Vol.3, No.2, 145-150 (2013)
http://dx.doi.org/10.4236/oje.2013.32017

Open Journal of Ecology

Modification of soil properties by *Prosopis* L. in the Kalahari Desert, South-Western Botswana

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Received 15 December 2012; revised 16 January 2013; accepted 14 February 2013

ABSTRACT

The aim of this research was to investigate the interactions between *Prosopis* plants and soils in the Kalahari area, south west of Botswana. The underlying assumptions of the research were that *Prosopis* plants significantly enhanced the nutrient content and improved the condition of soils in the study area, and that the height and canopy size of *Prosopis* plants affected the interactions between *Prosopis* plants and the soils. Firstly, soil samples were collected under 42 randomly selected *Prosopis* plant canopies and in the spaces between *Prosopis* plant canopies at the depth of 0 - 20 cm and 60 - 80 cm. Secondly, soil samples were collected under 45 randomly selected *Prosopis* plant canopies of three different categories of height and canopy size at the depth of 0 - 10 cm. The soil samples were analysed for soil organic carbon, pH, total nitrogen (N), electrical conductivity (EC), calcium (Ca), sodium (Na), potassium (K), and magnesium (Mg). Soil collected under *Prosopis* plant canopies and in the spaces between *Prosopis* plant canopies showed statistically significant difference in the soil organic carbon content ($F = 2.68$, $P = 0.05$, $\alpha = 0.05$), pH ($F = 44.81$, $P < 0.001$; $\alpha = 0.05$) and electrical conductivity (EC) ($F = 3.75$, $P = 0.01$, $\alpha = 0.05$). Statistically significant difference was also observed in the comparison of soils existing under Classes 1, 2 and 3 *Prosopis* plant canopies in relation to pH and EC ($F = 6.56$, $P = 0.01$ and $F = 4.77$, $P = 0.01$ respectively at $\alpha = 0.05$). Therefore, it was concluded that the fundamental assumptions of the study were valid.

Keywords: *Prosopis* Species; Soil Properties; Kalahari Desert; Botswana

1. INTRODUCTION

Prosopis Linnaeus amended Burkart genus belongs to the family Leguminosae (Fabaceae), sub-family Mimosoideae [1]. The genus range covers arid and semi-arid regions in Africa, Asia, Central, Northern and Southern regions of America [1]. The best known and most widely spread *Prosopis* species is *Prosopis juliflora* [1]. [2] described *Prosopis* species as trees or shrubs of various sizes which are primarily xerophilous, aculeate, and spiny. The taxonomy of the *Prosopis* genus compiled by [2] included 44 *Prosopis* species and a number of varieties. The species are aggressive pioneers which predominate over other flora wherever they are introduced [1]. They are famous for their rapid growth and their resilience under harsh arid and semi-arid environments [1]. They also have the capacity to assimilate and store nutrients and moisture in their root systems. Consequently, they usually have relatively large root mass [3]. Since their introduction in Africa, they have aggressively invaded and continue to invade large areas of rangelands [1]. The rangelands in the south east of Botswana are amongst the areas that are seriously affected by the invasion of *Prosopis* species.

Previous studies on the interactions between *Prosopis* species and soil indicated that leguminous tree species modify the characteristics of soil on which they grow [4,5]. Elevated soil nutrient content and lower values of pH are generally associated with soils found under canopies of *Prosopis* plants compared to the inter-canopy areas in arid and semi-arid environments [1,4,5]. Empirical research has shown that the size of a tree, particularly canopy cover, may affect the condition of soil under tree canopy [6,7]. For instance, at earlier stages when a tree is young and its canopy size is small, organic matter may not be efficiently trapped under a small tree canopy within a relatively short period of time [8,9]. With advancing developmental stage of an individual tree, the canopy size and duration of nutrient accumulation may increase, leading to the improvement in understory soil conditions [8,9]. Therefore, this research aims to investigate the interactions between *Prosopis* plants and soils in the Kalahari area, south west of Botswana. The research specifically tests the assumptions that *Prosopis* plants significantly enhance the nutrient content and improve the condition of soils in the Kalahari area and that the height and canopy size of *Prosopis* plant affect the interactions between *Prosopis* plants and the soils.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

The study focuses on four villages (Bokspits, Rappelspan, Vaalhoek and Struizendam) located in the Kalahari district in Botswana (**Figure 1**). The area lies within the Kalahari Desert; a vast area covered in sand stretching between the Orange River and the Zambezi River covering the western and central part of Botswana, eastern Namibia and North western regions of South Africa. The area is mainly undulating plains with interspersed pans, rocky outcrops, dry river valleys and dune fields [10]. It is dominated by longitudinal dunes and some barchan or transverse dunes [11].

It is generally believed that the Nossob-Molopo River valley that exists in the area was part of the Orange River system [10]. The sand stone and quartz comprise the rocky outcrops in the study area with calcrete dominating the riparian zones along the Nossob-Molopo River. The area is also characterized by ephemeral and often relict closed basins of varying scales and origin [12] called pans. The vegetation of the area is generally open tree and grass savanna with sparse cover of tussock grasses. *Acacia erioloba*, *Acacia haematoxylon*, *Rhigozum trichotomum*, *Lycium namaquense*, *Monechma incanum*, *Prosopis chilensis*, *Prosopis velutina*, *Prosopis juliflora*, *Prosopis glandulosa*, hybrids of *P. juliflora* and *P. glandulosa*, *P. Juliflora* and *P. pallida*, *P. chilensis* and *P. glandulosa*, *P. glandulosa* and *P. pallida*, and *P. juliflora* and *Acacia karoo* comprise the main trees and shrubs found in the study area [13] while *Schmidtia pappophoroides*, and *Eragrostis* species are the main grass species growing in the area [10].

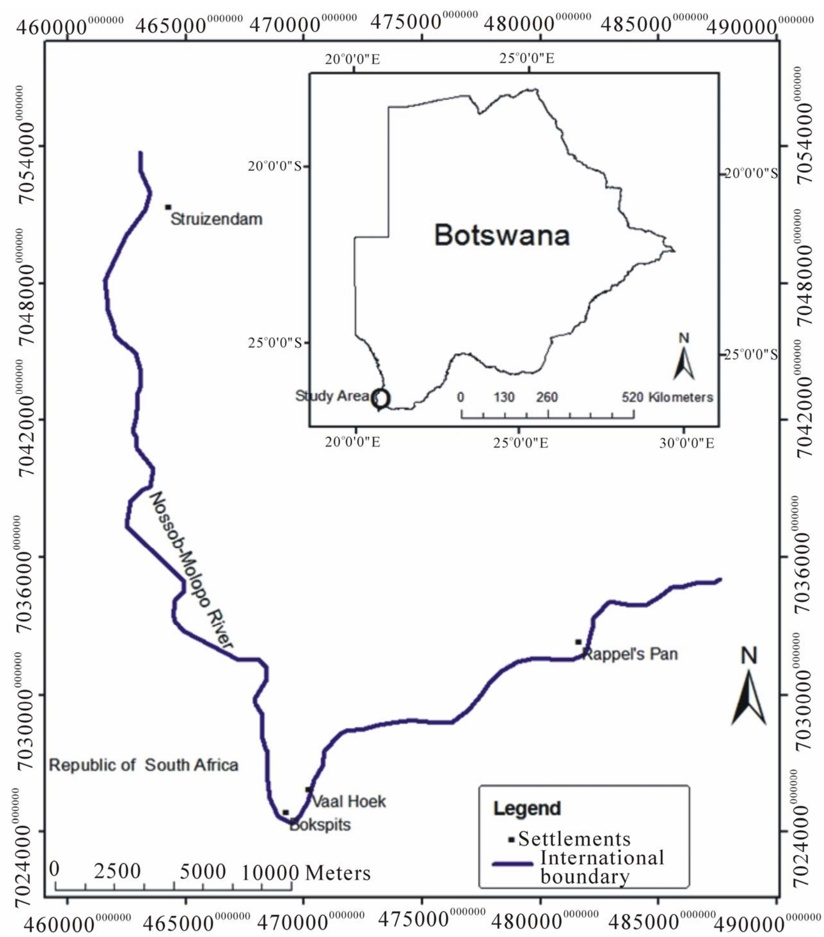

Figure 1. Location of the study area.

The study area forms part of the driest region of Botswana where the mean annual rainfall is 300 mm and the rainfall season is characterized by erratic rainfall pattern [14]. The period starting from November to April marks the season during which the area experiences about 80 per cent of the precipitation. The area experiences very high temperatures in summer which may reach up to over 40˚C, while the winter temperatures are normally between 2 to 4˚C [10].

2.2. Experimental Design and Laboratory Analyses

Firstly, soil samples were collected along three transects spaced equally and radiating from the main stem of 42 randomly selected mature (≥2.5 m height and ≥20 m^2 canopy cover) *Prosopis* tree. Using an auger, soil cores of 5 cm in diameter and 20 cm in length were obtained: 1) under plant canopy or crown at 0.5 m of the radius of the plant canopy and 2) in the space between plant canopy (inter-space/inter-canopy) at a distance of 150 m from the nearest *Prosopis* plants to reduce the influence of *Prosopis* plants on the inter-canopy soil samples. A total of 504 soil samples were collected at the depth of 0 - 20 cm and 60 - 80 cm and pooled by depth and location resulting in a total of 168 soil samples which were prepared for laboratory analysis.

Secondly, *Prosopis* plants were categorized into three classes (*i.e.* Class 1: 0.3-1.5 m height and 1-9 m^2 canopy cover; Class 2: 1.6-2.5 m height and 10-19 m^2 canopy cover; Class 3: 2.5+ m height and 20+ m^2 canopy cover). Soil samples were then collected along three transects spaced equally and radiating from the main stem of 45 randomly selected *Prosopis* plants (15 per class) at 20 cm distance from the stem under plant canopy. The depth of sampling was 0 - 10 cm and sampling was conducted by the use of a hand trowel. A total of 270 soils samples was collected and pooled according to sampling location to make 90 composite samples for laboratory analysis.

All soil samples were prepared by air-drying and sieving through a 2 mm mesh sieve to remove plant material. The soil samples were analyzed for total nitrogen (N), soil organic carbon, pH, electrical conductivity (EC), exchangeable cations (calcium (Ca), sodium (Na), potassium (K), and magnesium (Mg)) as outlined below.

- Total nitrogen and organic carbon were determined using the LecoTruspec CN instrument.
- Soil pH and electrical conductivity (EC) were investigated using the 1:2 (soil: water) ratio extract method [15]. The pH meter was used to measure soil pH and the electrical conductivity meter was used to measure soil EC.
- Ca, Mg, K and Na were analysed through the silver thiourea method [16] and the Varian 220 FS Atomic Absorption Spectrophotometer (AAS).

3. RESULTS

The mean values of the selected soil properties were determined and presented in **Tables 1** and **2**. Analysis of Variance (one way ANOVA) showed that soil organic carbon at 0 - 20 cm under canopy, 60 - 80 cm under canopy, 0 - 20 cm inter-canopy and 60 - 80 cm inter-canopy soil depths were statistically significantly different ($F = 2.68$, $P = 0.05$, $\alpha = 0.05$). Student's t-Test (one tailed) indicated that soil at 0 - 20 cm depth had statistically significantly lower soil organic carbon content in comparison with soil at 60 - 80 cm depth under *Prosopis* plant canopies (**Table 3**). Additionally, soil at 0 - 20 cm depth in the inter-canopy had statistically significantly lower soil organic carbon compared to soil at 60 - 80 cm under canopy and 60 - 80 cm inter-canopy depth. Generally soil organic carbon at 0 - 20 cm depth was statistically significantly lower than at 60 - 80 cm depth.

It was observed through Analysis of Variance (one way ANOVA) that soil pH differed significantly ($F = 44.81$, $P < 0.001$; $\alpha = 0.05$) at 0 - 20 cm under canopy, 60 - 80 cm under canopy, 0 - 20 cm inter-canopy and 60 - 80 cm inter-canopy soil depths. Student's t-Test (one tailed) showed that soil pH was significantly lower at 0 - 20 cm under canopy depth in comparison with 60 - 80 cm under canopy, 0 - 20 cm inter-canopy and 60 - 80 cm inter-canopy depths (**Table 3**). The soil pH was also significantly lower at 0 - 20 cm inter-canopy compared to 60 - 80 cm under canopy and 60 - 80 cm inter-canopy soil depths. The general pattern in the soil pH showed lower pH levels at 0 - 20 cm soil depth as compared to 60 - 80 cm soil depth (**Table 3**). The observed values were above pH7, indicating that the soils in the study area were generally basic.

Analysis of Variance (one way ANOVA) revealed statistically significant difference ($F = 3.75$, $P = 0.01$, $\alpha = 0.05$) in the soil electrical conductivity (EC) at 0-20 cm under canopy, 60 - 80 cm under canopy, 0 - 20 cm inter-canopy and 60 - 80 cm inter-canopy depths. Student's t-Test (one tailed) showed that soil EC was significantly higher at 0 - 20 cm under canopy depth compared to 60 - 80 cm under canopy, 0 - 20 cm inter-canopy and 60-80 cm inter-canopy depths (**Table 3**). In addition, soil had significantly higher EC ($P \leq 0.001$, $\alpha = 0.05$) at 0 - 20 cm depth under *Prosopis* plant canopies. The content of soil Ca, Mg, K and Na and N did not show statistically significant difference (**Table 3**). Statistically significant difference was observed through one way ANOVA in the comparison of soils existing under Classes 1, 2 and 3 *Prosopis* plant canopies in relation to pH and EC ($F = 6.56$, $P = 0.01$ and $F = 4.77$, $P = 0.01$ respectively at $\alpha = 0.05$). Further, Student's t-Test (one tailed) revealed that soils found under Class 3 *Prosopis* plant canopies were statistically significantly different from soils found under Classes 1 and 2 *Prosopis* plant canopies with respect to pH and EC (**Table 4**), while soils existing under Classes 1 and 2 *Prosopis* plant canopies were not statistically significantly different.

4. DISCUSSION

Studies similar to the current research have indicated that *Prosopis* plants significantly modify the characteristics of soils on which they grow (e.g.[5,17]). Such studies showed that increased soil nutrient content (e.g. soil organic matter, Ca, Mg, K and Na and N) and lower values of pH levels are normally associated with soils found under the canopies of *Prosopis* plants compared to the inter-canopy areas in arid and semi-arid environments [1,17]. However, the Ca, Mg, K, Na and N in the soils were low and the soils under *Prosopis* plant canopies and the inter-canopy areas were not statistically significantly different in relation to the afore-mentioned soil nutrients in the study area. This suggested that *Prosopis* plants did not significantly enhance the Ca, Mg, K, Na and N content of soils in the study area.

The general pattern in the soil pH indicated significant lower pH levels at 0 - 20 cm soil depth as compared to 60 - 80 cm soil depth. *Prosopis* plants growing in the study area produced considerable amount of litter fall as it is usually the case in other habitats where *Prosopis* plants grow. For instance, [21] observed that a 4 to 6 year old *Prosopis juliflorast* and produced 5 to 8 tonnes per hector per year of dry leaf litter, while 8 year old *Pro-*

Table 1. Selected soil properties under *Prosopis* plant canopies and the spaces between tree canopies.

Sampling Site	pH	EC (µS/cm)	Ca (cmol/kg)	Mg (cmol/kg)	K (cmol/kg)	Na (cmol/kg)	C (%)	N (%)
Under Canopy 0 - 20 cm	7.75 ± 0.44	308.70 ± 10.21	1.11 ± 0.03	0.62 ± 0.01	0.11 ± 0.03	0.04 ± 0.01	0.344 ± 0.041	0.066 ± 0.002
Under Canopy 60 - 80 cm	8.70 ± 0.42	202.57 ± 8.37	1.29 ± 0.05	0.20 ± 0.03	0.09 ± 0.05	0.08 ± 0.01	0.541 ± 0.063	0.069 ± 0.001
Inter-canopy 0 - 20 cm	8.11 ± 0.43	223.72 ± 12.16	1.17 ± 0.07	0.17 ± 0.01	0.10 ± 0.01	0.05 ± 0.01	0.340 ± 0.022	0.043 ± 0.003
Inter-canopy 60 - 80 cm	8.19 ± 2.14	212.72 ± 9.43	1.21 ± 0.02	0.16 ± 0.02	0.09 ± 0.03	0.07 ± 0.01	0.500 ± 0.015	0.045 ± 0.002

Table 2. Selected soil properties under canopies of three categories of *Prosopis* plants.

Sampling Site	pH	EC ($\mu S \cdot cm^{-1}$)	Ca ($cmol \cdot kg^{-1}$)	Mg ($cmol \cdot kg^{-1}$)	K ($cmol \cdot kg^{-1}$)	Na ($cmol \cdot kg^{-1}$)	C (%)	N (%)
Class 1	8.28 ±0.27	158.48 ± 13.54	1.20 ± 0.42	0.12 ± 0.06	0.12 ± 0.05	0.15 ± 0.01	0.455 ± 0.023	0.058 ± 0.001
Class 2	8.19 ± 0.22	170.72 ± 9.47	1.11 ± 0.37	0.11 ± 0.05	0.12 ± 0.04	0.14 ± 0.01	0.461 ± 0.012	0.080 ± 0.003
Class 3	8.09 ± 0.20	218.30 ± 10.23	1.29 ± 0.44	0.13 ± 0.05	0.15 ± 0.06	0.15 ± 0.01	0.572 ± 0.014	0.053 ± 0.001

Table 3. Comparisons (t-Test *P*-values) of soil properties in the study area.

Sampling sites		pH	EC	Ca	Mg	K	Na	N	C
0 - 20 cm canopy	60 - 80 cm canopy	<0.001*	<0.001*	0.28	0.27	0.22	0.05*	0.11	0.05*
	0 - 20 cm inter-canopy	<0.001*	0.020*	0.69	0.87	0.42	0.67	0.06	0.95
	60 - 80 cm inter-canopy	<0.001*	0.021*	0.59	0.91	0.13	0.13	0.19	0.07
60 - 80 cm canopy	0 - 20 cm inter-canopy	<0.001*	0.610	0.47	0.34	0.63	0.07	0.08	0.04*
	60 - 80cm inter-canopy	0.861	0.472	0.42	0.26	0.77	0.78	0.09	0.71
0 - 20 cm inter-canopy	60 - 80 cm inter-canopy	<0.001*	0.871	0.92	0.80	0.13	0.20	0.60	0.05*

*The mean difference is significant at $\alpha = 0.05$.

Table 4. Comparison (t-Test *P*-values) of soils under canopies of three categories of *Prosopis* plants.

		pH	EC	Na	K	Ca	Mg	N	C
Class 1	Class 2	0.176	0.395	0.371	0.863	0.453	0.877	0.532	0.937
	Class 3	0.004*	0.004*	0.976	0.105	0.411	0.415	0.963	0.126
Class 2	Class 3	0.079	0.013*	0.397	0.134	0.112	0.311	0.423	0.121

*The mean difference is significant at the $\alpha = 0.05$ level.

sopis juliflora stand produced 7.4 tonnes per hector per year of dry leaf litter [17] in India. The dominant tree forms of *Prosopis* plants that grow in the study area are prostrate and decumbent, and these types of plant growth promote the accumulation of tree litter under the trees. The accumulation of tree litter under *Prosopis* plant canopies appeared to have led to the establishment of the conditions that promoted reduction in soil pH, such as low evaporation rates and initiation of biological activeties [20,21]. Additionally, the accumulation of tree litter under *Prosopis* plant canopies promoted the accumulation of soil organic carbon in soil existing under *Prosopis* plant canopies. *Prosopis* plants evidently enhanced soil organic carbon content and also influenced the soil pH particularly under *Prosopis* plant canopies.

Tree growth and canopy development normally lead to increase in the period of nutrient accumulation and improvement in understory soil conditions [8,9]. For this reason, statistically significant differences in the soils existing under the canopies of Classes 1, 2 and 3 *Prosopis* plants in relation to the selected soil properties was expected. On the contrary, no statistically significant difference in the soils existing under the canopies of Classes 1, 2 and 3 *Prosopis* plants in relation to soil organic carbon, Ca, Mg, K, Na and N was observed, suggesting that the influence of height and canopy size of *Prosopis* plants on the soil properties was not significant. Statistically significant different observed between soils found under Class 3 *Prosopis* plant canopies and soils found under Classes 1 and 2 *Prosopis* plant canopies in relation to soil pH and EC indicated that mature *Prosopis* plants influenced the understory soil pH and EC.

5. CONCLUSION

This study specifically tested the assumptions that *Prosopis* plants significantly enhance the nutrient content and improve the condition of soils in the Kalahari area and that the height and canopy size of *Prosopis* plants affect the interactions between *Prosopis* plants and the soils. Empirical evidence from this study showed that *Prosopis* plants enhanced soil organic carbon content and also influenced soil pH and EC in soils existing under-*Prosopis* plant canopies. In addition, the height and canopy size of *Prosopis* plant affected the interactions between *Prosopis* plants and the soils.

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