Effect of *Acacia* spp. on soil properties in the highlands of Saudi Arabia

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Abstract: Saudi Arabia is characterized by its low and sporadic rainfall, huge areas of semi-arid and arid nature including desert. Consequently, the vegetation cover is sparse and limited to certain valleys and water courses. *Acacia* spp. constitutes one of the major woodlots along the valleys. The impact of these woodlots on soil properties and nutrients has not been investigated yet. Trees in arid areas have a magnificent capability of modifying soil properties; however knowledge in this respect has been mostly observational. Few studies have used realistic field conditions and indigenous species which farmers prefer. In addition, studies on *Acacia* spp. on the highlands are limited. The present study was conducted with the objective of determining the effect of *Acacia* spp. in the highlands on soil properties and nutrients. Four locations in Al Baha region (south-western Saudi Arabia) where *Acacia* spp. woodlots existed were chosen. Altitude of the study locations was 1495-2566 m.a.s.l. Variability of species was the main criterion for choice of locations. Soil organic matter (OM %), soil texture (clay, sand and silt), and available soil macronutrients [N (nitrogen), P (phosphorus) and K (potassium)] were determined under the canopy of trees and outside the canopy (control) and compared. Since soil under and outside the canopy has been under the same climate, it was assumed that possible differences in soil properties were due to *Acacia* spp. The results revealed significant increase in OM % and available NPK and differences in clay and sand % under the canopy compared to outside the canopy. *Acacia etbaica* Schweinf under its canopy provided comparatively the best soil structure and the highest quantities of OM % and available NPK. Thus, Acacia woodlots in these locations paved the way for future agricultural and agrosilvopastural production in a country which imports most of its food stuff and fodder.
[El Atta H. Ali, Aref M. Ibrahim, Ahmed A. Ismail. **Effect of *Acacia* spp. on soil properties in the highlands of Saudi Arabia.** *Life Sci J* 2013;10(4):100-105] (ISSN:1097-8135). http://www.lifesciencesite.com. 14

Keywords: *Acacia* spp.; Soil texture; Macronutrients; Organic matter

Introduction

Soil fertility is a crucial factor in determination of ecosystem productivity. Edaphic conditions may have a strong effect on species growth and survival (Van Breugel et al., 2011). Research in Africa revealed that the low levels of soil organic matter and the limited available plant nutrients, particularly nitrogen and phosphorus constitute the main constraints to agricultural productivity, which is further affected by topsoil losses (Schlecht et al., 2006). It has been well established that trees are capable of significantly improving soil physical and chemical properties (Nyberg, 2001; Gindaba et al., 2004). Acacia woodlands play a significant ecological and economic role in semi-arid and arid agroecosystems (Wiegand and Jeltsch, 2000). Trees have a strong ability to modify soil properties and hence ecosystem dynamics (Vågen et al., 2005; Valiente-Banuet et al., 2006). Isichei and Muoghalu (1992) investigated the effect of tree canopy cover on the soil nutrient status in comparison to neighboring open grasslands in a Nigerian savanna. It was observed that soils under tree canopies had significantly greater levels of organic matter, Ca, Mg, K, total exchangeable bases, cation exchange capacity and pH than those in open grasslands. The ability of trees to improve soil fertility offered an excellent chance to produce filed crops (Mubarak et al., 2012). The authors reported a high rate of P and K release from *Azadirachta indica* and *Balanites aegyptiaca* litters. Swart (1994) reported that the degree of soil enrichment can differ between tree species that grow in the same environment. He found that soil under both leguminous trees (*Acacia erubescens*) and non-leguminous trees (*Combretum apiculatum*) was richer in % total N, % organic C, Ca and Mg, but that nutrients such as K and Mg were found in higher concentrations under *A. erubescens* compared to *C. apiculatum*. Clearing of *Acacia aneura* for pasture production and cropping was investigated by Dalal et al. (2005). This change of land use had led to substantial decline of soil organic matter in topsoil. Pandey et al. (2000) studied soil properties under mid, at the edge and canopy gap *A. nilotica* in India. They found that sand particles declined by 10% and 9% whereas clay particles increased by 14% and 10% under canopy and canopy edge, respectively, as compared to the adjacent open area. Also soil organic C, total N, and total P were higher under canopy and canopy edge as compared to open area. Similarly, El-Tahir et al. (2004) investigated the effects of *A. senegal*, *A. seyal* and *A. tortilis* on some chemical properties and particle size distribution of sandy soil three years from planting in north Kordofan State, Sudan. They reported that percentage of P was significantly greater under the trees than in bare soil with noticeable differences among the three species. It was also observed that the magnitudes of N and C significantly decreased with increasing distance from the tree base. A study by Forrester et al. (2005) showed that *A. mearnsii* fixed significant amounts of N and improved the cycling of P through litter fall whether in monoculture or mixed with *E. globules*. Despite low growth rates, plants in arid areas have a strong ability to modify soil surface properties affecting ecosystem processes and community dynamics. But our knowledge on species effects on soil properties in these areas comes largely from observational studies, increasing the risk of confounding factors and precluding estimations of rates of change. Although there have been many studies of decomposition and nutrient release in the tropics and particularly in Africa, most were on a few exotic species. Saud Arabia has been well known for its very rare and sporadic rains and scarcity of vegetal cover. It occupies an area of 2.25 million km^2 comprised mainly of desert and semi-desert areas besides the mountains of the south-west region, scattered valleys and the western and eastern coasts (Chaudhary, 1983; Aref & El-Juhany, 2000). Acacias are of great economic importance in Saudi Arabia as they yield wood that is used as firewood and timber. They are also a good source of gum, tannins and forage. In addition, Acacia natural forests and woodlands constitute a good habitat for the honeybee that produces good quality honey (Aref et al., 2003). However, the role of *Acacia* spp. on improving soil physical and chemical properties has not been investigated in Saudi Arabia. In addition, very few studies were conducted on *Acacia* spp. growing at high altitudes (> 1000 m.a.s.l.) which is the case in this study. Such a study is of paramount importance in a country where more than 30% of its area is desert. The present study was conducted to investigate the effect of *Acacia* spp. on some soil physical and chemical properties in the high lands of the Kingdom of Saudi Arabia.

Materials and Methods

2.1. The study area

The study was conducted in four locations in Al Baha region (South-Western Saudi Arabia) (Table 1). Altitude was 1495-2566; 132.3 and 9.2 mm mean maximum and mean minimum monthly rainfall, respectively; 36.1 and 9.9 °C mean maximum and mean minimum monthly temperature. Al Baha region falls in the semi-arid zone (Al-Mefarrej, 2012) on the basis of the pluviometric index of Emberger (1971). Six naturally growing *Acacia* spp. have been recognized in the study locations namely; *A. etbaica* Schweinf, *A. origena* R.B., *A. asak* (Forssk.) Willd., *A. tortilis* subsp. *raddiana* Savi, *A. ehrenbergiana* Hayne and *A. gerrardii* Benth. The species were mostly woodlots either as one or mixed. At higher altitudes the only species was *A. origena* which was mixed with a conifer (*Juniperus procera* Hochst. ex Endl.) up to about 2800 m.a.s.l.

2.2. Soil analysis

In each location 3 samples of soil were taken at 1-30 cm soil depth from under the canopy of randomly selected 12 trees of *Acacia* spp. and from 5 m outside the canopy. Each sample had 3 replicates. Soil samples were analyzed at the Dept. of Soil Science, College of Food and Agri. Science, King Saud University.

2.3. Soil texture

Soil texture was determined according to Robinson pipette method (Van Reeuwijk, 2002). Organic matter was destroyed by the addition of H_2O_2, Carbonates were removed by HCl, and particle dispersion with sodium hexametaphosphate (Van Reeuwijk, 2002). Soil samples were sieved into clay (< 2 mm), silt (2-50 mm) and sand (> 50 mm).

2.4. Soil organic matter (OM)

The OM % of soil was measured by the ignition method according to Wang et al. (1996). Approximately 2 g of dried soil which was sieved to < 2 mm was placed in ceramic crucibles in a muffle furnace at 375 °C for 16 h. On the basis of weight loss by ignition OM % was measured.

2.5. Macronutrients

Available N, P and K were analyzed according to Van Reeuwijk (2002).

2.6. Statistical analysis

Data were analyzed by the T-test of significance to compare between values under and outside the canopy using SAS computer statistical package (SAS, 1985).

3. Results and discussion

3.1. Soil texture

Soil texture under the canopy of *Acacia* spp. was significantly different compared to that outside the canopy (Table 2). Clay % was more under the canopy 44%, 44%, 52% and 47% than outside the canopy (20%, 16%, 11% and 14%) in Aqeeq, Ghimda, Mekhwa and Kara, respectively. The highest clay content was recorded in Mekhwa which was dominated by *A. asak*. followed by Kara (*A. tortilis* subsp. *raddiana*, *A. ehrenbergiana* and *A. gerrardii*). In contrast sand% was significantly less under the canopy compared to outside the canopy (Table 2). It was 30%, 23%, 30% and 28% under the canopy and 52%, 50%, 59% and 55% outside the canopy in Aqeeq, Ghimda, Mekhwa and Kara, respectively. The highest was recorded in Mekhwa (*A. asak*) and Kara (*A. tortilis* subsp. *raddiana*, *A. ehrenbergiana* and *A. gerrardii*) which was approximately 50%. However, no significant change in silt% occurred in Aqeeq (*Acacia* *etbaica*) and Ghimda (*A. origena*). Nevertheless, silt% was significantly more outside the canopy than under the canopy in Mekhwa (66.7%) and Kara (24%) (Table 2). These results are in line with several investigators. They suggested that changes in soil texture under tree canopy depended on tree species and location. Mann & Saxena (1980) reported an increase in clay content under the canopy of *Prosopis cineraria* under aridisols of Rajasthan, India. Clay particles also increased under the canopy of *A. nilotica* (Pandey, 1999). The increase in clay proportion under the canopy of trees was attributed to the accumulation of litter which protects the soil from the impact of wind erosion and rain drops which increases the defloculation and erosion of clay particles. In addition, accumulation of organic matter under tree canopy also maintains the soil structure. Generally, soil organic substances bind soil particles together and protect them from erosion (Pandey et al., 1995). A decrease in clay content was recorded when 6-year-old *A. senegal* was cleared to another type of land use in western Sudan (El Tahir et al., 2009). Ayoub (1998) mentioned that the major soil degradation factor in these semi-arid lands is the clearing of vegetation and continuous cultivation in the absence of nutrient inputs. Generally, soils under trees were characterized by a better soil structure (Abule et al., 2005).

3.2. Soil OM %

Similarly, highly significant increases in OM % were recorded under canopy compared to outside canopy (Table 3). The OM % increased by 320%, 375%, 300% and 250% under copy of *Acacia* spp. in Aqeeq, Ghimda, Mekhwa and Kara, respectively. Ghimda (*A. origena*) had the highest increase in OM % followed by Kara (*A. tortilis* subsp. *raddiana*, *A. ehrenbergiana* and *A. gerrardii*). Generally, OM % was extremely low outside the canopy perhaps due to lack of vegetation cover. The increase of OM % under canopy might be attributed to accumulation of leaf litter and dead roots (Pandey et al., 2000). Among other factors, increased organic matter above and below soil surface plays an important role in improving soil fertility (Nair, 1993; Palm, 1995). Litter has a significant contribution to soil organic matter and soil fertility including available P and N (Xion et al., 2008). Tree litter had encouraged the enzymatic activity in the soil which was significantly correlated with available P content and nitrate concentrations (Mukhopadhyay & Joy, 2010). In addition, litter protects the soil against erosion (Pandey et al,. 1995).

3.3. Soil macronutrients

A highly significant increase in available N was recorded under canopy in all study locations compared to outside tree canopy (Table 4). The quantity of available N under tree canopy differed among species in different locations. Comparatively, the highest quantity of available N (147.4 mg/kg) occurred under the canopy of *A. etbaica* (Aqeeq) and *A. origena* (140.5 mg/kg) (Ghimda), whereas the least was recorded under *A. asak* (92.5 mg/kg) (Table 4). The results agreed with those of other investigators. The most important nutrient in the semi-arid areas is N (Hooper and Johnson 1999), and the major source of it is N^2 fixed biologically by legumes through their symbiosis with rhizobia (Cleveland et al. 1999).Nitrogen fixed by *Acacia* spp. is released into the soil through litter fall, root and nodule decay (Khanna, 1998). *A. dealbata* significantly increased total N in soil (González et al. 2012). Also *A.mangium* fixed 128 kg N ha-1 amounting to 1208 kg N fixed ha-1 over 12 years in Misamis Oriental, Philippines (Mercado et al., 2011). Contribution of trees through fallow, hedgerow and shade to N economy of tropical systems has been well established (Hairiah et al., 2000; Giller, 2001; Gathumbi et al., 2002; Leblanc et al., 2007; Nygren and Leblanc, 2009). *A. melanoxylon* increased N supply under the canopy as compared to open pasture and that increased the pasture yield in North Island, New Zealand (Power et al., 2003). Swart (1994) reported that the degree of soil enrichment can differ between tree species that grow in the same environment. Variation in quantities of N under the canopy of *Acacia* spp. in the present study might be attributed to species differences, stand age, climate and other environmental conditions (Power et al., 2003). Higher clay contents might have increased the nitrification potential of soil beneath the canopy. Also the higher clay mineral surfaces with adsorbed $NH4^+$ ions are colonized by nitrifiers (Kunc and Stotzky, 1980). The immobilization of nutrients by microbes was considered as a reservoir of mineralizable N and other nutrients which when biologically transformed become available to plants (Singh et al., 1989). *Acacia* spp. are well known for their ability to fix atmospheric nitrogen through their root system symbiosis with *Rhizobium*. These Bacteria are common in the semi-arid tropics around the world (Martins *et al.*, 2003). Similarly, available P increased significantly under the canopy of *Acacia spp.* in all locations (Table 4). Available P was comparatively higher under the canopy of *A. etbaica* (10.6 mg/kg). The increase in OM % of soil contributes to soil fertility. Microbes use OM as a source of energy and through their activity they may play a partial role in increasing levels of available P in the soil (Lee et al., 1990). Fungi and Bacteria may solubilize inorganic phosphate in minerals and P bound to organic matter (Tate, 1984; Thomas et al., 1985). The trend is similar for available K which increased significantly under tree canopy of all species with the maximum increase under *A. etbaica* (Table 4). Hence, it is evident that the macronutrients were more available under the canopy of *A. etbaica*.

Table 1. The study locations

Location	Coordinates	Altitude (m.a.s.l.)	Species
Aqeeq	N 1949613 E4134380	2102	*Acacia etbaica*
Ghimda	N 1949613 E4135280	2566	*A. origena*
Mekhwa	N 2039543 E4136476	2042	*A. asak*
Kara	N 1946432 E4137133	1495	*A. tortilis* subsp. *raddiana* *A. ehrenbergiana* A. *gerrardii*

Table 2. Effect of *Acacia* spp. on soil texture in the study locations

Aqeeq					
Clay particles %		Sand particles %		Silt particles %	
Under Canopy	Outside Canopy	Under Canopy	Outside Canopy	Under Canopy	Outside Canopy
44 ^{a}	20 ^{b}	30 ^{a}	52 ^{b}	26 ^{a}	28 ^{a}
Ghimda					
44 ^{a}	16 ^{b}	23 ^{a}	50 ^{b}	33 ^{a}	34 ^{a}
Mekhwa					
52 ^{a}	11 ^{b}	30 ^{a}	59 ^{b}	18 ^{a}	30 ^{b}
Kara					
47 ^{a}	14 ^{b}	28 ^{a}	55 ^{b}	25 ^{a}	31 ^{b}

Means of a parameter in a row followed by the same superscript are not significantly different at P = 0.05

Table 3. Effect of *Acacia* spp. on soil OM % in the study locations

Location	OM %		
	Under canopy	Outside canopy	P
Aqeeq	2.1 ^{a}	0.5 ^{b}	0.0001
Ghimda	1.9 ^{a}	0.4 ^{b}	0.0001
Mekhwa	1.2 ^{a}	0.3 ^{b}	0.01
Kara	1.4 ^{a}	0.4 ^{b}	0.001

Means in a row followed by the superscript are not significantly different at P = 0.05

Table 4. Effect of *Acacia* spp. on available macronutrients in the study locations

Available N (mg/kg)			
	Under canopy	Outside canopy	P
Aqeeq	147.4 ^{a}	73.7 ^{b}	0.0001
Ghimda	140.5 ^{a}	49.5 ^{b}	0.0001
Mekhwa	92.5 ^{a}	78.0 ^{b}	0.0001
Kara	122.9 ^{a}	45.1 ^{b}	0.0001
Available P (mg/kg)			
	Under canopy	Outside canopy	
Aqeeq	10.6 ^{a}	2.9 ^{b}	0.001
Ghimda	3.4 ^{a}	1.4 ^{b}	0.01
Mekhwa	8.3 ^{a}	1.4 ^{b}	0.01
Kara	5.4 ^{a}	2.0 ^{b}	0.01
Available K (mg/kg)			
	Under canopy	Outside canopy	
Aqeeq	143.6 ^{a}	53.6 ^{b}	0.0001
Ghimda	60.8 ^{a}	14.7 ^{b}	0.001
Mekhwa	123.2 ^{a}	22.7 ^{b}	0.001
Kara	69.7 ^{a}	33.8 ^{b}	0.001

Means in a row followed by the same superscript at not significantly different at P = 0.05

Concentration and availability of nutrients under tree crown vary with distance from trees (Mazzarino et al., 1991). The increase in organic matter and availability of nutrients under tree canopies was attributed to accumulation and mineralization of leaves, respectively (Bolton et al., 1990). Soil OM, nutrients and physical and chemical properties improved significantly under *A. etbaica* and *Euclea racemosa* as compared to open grazing lands in the Tigray Region, Ethiopia (Mekuria *et al*., 2007). Consequently, the biomass of both species amounted to 51 tons 114 ha^{1}. The increasing mis-use of N and P fertilizers caused Global changes in the biogeochemical cycles of these major nutrients in addition to their unaffordable price in many developing countries (Amanuel et al., 2000; Anon., 2003). Therefore, intensification of agroecosystems is urgently needed (Godfray et al., 2010). The present study demonstrated the role of *Acacia* spp. in improving soil properties and nutrients which paved the way for using such ecosystems for agricultural production.

Conclusions

Acacia spp. in the highlands of Saudi Arabia played a significant role in improving soil structure and nutrients. Significant increase in clay%, OM % and available NPK were recorded under all species canopies compared to the open bare areas. Although all species were effective, however *A. etbaica* was the most effective in improving soil properties. The study suggested that *Acacia* spp. even at high altitude provided a good opportunity for agricultural and agrosilvopastoral activities.

Acknowledgements

"The authors would like to extend their sincere appreciation to the Deanship of Scientific Research at King Saud University for its funding of this research through the Research Group Project No.RGP-VPP-226".

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9/12/2013