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Effect of tree species on understory vegetation, herbaceous biomass and soil nutrients in a semi-arid savanna of Ethiopia

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A B S T R A C T

The effect of tree species on understory vegetation, herbaceous biomass and soil nutrients were studied in a semi-arid savanna of Ethiopia. Twenty large trees, from each of the species: *Acacia robusta*, *Ziziphus spina*-christi, and *Balanites aegyptiaca*, a total of 60 trees, and 480 samples were used for measuring understory vegetation, herbaceous biomass, and soil nutrients during the study. The inside tree canopies had a higher speciesdiversityand plant abundance than the outside tree canopies. *Acacia robusta* had a higher number of species and plant abundance in the understory vegetation compared to other tree species. The biomass yield of herbaceous vegetation under the inside canopies of *A. robusta*was higher than the canopies of other tree species. Similarly, most soil nutrient contents were higher under *A. robusta* than other tree species, and the inside canopies had a higher soil nutrient contents compared to outside tree canopies. Hence, the presence of larger trees in semi-arid African savannas confirmed to maintain more species composition and diversity of understory vegetation, higher herbaceous biomass and improved soil nutrients. Therefore, conservation of larger tree species is crucial for proper utilization and ecological stability of semi-arid African savannas under the changing climate and global warming.

1. Introduction

Savannas are found in tropical or subtropical ecosystems (Scholes and Archer, 1997), occupying about 50% of the southern continents (Sankaran et al., 2004). It is highly dynamic over temporal and spatial scales, and varies with changes in rainfall, soil nutrients, fire and herbivory (Rietkerk and van de Koppel, 1997), characterized by the coexistence of scattered trees and continuous grass layers (Scholes and Archer, 1997; Sankaran et al., 2004). These scattered trees alter the composition and spatial distribution of herbaceous vegetation in a semi-arid savanna. The spatial pattern and abundance of grass species in semi-arid savannas are dictated by a complex and dynamic interactions between trees and grasses (Scholes and Archer, 1997).

Various plant communities consisting of mixtures of grasses, annual forbs and seedlings and saplings grow together under the canopy of larger trees in semi-arid savannas. These plant communities play an important role in primary production, and as habitats for insects, birds, mammals and other species (Legare et al., 2001). Previous studies in semi-arid savannas showed that grass composition is higher under trees compared to open areas (Weltzin and Coughenour, 1990), as a result of increased soil nutrients and shade under tree canopies (Belsky, 1994; Ludwig et al., 2001). Increased soil moisture availability due to hydraulic lift (Ludwig et al., 2001) could also potentially increase grass composition and productivity under tree canopies. Moreover, the accumulation of soil nutrients under tree canopies is often higher under leguminous trees than non-leguminous trees (Belsky et al., 1993). In semi-arid African savannas, where there is an extreme variation in water and nutrients, larger trees usually modify the micro-climate and soil properties, leading to complex local interactions between vegetation and soils under their canopies (Mitchell et al., 2012). These trees also create micro-sites, which exert influences on plant communities grown under their canopies, differently from open areas (Jeltsch et al., 1996).

However, larger trees in semi-arid eastern and southern African savannas are being cleared for charcoal, firewood and timber production (Caro et al., 2005; Tessema et al., 2011), despite their importance in maintaining biological diversity and ecological

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stability of the system. Consequently, this causes a reduction in understory herbaceous vegetation composition, herbaceous biomass, and depletion of soil quality (Mekuria et al., 2007; Tessema et al., 2011). However, the effects of larger trees on understory vegetation vary with the environment (Burrows, 1993), as different herbaceous species respond differently to different tree species (Jeltsch et al., 1996; Kahi et al., 2009). In addition, the influence of larger trees on plant communities underneath is reported to be site and plant species-specific in semi-arid savannas (Kahi et al., 2009; Mitchell et al., 2012). However, information is lacking about the impact of larger trees on the composition of herbaceous vegetation growing under tree canopies compared to the outside canopies in semi-arid Ethiopian savannas. Moreover, results from one area with specific tree species cannot be extrapolated to other areas with different tree and herbaceous plant species (Kahi et al., 2009). Indeed, information about the composition of understory vegetation, herbaceous biomass and soil nutrients in relation to larger tree species under their canopies and open areas are lacking in semi-arid savannas of Ethiopia. Therefore, we studied the effect of leguminous and non-leguminous tree species on the composition of understory vegetation, herbaceous biomass and soil nutrients in an experimental setup, and tested the following hypotheses: (i) inside tree canopies amplify increased understory vegetation composition, herbaceous biomass and soil nutrients than the surrounding open areas, and (ii) the composition of understory vegetation, herbaceous biomass and soil nutrients are higher under leguminous tree species than non-leguminous species in a semi-arid savanna of Ethiopia.

2. Materials and methods

2.1. Description of the study area

The study was conducted at Babile Elephant Sanctuary (BES: 08 °22′30″- 09 °00′30″ N; 42 °01′10″- 43°05′50″ E; 850–1785 m asl), located in the eastern lowlands of Ethiopia (Fig. 1). The BES was selected because there are larger tree species found in isolation and it was possible to contrast tree canopies between the inside canopies versus the outside open areas for understory composition, herbaceous biomass and soil nutrients.

The BES was established in 1970, covers 6982 km^2 and is located 560 km southeast of Addis Ababa, in a semi-arid trans-boundary between Oromia and Somali regions of Ethiopia (Demeke, 2008). The mean annual rainfall was 702.9 mm, ranging between 452 and 1116.9 mm, and was highly variable among years. Its main rainy season is from July–September, with a short rainy season from March–April. The mean daily minimum and maximum temperatures are 11.9 °C and 27.2 °C, respectively, with a mean daily temperature of 19.6 °C (Demeke, 2008).

The BES was established to protect the only surviving African elephant *(Loxodonta africana orleansi)* population in the Horn of Africa (Barnes et al., 1999). The area is also known for its diverse groups of wild animals, which include Crested porcupine (*Hystrix cristata*), Abyssinian hare (*Lepus habessinicus*), Grivet monkey (*Cercopithecus aethiops*), Lesser galago (*Galago senegalensis*), Black-backed jackal (*Canis mesomelas*), White-tailed mongoose (*Ichneumia albicauda*), Dwarf mongoose (*Helogale parvula*), Spotted hyena (*Crocuta crocuta*), Large-spotted genet (*Genetta macullata*), Caracal (*Lynx caracal*), Rock hyrax (*Procavia capensis*), Warthogs (*Phacochoerus africanus* and *P. aethiopicus*), Lesser kudus (*Tragelaphus imberbis)* and Greater kudus (*T. strepsiceros*), Bush duiker (*Sylvica pragrimmia*), Phillip's dik-dik (*Madaqua saltiana*) and Guenther's dik-dik (*Rhyncho tragus guentheri*) (Demeke, 2008). The vegetation of BES was represented by *Acacia* – *Commiphora* woodland, semi-desert scrubland and evergreen scrub ecosystems, dominated with *A. robusta* Burch., *Tamirandus indica* L., *Oncoba spinosa* Forsk, *A. tortilis, Balanites aegyptiaca,* and *Ziziphus spina-christi. Lantana camara*, *Grewia shweinfurtii* and *Glycine* spp. are the dominant shrub species in addition to other herbaceous vegetation available in BES (Belayneh et al., 2011).

2.2. Selection of sampling sites

Based on visual field observation and previous vegetation studies (Belayneh et al., 2011), three dominant tree species, representing one leguminous (*Acacia robusta* Burch*)* and two non-leguminous tree species (*Ziziphus spina-christi* and *Balanites aegyptiaca* (L.) Del), found in isolation, were selected for this study. The species used in this study are representative of the dominant trees in the region (Belayneh et al., 2011; Biru and Bekele, 2012). Based on their abundance (distribution), canopy sizes, basal areas and tree heights, compared to other shrubby woody species, they represent suitable species for a systematic study of the effects of tree canopy cover on understory vegetation and soil nutrient dynamics. Accordingly, 20 matured trees, from each species, were systematically selected based on their similar canopy size ($\approx$25 m^2 diameter) and tree height ($\approx$8 m) according to previous studies (Ludwig et al., 2004; Kahi et al., 2009), without shrubs or termite mounds under or close to their canopies. Moreover, exclosures were erected around all the experimental trees and adjacent open areas before the start of the main rain, beginning of June 2012, to keep off wild and domestic herbivores. In total, 60 trees (3 tree species $\times$ 20 trees/species) were selected for this study. The height of each individual tree from each tree species was estimated by walking away from the tree bending forward and look through two legs back to the tree by stopping as reached at a point where it is possible to see the top of the tree (at 45°) and measuring the distance along the ground to the tree. It is assumed that this distance is equivalent to the height of the tree (Savadogo and Elfving, 2007). The canopy diameter (CD) of trees was measured by using measuring tape on ground level throughout the canopy length in two dimensions, at right angle to each other. According to Savadogo and Elfving (2007), the vertical projected canopy area of each tree species was calculated using the formula: $CA = (CD_1 \text{ x } CD_2) \text{ x } \pi/4$, where CD_1 and CD_2 are the two canopy diameter in two dimensions at right angle to each other.

2.3. Sampling of understory vegetation

Under each selected individual tree, the species composition of understory vegetation, including, herbaceous species, as well as seedlings and saplings of woody species, were assessed, recorded and identified using 1-m^2 quadrat under inside and outside canopies of individual trees (Fig. 2) in September 2012, during the flowering stage of most herbaceous species. Four quadrats in four directions (north, south, east and west) were used under the inside and outside canopy of each individual tree, totaling 480 samples (3 tree species x 20 trees/species x 2 canopy cover x 4 directions as sample quadrats). For those species that were difficult to identify in the field, their local names recorded, herbarium specimens collected, pressed and dried properly and transported to Haramaya University Herbarium, for further identification. The species were further classified in to grasses (annuals and perennials), herbaceous legumes, forbs and woody species to determine the contribution of each functional group. Individual plants were counted in each quadrat to determine the relative abundance of each species. The herbaceous biomass (in DM basis) was determined by harvesting the whole fresh biomass within each quadrat, and oven-drying at 70 °C for 48 h and weighing. Plant nomenclature follows Cufodontis (1953–1972), Fromann and Persson (1974), and Philips (1995).