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# Positive versus negative environmental impacts of tree encroachment in South Africa

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ABSTRACT

Woody plant encroachment in grasslands is a worldwide phenomenon. Despite many studies, the consequences of woody plant encroachment on sub-canopy vegetation and soil properties are still unclear. To better understand the impacts of trees on grassland properties we examined the following questions using a mountainous sub-tropical grassland of South Africa encroached by an indigenous tree, *Acacia sieberiana* as a case study: (1) Do trees increase sub-canopy herbaceous diversity, quality and biomass and soil nitrogen content? (2) Do large trees have a stronger effect than medium-sized trees on grass and soil properties? (3) Does the impact of trees change with the presence of livestock and position of trees in a catena? We studied grass and non-graminoid species diversity and biomass, grass quality and soil properties during the wet season of 2009. Nitrogen in grass leaves, soil cation exchange capacity and calcium and magnesium ion concentrations in the soil increased under tall *Acacia* versus open areas. Medium-sized *Acacia* decreased the gross energy content, digestibility and neutral detergent fibre of grasses but increased the species richness of non-graminoids. Tall and medium *Acacia* trees were associated with the presence of *Senecio inaequidens*, an indigenous species that is toxic to horses and cattle. The presence of livestock resulted in a decrease in herbaceous root biomass and an increase in soil carbon and leaf biomass of grass under *Acacia*. Tree position in the catena did not modify the impact of trees on the herbaceous layer and soil properties. For management of livestock we recommend retaining tall *Acacia* trees and partially removing medium-sized *Acacia* trees because the latter had negative effects on grass quality.



## 1. Introduction

Grasslands and savannas cover 51% of the total land area of the earth (Asner et al., 2004) and almost 40% of the global population depends on these biomes (Reynolds et al., 2007). Any degradation occurring in these ecosystems will have a strong impact on local human populations, especially on rural livestock-dependent communities. Woody plant encroachment into grasslands and savannas is a widespread phenomenon (Ward, 2005; Wiegand et al., 2005; Bond, 2008; Graz, 2008; Van Auken, 2009) that reduces the area available for grazing and transforms grasslands into savannas or woodlands (Archer, 1995; Eldridge et al., 2011).

In the last 50 years, the phenomenon of woody plant encroachment has increased, and both positive and negative effects on grassland and savanna functions and properties have been reported (Scholes and Archer, 1997; Archer et al., 2001; Van Auken, 2009; Eldridge et al., 2011). The effects of encroachment are highly variable and, despite many studies (e.g. Treydte et al., 2007; Riginos et al., 2009; Ravi et al., 2010), the impact of woody plant encroachment in grasslands and savannas is still unclear. For example, trees increased grass biomass and soil nutrient content in Ethiopia (Abule et al., 2005), while they decreased grass cover and the ability to take up nutrients and fix carbon in grassland of the central USA (Lett and

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Knapp, 2003). Woody plant encroachment has been inconsistently linked to ecosystem degradation or desertification (Maestre et al., 2009; Eldridge et al., 2011). In arid and semi-arid areas where water limitation occurs, shading by trees can have more positive impacts on the herbaceous layer than in more humid areas (e.g. Belsky et al., 1993; Treydte et al., 2007). The impact of trees on grassland properties in wetter areas may be less conspicuous or more difficult to test experimentally (Treydte et al., 2007). Moreover, few studies have dealt with the impact of trees on non-graminoid herbaceous species (Belsky et al., 1993), which may also play an important role for pastoralism and biodiversity (Hector et al., 1999; Pfisterer et al., 2003; Schmidtke et al., 2010).

Since many studies have focused on woody plant encroachment in semi-arid and arid areas (Belsky et al., 1989; Abule et al., 2005; Ward, 2009), this study uses a mesic grassland in South Africa. The main goal was to better understand the impact of trees on the herbaceous layer and soil properties, with a focus on their effects on livestock grazing. Tree effects on the herbaceous layer and soil properties are expected to depend on the tree species and tree size/age (Treydte et al., 2007, 2009). *Acacia* species, as legumes, usually increase soil nitrogen (Kambatuku et al., 2011), with the magnitude of increase correlated with tree size (Ludwig et al., 2004). In addition, shading effects on the herbaceous layer change with canopy size (Belsky, 1994). We studied two other factors (catena position and the presence or absence of livestock) that may modify the impact of trees on the herbaceous layer and soil properties. While the effects of grazing have frequently been studied (e.g., Belsky et al., 1993; Abule et al., 2005; Mbatha and Ward, 2010; Dunne et al., 2011), their interaction with catena position is not known. Catena position is one of the determinants of soil depth and texture and therefore of soil properties (Oztas et al., 2003; Salako et al., 2006). Soil properties such as bulk density affect soil moisture (Famiglietti et al., 1998) or soil fertility which can drive ecosystem processes, modifying the effects of trees on the soil and herbaceous layer (Treydte et al., 2007). Livestock have a large impact on grassland (Mbatha and Ward, 2010; Dunne et al., 2011). Their presence, through grazing, trampling or dung fertilization may also modify the impact of trees on the herbaceous layer and soil properties. We aim, through this multi-factorial field study, to highlight mechanisms of the impacts of woody plant encroachment on the sub-canopy herbaceous layer and soil properties. Based on the previously cited literature, we tested the following predictions from the perspective of the impacts of grazing by cattle (the main herbivores at our study site):

1) The legume, *Acacia sieberiana* var. *woodii* (Burtt Davy) Keay & Brenan, increases the quality and biomass of the sub-canopy herbaceous layer and improves soil properties, especially by increasing soil N. We also predict that the array of herbaceous species may be modified under *A. sieberiana*, favouring some less palatable species for cattle grazing.
2) The stronger shading effect of large trees compared to medium-sized trees reduces herbaceous biomass but increases soil moisture. Soil nitrogen is higher under large trees than under medium-sized trees (Treydte et al., 2007), and large trees improve the quality of the herbaceous layer in terms of grass digestibility, nitrogen, phosphorus, and gross energy.
3) The impact of trees on grass growth is greater in the upper part of the catena on relatively unfertile soils than in the lower part where soils are more fertile.
4) Grazing masks the beneficial effects of trees on the herbaceous layer biomass due to removal of the aboveground grass layer. Livestock increase soil carbon and soil nitrogen under trees through dung and urine deposition (Belsky et al., 1989).

## 2. Materials and methods

### 2.1. Study site

The study site was located in Potshini, 8 km south-east of Bergville (28° 48′ 37″ S; 29° 21′ 19″ E), KwaZulu-Natal, South Africa (Fig. 1). The site was on a north-sloping watershed of the Tugela Basin (30,000 km$^2$) and is representative of the topography, vegetation, climate and human habitat of the KwaZulu-Natal Drakensberg foothills. The altitude of the study site varied between 1217 and 1452 m and covered an area of 2.5 km$^2$. The climate is broadly described as mesic and is sub-humid sub-tropical with two well marked seasons: a rainy summer period (October–April) and a dry winter period (May–September). The area has a mean annual precipitation (calculated over the last 65 years) of 750 $\pm$ 162 mm (Grellier et al., 2012) and mean annual temperatures were 16.5 and 16.1 °C in 2008 and 2009, respectively. Mucina and Rutherford (2006) classified the vegetation as Northern KwaZulu-Natal moist grassland, which is usually dominated by *Themeda triandra* Forssk and *Hyparrhenia hirta* (L.) Stapf. Encroachment by a single indigenous tree species, *A. sieberiana*, occurs in the watershed. Aerial photography of the site confirms tree encroachment over the last 30 years (Grellier et al., 2012). The general soil type is luvisol (World Reference Base, 1998).

We studied three areas with different geomorphologies along the catena (Fig. 1). These areas are distinguished mainly by their slope as well as geomorphological and ecological characteristics. The first area (hereafter referred to as Upslope) had a steep slope (17.5 $\pm$ 4.5°) and patches of doleritic rocks. The second area (hereafter referred to as Midslope) in the catena was not as steep (9.7 $\pm$ 2.5°), and the third area (hereafter referred to as Downslope), located at the bottom of the watershed had a gentle slope (5.9 $\pm$ 1.4°).

The site is a communally-owned grassland and follows two rotation periods regarding management of livestock (mostly cattle). During the maize-growing season and until harvest (a period of 8 months), the cattle are kept in the grassland areas (November–June). During the winter (for a period of 4 months), the cattle feed on the maize residues in the fields (July–October) located around the community settlement (separated from the grassland areas). There is no clear fire management protocol for this area, which is only affected by natural and accidental fires.

### 2.2. Experimental design

Our multi-factorial design included three treatments: position on the catena, presence-absence of an *Acacia* (and its size) and presence-absence of livestock. To study spatial variation at the landscape scale, we considered the three geomorphological areas described above (Upslope, Midslope, Downslope). To examine the effect of tree presence and size, we sampled 40 individual *Acacia* trees of two size classes, 20 tall *Acacia* trees (>3 m height) and 20 medium-sized *Acacia* trees (1–3 m height) according to their position in the catena, which were almost equally distributed in each of the three zones (Fig. 1). *Acacia* height was measured instead of age as dendrochronology could not be used due to large variation between seasons and associated tree rings observed in this sub-tropical tree. Moreover, size has been successfully used in previous studies (Treydte et al., 2009). The tall *Acacia* trees were on average ($\pm$standard deviation) 5.5 $\pm$ 1.0 m in height and they had a mean diameter at breast height (dbh) of 0.3 $\pm$ 0.1 m and a canopy radius of 4.7 $\pm$ 1.8 m. The medium *Acacia* trees were on average 2.6 $\pm$ 0.5 m tall, with a mean dbh of 0.08 $\pm$ 0.02 m and a canopy radius of 1.6 $\pm$ 0.3 m. As a comparison to areas under tree canopy (see below for details) we selected “open areas” in 24 locations away from *Acacia* in open grassland and distributed in the three areas of the catena. To