutrients close to the water relative to those of commercial systems. In contrast, as the distance to the water increased, the nutrient stocks of these communal systems were higher. Changes in soil nutrient stocks were related to a zone of increased bush encroachment (up to 25%). Specific analyses (phosphorus fractions, particulate organic carbon, $\delta^{13}C$) confirmed that the soils of the communal grazing systems benefited from the shift of grass-dominated to bush-dominated system with woody *Acacia* vegetation, while the rangeland degraded in the sense that it lost palatable grass species.

1. Introduction

Rangelands play an important role in the delivery of ecosystem services and goods for livelihoods worldwide, with the provisioning of livestock being one of the most important services in arid and semiarid savannas. In South Africa, these ecosystems comprise the northern and eastern parts of the country, with the arid savanna extending into the southern Kalahari. In such locations, the harsh and unpredictable environmental conditions require a flexible and adaptive management strategy regarding natural resources. Extensive livestock management is commonly practiced, either on privately owned commercial ranching or on communal rangeland management, where the land is used collectively by the members of small villages. The different ownership forms now coincide with differences in rangeland management practice. Commercial farmers have proceeded with rotational grazing systems, which include resting of camps to allow soil to restore after high grazing pressure, therewith promoting vegetation regrowth. In contrast, communal farms frequently lack fences, due to the fact that continuous grazing systems developed after the termination of the country's Apartheid regime in 1994. However, little is known about the effect that such differences have on soil properties in rangeland management.

Today, savannas are subject to various transformations, to the point of rangeland degradation, as they are exposed to climate change, but also to social, land-use or institutional change (Reynolds et al., 2007). The term land degradation as a sole ecological “problem” has been replaced by a social-ecological view

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on land changes, which is seen as a reduction in the capacity of land to perform ecosystem functions and services that support society and development (FAO, 2010). This reduction of ecosystem services may depend on a farmer's perception and options to support them. Rangeland degradation could be a major threat to the livelihood of the people living on the rangeland. In particular, the continuous grazing management system has faced criticism for its observed rangeland degradation (Smet and Ward, 2006). According to Hardin (1968) and his "tragedy of the commons," communal systems were often regarded as endangered because of their inability to collectively manage common resources on a sustainable basis (Palmer and Bennett, 2013). However, communal sites have to be related to the amount of time they have been under "free" communal management (Wessels et al., 2007), and a historical view on environmental development may be necessary. Most of the communal land in South Africa belongs to former homelands that were established during the 1970s as geographically separated areas in the country, occupying 13% of the country's total land surface and having a maximum concentration of humans and animals. One of these homelands was located on the edge of the Kalahari, close to Kuruman. From 1910 to 1977, the Kuruman area had a long history in the segregation of black and white communities (Jacobs, 2003). At the end of this period, "black spots" – small reserves in areas designated for whites only – were cleared and blacks were moved to "Bophuthatswana," northeast of Kuruman. This, combined with the Betterment Scheme (a development program for reserves), involved relocating people in compact villages, demarcation and fencing off of areas for cultivation and grazing, and calculation of carrying capacities of grazing land (Jacobs, 2003). Consequently, a system of rotational grazing with development of artificial water sources arose in the former homeland, northeast of Kuruman. After 1994, however, a breakdown of institutions and infrastructure transformed the use of the communal grazing land.

Nowadays, fences are broken or even lacking, and livestock is allowed to continuously and selectively graze without any control around water sources, such as artificial water points. A detailed survey of 453 agricultural resource experts compiled in the *National Review of Land Degradation* found that communal areas are widely believed to be degraded (Hoffman and Todd, 2000). Despite this, the former homeland near Kuruman provides us with the opportunity to investigate the effects that the rangeland management system has had on soil properties in communal areas, where management has changed within the last 20 years from a rotational to a continuous grazing system. On commercial farms, the rotational grazing systems in contrast has prevailed and may therefore serve as a kind of benchmark for the effects that rangeland management has on soil properties.

Changes of rangelands in savannas are often accompanied by bush encroachment, which has become a widespread phenomenon in arid and semi-arid environments. Worldwide, 10–20% of these drylands have already undergone encroachment of woody plants (Eldridge et al., 2011). This includes large areas of rangelands in South Africa, especially in the arid sandy savanna biome of the Northern Cape and North-West Provinces (Jacobs, 2003; Wigley et al., 2010). Several factors have promoted the spread of bushes and trees in arid savannas. External drivers (Sankaran and Anderson, 2009) or so-called bottom-up controls (Bond, 2008) such as climate change (for example, rising temperatures, frequency of droughts, rising atmospheric CO_2 levels) and soil nutrient supply interact with internal drivers or top-down controls such as fire and herbivores on bush abundance (Vetter, 2009). With regard to the latter, land use practices regarding animal species, stocking numbers and management systems may exert a strong influence on bush encroachment (Bond and Midgley, 2012). In this context, the continuous grazing system has faced particular criticism, as the removal of palatable grasses by the animals may go along with the encroachment of woody species and changes in plant composition (Todd, 2006).

Nevertheless, the role that grazing and rangeland management have played in the extent of degradation, such as bush encroachment, remains under debate. In the 1980s and 1990s, a paradigm shift in ecological thinking replaced equilibrium theory. Equilibrium theory assumes that vegetation tends towards a climax state in equilibrium with long-term rainfall, soil, and topographic factors (Behnke and Scoones, 1993). Hence, an optimum carrying capacity can be calculated based on the survival of near-climax-state vegetation. In contrast, non-equilibrium theories have described savannas as ecosystems in which temporal and spatial variability are normal characteristics of vegetation. Main factors for the variability are animals and climate (Thomas and Twyman, 2004). Cause analysis for rangeland degradation must include both natural heterogeneity and livestock management. In communal areas of Kuruman, the livestock system changed from 1994 onwards, from a rotational system to a continuous grazing system.

Early indicators of a change in management practices may first become visible in areas with maximum load. As the distribution of livestock is restricted by water availability, water points are areas of the highest animal activities. Grazing pressure changes considerably over short distances – which was equated early on with the "piosphere" pattern (Lange, 1969) – and environmental changes as consequence of management could be interpreted as first signs of shifts (Dougill et al., 1999). Piospheres are "hotspots" of land degradation with a sacrifice zone close to the water points (and with radial zones around. However, this piosphere model increasingly faced criticism in heterogeneous environments because of the fact that animal movement is affected not just by water, but also by the spatial heterogeneity of vegetation (Farmer, 2010). Heterogeneity within the surroundings of water points could have ecological relevance and could be important to management (Chamaillé-Jammes et al., 2009). In particular, when implementing the piosphere model as a management tool for water supplementation, this approach has clearly failed in heterogeneous environments (Farmer, 2010) because the development of radial, concentric rings around water requires homogeneous environments. Putting all the criticism to one side, an approach that investigates changes in "distance to water" is still very valuable for finding early warning indicators about how different rangeland management systems may affect soil properties. Such an approach makes it possible to allocate rangeland management impacts on areas with maximum load (e.g., Kotzé et al., 2013) and study areas away from the water points provides a sensitive study area to changes in rangeland management, which happened in this location 20 years ago.

The study of grazing effects on vegetation and soil properties along transects with decreasing grazing intensity remains a widely used approach today (e.g. Tefera et al., 2007; Moreno Garcia et al., 2014). Moreover, combining this "distance to water point approach" with a "rangeland condition-driven approach" (Snyman and Du Preez, 2005; Van der Westhuizen et al., 2005) makes it possible to compare several ecological properties of different management systems under the same visual rangeland conditions. The term rangeland condition is used here to describe vegetation in relation to its long-term potential for livestock production (Van der Westhuizen et al., 2005). Therefore, the assessment is related to grass and palatable species and excludes woody species. Differences in rangeland quality are linked to the dominance of several main palatable grass species (e.g., *Stipagrostis uniplums, Centropodia glauca*), which may be lacking or replaced by annual species (poor rangeland conditions), have poor-to-intermediate abundance (moderate), or be frequent as observed under sufficient rainfall and low grazing pressure conditions (good). The results of various