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Full Length Research Paper

Soil physicochemical properties under *Acacia senegal* varieties in the dryland areas of Kenya

Eunice W. Githae[1]*, Charles K. K. Gachene[2] and Jesse T. Njoka[2]

[1]School of Natural Resource Management, Narok University College, P. O. Box 861, Narok, Kenya.
[2]Department of Land Resource Management and Agricultural Technology, University of Nairobi, P. O. Box 29053-00625, Nairobi, Kenya.

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***Acacia senegal* is a multipurpose drought-tolerant tree or shrub legume and is commonly used in agroforestry systems in sub-Saharan Africa for gum arabic production and soil fertility improvement. Despite its wide distribution in Kenya, there has not been exhaustive evaluation on the effects of the extant varieties (*kerensis*, *leiorhachis* and *senegal*) on soil properties under their canopies for sustainable utilization of the species. Three sites in the drylands of Kenya representing the three varieties were selected for assessment. Soil samples were collected under tree canopies at a depth of 0 to 25 cm and were compared with the soils from the open canopies. There were significant differences in soil physicochemical properties among the three varieties ($P<0.05$ and $P< 0.01$). Soil nutrients under the canopies were higher than in the open canopies mainly due to effects of litter accumulation. The three varieties have beneficial effects on soil nutrient status in their natural ecosystems and would most likely improve crop productivity in agroforestry systems as well as enhance herbage productivity in the rangelands. The varieties growing under different soil types may have an effect on their gum Arabic production and quality.**

Key words: *Acacia senegal* varieties, soil nutrients accumulation, sustainable utilization.

INTRODUCTION

Acacia senegal (L.) Willd. is a tree or shrub legume widely distributed in sub-Saharan Africa, extending to Arabian Penisula, Pakistan and India (Fagg and Allison, 2004). It is mostly found in the arid and semi arid zones of Kenya especially in dry *Acacia- Commiphora* bushlands and wooded grasslands (Maundu and Tengnäs, 2005). It is a drought tolerant species and grows in areas with low rainfall of 300 to 400 mm per year but can grow in areas with as little as 100 mm, and a dry period of 8 to 11 months (Jøker, 2000). *A. senegal* is known to be highly variable in growth form (Brenan, 1983). Three varieties are currently recognized in Kenya namely; *A. senegal* var. *senegal* Schweinf, *A. senegal* var. *kerensis* Schweinf and *A. senegal* var. *leiorhachis* Brenan (Fagg and Allison, 2004). Their differences are based on variation in natural distribution and morphological characteristics. Whilst this variation is desirable in terms of adaptability and potential for genetic improvement, challenges in its management and sustainable utilization in Kenya are constrained, among other factors, by poor delimitation of the varieties (Brenan, 1983; Maundu and Tengnäs, 2005), inconsistency in gum arabic production (Chretin et al., 2008) and low gum Arabic quality (Chikamai and Banks, 1993). The specie is important in the drylands where pastoralism is the main source of livelihood. *Acacia senegal* (L.) is known for its exudate named “gum arabic”, a water-soluble gum that is used internationally in the processing of food and medical products in industries. The gum is also widely used in the manufacturing of dyes, polish, glue and thickeners (Maundu and Tengnäs, 2005). There also exists a wide variation in gum chemistry within and between varieties but to what extent this is due to genetic differences rather than environmental in which they grow remains to be evaluated (Fagg and Allison, 2004). Soil characteristics are major factors that influence gum quality and production. A study conducted by Lenon et al. (2010a) in

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*Corresponding author. E-mail: egithaeh@gmail.com. Tel: +254 725 286 095.

Table 1. Environmental characteristics of the study sites.

Population	Altitude (m)	Mean-annual rainfall (mm)	Condition	Mean-annual temperature (°C)	Variety
Kajiado	1730	300 to 900	Semi-arid	21 to 32	*Senegal*
Kibwezi	731	300 to 1200	Semi-arid	23 to 32	*Kerensis*
Magadi	1460	300 to 600	Arid	28 to 33	*Leiorhachis*

the northern part of Kenya revealed that soil chemical properties affected the gum quality of *A. senegal* var. *kerensis* and this also differed between sites. In addition, the physical properties of gum arabic from *A. senegal* var. *senegal* was of higher quality than that of *A. senegal* var. *kerensis* (Lenon et al., 2010b) and these differences may have evolved as a result of the differences in edaphic and climatic factors. In addition to provision of wood and non wood forest products, the tree also provides other benefits such as restoration of soil fertility through its potential to fix nitrogen, fodder especially during the dry season, improve the microclimate by buffering winds, provides shade and acts as a bee forage (Eisa et al., 2008; Maundu and Tengnäs, 2005). Several studies have shown that *A. senegal* is highly suitable in agroforestry systems especially in shifting cultivation where it is intercropped with crops such as millet, sorghum, sesame and groundnuts (Ballal et al., 2005; Elmqvist et al., 2005; Gaafar et al., 2006). This system ensures optimum and sustainable utilization of the natural resources, since both the gum production and the crop cultivation form productive components of the system (Eisa et al., 2008). The rare outstanding characteristics and adaptive responses to moisture stress and drought allow this species to produce a high biomass in extremely dry environments (Gaafar et al., 2006). The environmental sustainability of gum production system involves mainly its impact on soil fertility (Elmqvist et al., 2005). The ability of the species to fix nitrogen makes it grow better on nitrogen-depleted soils and restores soil fertility of such soils, and this would be important in farming systems where the application of fertilizers is limited. In addition, there is hardly any documented information on the effects of *A. senegal* varieties on soil under their canopies in their natural ecosystems, which is essential for evaluating their role in improving soil properties in the dryland ecosystems. The present study evaluates and compares the effects of three varieties of *A. senegal* on soil physicochemical properties in the dryland areas of Kenya.

MATERIALS AND METHODS

Study sites

Three sites located in the arid and semi-arid lands of Kenya that represented the three putative varieties were selected for this study as shown in Table 1. They were selected based on the varieties distribution at a proximate location (Figure 1).

Data collection

Ten trees were randomly selected in each variety population. The location, diameter at breast height (dbh) and the height of each tree were determined. Soil samples were collected from beneath the ten trees in each population at a depth of 0 to 25 cm and sampled at 0, 1 and 2 m distant from the trunk. Four samples were randomly collected at each distant and mixed together to form a composite sample for analysis. Soil samples were also collected at the same depth in the open canopy as a control. Soil analysis was done using standard procedures as outlined by Okalebo et al. (2002). They were analyzed for soil organic carbon (SOC) {Walkly-Black method}, pH (1:2 soil water suspension), % total nitrogen (N) {Kjeldahl acid digestion method}, Cation Exchange Capacity (CEC), phosphorus (P) {Olsen method)} exchangeable bases; potassium (K), calcium (Ca), magnesium (Mg), sodium (Na) and exchangeable acidity (Hp) {Mehlich 3 method} and particle size distribution (Hydrometer method). Soil OC and total N input was calculated as the difference between the content under canopies and in the open canopies.

Data analysis

The mean values of soil properties under the canopies and in the open canopies were tested for differences using one-way analyses of variance (ANOVA) with Turkey's significance difference at 5% probability level. The correlations between soil property values were analyzed using the Pearson's linear correlation coefficient. Least significant differences (LSD) were used to detect differences among means.

RESULTS AND DISCUSSION

Soil physicochemical properties

There were significant differences in soil physicochemical properties among the three *A. senegal* varieties at a depth of 0 to 25 cm. This is similar to studies conducted for other tree species such as *Prosopis juliflora* and *Dalbergia sissoo* in sodic lands of India (Mishra and Sharma, 2002), *Pinus radiata* in New Zealand (Chang et al., 2002) and for three species *Polyscia fulva*, *Casuarina equisetifolia* and *Eucalyptus* spp. in Rwanda (Nsabimana et al., 2008). The correlations between soil physicochemical properties investigated in the three *A. senegal* populations are shown in Table 2. There were significant and negative correlations between soil pH and soil P ($r= -0.997$, $P< 0.05$) and between soil pH and Hp

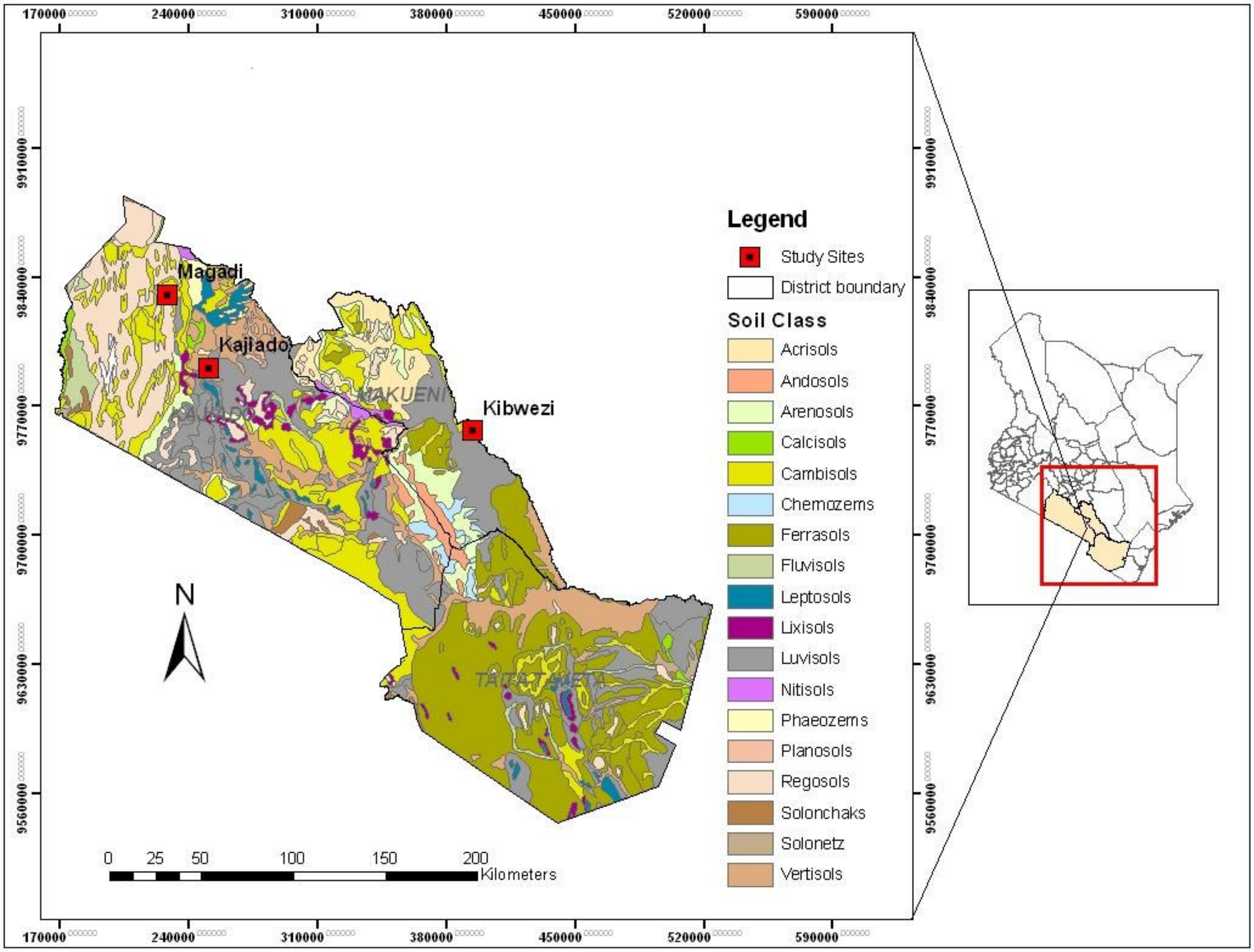

Figure 1. Locations and soil types of the three study sites representing *A. senegal* varieties in Kenya.

Table 2. Pearson correlation coefficients between soil physicochemical properties investigated for *A. Senegal.*

Data	pH	CEC	P	%OC	%N	Ca	Mg	K	Na	Hp
pH	1									
CEC	-0.538	1								
P	-0.997*	0.638	1							
%OC	-0.51	0.999*	0.57	1						
%N	-0.27	0.956	0.34	0.97	1					
Ca	0.86	-0.037	-0.82	0.00	0.26	1				
Mg	0.49	-0.999*	-0.56	-1.00**	-0.97	-0.01	1			
K	-0.99	0.631	1.000*	0.59	0.36	-0.81	-0.58	1		
Na	0.6	0.354	-0.54	0.39	0.61	0.92	-0.4	-0.51	1	
Hp	-0.999*	0.493	0.99	0.46	0.22	-0.89	-0.45	0.99	-0.64	1

*P < 0.05; **P < 0.01.

(r= -0.999, P< 0.05). K was positively and significantly correlated with P (r= 1.00, P< 0.05). Soil organic carbon was significantly and positively correlated with CEC. Both of them were significantly and negatively correlated with

Table 3. Soil texture, pH and cation exchange capacity for soils under *A. senegal* varieties.

Variety	Particle size distribution			pH	CEC	Soil textural type
	% silt	% sand	% clay		meq/100 g	
Senegal	8.78	69.33	21.89	6.33	18.78	Sandy clay loam
Kerensis	6.56	74.44	19.00	7.51	12.75	Loamy sand
Leiorhachis	17.22	66.11	15.22	7.46	18.73	Sandy loam
LSD	0.079^{NS}	0.001**	0.010*	0.003**	0.014*	

^{NS} Not significantly different; *P < 0.05; **P < 0.01.

Mg (r= -1.00, P< 0.01; r= -0.999, P< 0.05 respectively). Though not significantly different, there were high correlations between soil organic C and soil N (r= 0.97). Correlation between Mg and other exchangeable bases were all negative. Soil particle size distribution was determined in order to ascertain whether the soils under the canopies of the three varieties were different. The soils under the three varieties canopies were predominantly sandy with sand content accounting for more than 60% of the inorganic mineral components in the soil. Eldin et al. (2009) collected data for soil particle sizes in Northern Sudan for sole *A. senegal* system and *A. senegal* intercropped systems and reported that sand accounted for more than 90% indicating that these varieties can grow well in sandy soils. There were no significance differences in the mean proportion of the soil particle sizes between the soils under the canopies and in the open canopy. However, the soil particle sizes under the three varieties were significantly different (P = 0.0035) (Table 3). The observed differences in the soil particle size distribution between the three sites are most likely due to the effects of the mineralogical differences between the parent materials across the sites. These differences are often associated with different vegetation types, both of which can contribute to variation in soil pH and exchangeable cations (Finzi et al., 1998). However, the differences among the study sites indicate that the soils have been derived from different parent materials under difference climatic conditions and topography. According to Sombroek et al. (1982), soils under *A. senegal* var. *kerensis* are derived from gneisses while those under var. *senegal* and var. *leiorhachis* are derived from biotite gneisses and basalts respectively.

The variations in soil pH beneath the three varieties probably reflect the composition of the parent material as well as differences in climatic conditions under these trees. Soil pH was low (6.33) under *A. senegal* var. *senegal* canopy compared with the other two varieties (7.51 and 7.46 for var. *kerensis* and var. *leiorhachis* respectively). The mechanisms by which tree species influence soil acidity and exchangeable cations include inter-specific differences in the uptake of exchangeable bases, nitrogen fixation, production of litter high in organic acid content and the stimulation of mineral weathering (Finzi et al., 1998). The soil type of *A. senegal* var. *senegal* was slightly acidic with the highest proportion of clay, *A. senegal* var. *leiorhachis* was found in sandy loam soils with the lowest proportion of clay while var. *kerensis* was found in loamy sand soils with the lowest CEC.

A. senegal var. *senegal* and *A. senegal* var. *leiorhachis* had similar levels of CEC (18.78 and 18.73 respectively, Table 3). Their contributions to these high values were probably from soil clay content and soil organic matter OM, respectively. The CEC measurements indicate overall assessment of the potential fertility of a soil and possible response to fertilizer application. Soils with a CEC of <16 meq/100 g are considered not to be fertile and such soils are highly weathered while fertile soils have a CEC of >24 meq/100 g (Gachene and Kimaru, 2003). This means that var. *senegal* can grow well in fertile soils, var. *leiorhachis* in intermediate soils while var. *kerensis* can perform well in poor soils. The CEC of coarse-textured soils that characterize drylands in the study areas appears to depend largely on their organic matter content, as their clay content is very low. There were significant differences in soil phosphorus P under the canopy of the three varieties (*P*= 0.0037). Soil phosphorus was generally high under *A. senegal* var. *senegal* soils (499.36 ppm) compared with the other two varieties (4.21 and 65.06 ppm for var. *kerensis* and var. *leiorhachis* respectively). The extremely high presence of phosphorus under *A. senegal* var. *senegal* could probably be only attributed to the parent material as the soils outside the canopy were also relatively high in P. Phosphorus is present in soils in smaller quantities than N but is classified as a primary nutrient because it is essential to plant growth and is often deficient especially in the drylands (Mati and Mutunga, 2005). There were significant differences in exchangeable Ca, Mg and K levels (P= 0.005, P= 0.031 and P= 0.035 respectively) among the three varieties. The levels of exchangeable bases were higher under the canopies than in the open canopies. Values of exchangeable Ca and Na were markedly higher in soils under *A. senegal* var. *leiorhachis* compared to the soils from the other two varieties (Figure 2). Aweto and Dikinya (2003) reported that exchangeable K, Mg and Ca were 66 to 106% higher than their respective levels in the open canopy for *Combretum apiculatum* and *Peltophorum africanum* in semi-arid traditional grazing land in south eastern Botswana. Kho et al. (2001) studied the topsoil under the canopies of

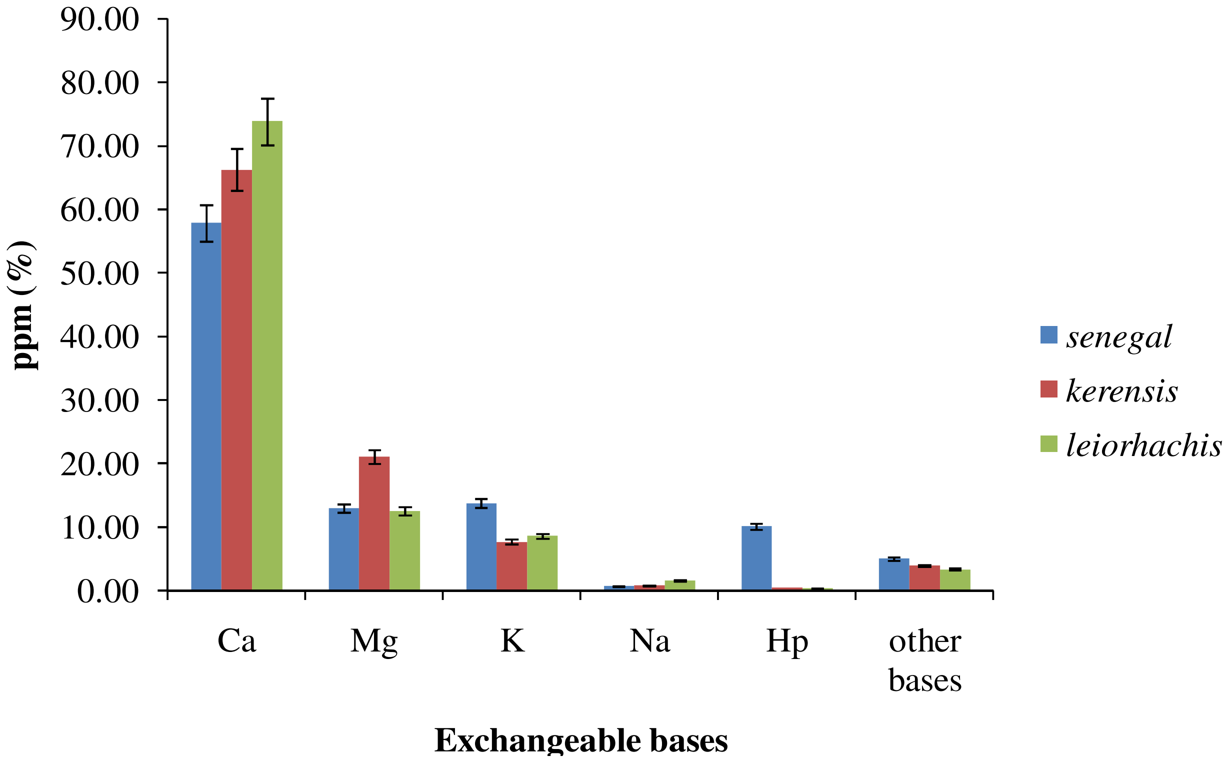

Figure 2. Exchangeable bases in the 0 – 25 cm soil depth under *A. senegal* varieties.

Table 4. Soil C and N accumulation under canopies (C) and in the open canopies (OP).

Treatments	%OC	%N	C:N
Senegal canopy C	3.12	0.18	17.33
Senegal open canopy OC	1.97	0.10	19.70
Kerensis	0.90	0.06	15.00
Serensis open canopy	0.78	0.04	19.50
Leiorhachis canopy	3.20	0.23	13.91
leiorhachis open canopy	2.20	0.15	14.67
LSD	0.005**	0.008**	0.000 **

**P < 0.01.

Faidherbia albida in a semi-arid savanna in Niger and reported that the levels of exchangeable potassium, calcium and magnesium in the top- soils under the canopies were only 5 to 20% higher than in soil outside the tree canopy. The soils under *A. senegal* var. *kerensis* had the highest level of magnesium as compared to the other two varieties.

Soil carbon and nitrogen accumulation

There were significant differences in soil C and N accumulation among the three varieties (Table 4). The highest soil C and N input were under *A. senegal* var. *senegal.* The lowest accumulation was under the canopy of *A. senegal* var. *kerensis*. Since *A. senegal* is a deciduous tree that sheds its leaves during the dry season and is adapted to harsh environmental conditions, the accumulation of organic carbon and nitrogen in the topsoil may be as a result of leaf litter decomposition (Mohamed, 2005). The soil organic carbon content observed in the present study ranged from 0.9 to 3.2%. Jakubaschk (2002) studied natural stands of *A. senegal* var. *senegal* in Sudan and reported that the carbon content ranged from 0.04 to 0.97%. This is an indication of the species' potential of increasing soil organic carbon stock and hence soil fertility in the dryland areas of Kenya. Mohamed (2005) reported that *A.*

senegal improved soil fertility and yield of sorghum and karkadeh on sandy soil in western Sudan. Jakubasck (2002) also found a significant difference between the carbon and nitrogen content of *A. senegal* and that of crop land at 0 to 20 cm depth in the North Kordofan region in Sudan. Another study conducted by Eldin et al. (2009) on the effect of *A. senegal* on growth and yield of groundnut, sesame and roselle in an agroforestry system in North Kordofan state in Sudan reported that yield and net revenues were higher in intercropping than in the mono-cropping system. All these were attributed to improved soil fertility as may be the case in this study. Apart from water availability, nitrogen seems to be the most important factor limiting productivity in arid land ecosystems. The N content observed in this study may be attributed mainly due to litter fall or nitrogen fixation although no nodules were found in the soils collected. Studies have shown that nitrogen- fixing nodules do not exist on adult trees although these trees fix substantial amount of N. Mohamed (2005) excavated the root system of *A. senegal* of different sizes and showed no presence of nodules but the amount of soil N was higher than in sole cropped systems. This is similar to a study conducted by Bernhard-Reversat and Poupon (1980). The lack of nodulation in the field, even when compatible rhizobia are present in the soil, may be because they decompose rapidly, are too small to be detected or are located at 5 to 10 m depth (Johnson and Mayeux, 1990). There were no significant differences between soil C and N and the distance from the trunk for all the three varieties. However, soil C and N were higher under the canopies of the three varieties as compared to the open canopies (Figure 3). It is known that litter production and the rate of litter decomposition are the most important factors by which tree species regulate the size and distribution of soil C and N pools (Wang et al., 2010). This is because under canopy the soil moisture status is increased, which increases the moisture content of the surface litter, litter breaks down and hence mineralization of organic matter (Meenakshi and Kailash, 2002). The increase of nutrient accumulation under canopies may be due to the nutrient input by tree litter. In this sense, Aweto and Dikinya (2003) studied the effects of *apiculatum* and *P. africanum* on the soil under their canopies in semi-arid traditional grazing land in south eastern Botswana and found that the mean organic carbon and N levels under the canopies were higher than in the open grassland. Pandey et al. (2000) reported that *Acacia nilotica* trees had enriched the organic matter and nutrient levels in the soil under their canopies. It is known that litter production and the rate of litter decomposition are the most important factors by which tree species regulate the size and distribution of soil C and N pools (Bernhard-Reversat and Poupon, 1980). The shade of tree canopies also has the effect of reducing soil temperatures and hence the rate of organic matter decomposition (Wang et al., 2010). Podrázský and Remeš (2006) studied changes under forest canopy in forest regeneration and confirmed marked changes in the quantity and quality of surface humus under the canopies. On the other hand soil outside the influence of tree canopies is exposed to direct solar radiation that enhances soil organic matter decomposition on account of elevated soil temperatures. Chang et al. (2002) reported that soil C and N in the 0 to 10 cm depth were higher in the *Pinus radiata* than in the bare ground plots, reflecting the organic C and N input in the *P. radiata* plots, as well as greater N loss from the bare ground plots in the form of nitrate leaching and or denitrification. The current study indicates that *A. senegal* varieties has the potential of enhancing herbage productivity in the rangelands as they improve soil fertility under their canopies.The soils' C: N ratio is an indicator of N mineralization in the soil and has a strong influence on the decomposition of organic material (Gachene and Kimaru, 2003). The C: N ratios under the three varieties (ranged from 13.91 to 17.33) but lower than that of the open canopies (ranged from 14.67 to 19.7) indicating that organic materials under the canopy were of higher quality than in the open canopy. High C: N ratio of 10 or above indicates that there is N mineralization occurring in the soil (Agbenin and Goladi, 1997) which is typical in arid and semi arid regions. Nsabimana et al. (2008) found the same C: N range under *Eucalyptus* species (average C: N ratio of 15.17), which was higher than that for other studied legumes; *Calliandra calothysus* (13.4), *Casualina equisetifolia* (13.1) and *Leucaena leucocephala* (12.2). These C: N ratios vary with regard to different soil types and different types of organic material applied (Jakubaschk, 2002). Mineralization takes place in the presence of soil microorganisms and is most rapid when the soil temperatures are high, the case observed in this study.

Conclusion

The study shows that the three *A. senegal* varieties have beneficial effects on soil fertility improvement and this would most likely enhance herbage productivity in the rangelands as well as improve crop productivity in agroforestry systems. Integrating these varieties in cropping systems and preserving these trees in the arid and semi-arid areas would help to maintain or possibly enhance sustainability of these ecosystems in the long term. The adoption of these trees in agroforestry systems can exert a significant influence on the nutrient content of understorey plants by their rapid leaf turnover and nutrient release through decomposition, which can result in significant increase in soil fertility. This in turn can lead to consistency in gum Arabic production and quality and hence improve the livelihoods of drylands communities. The three varieties are distributed in different soil types, which are found under different climatic conditions and topography. These soil characteristics are major factors

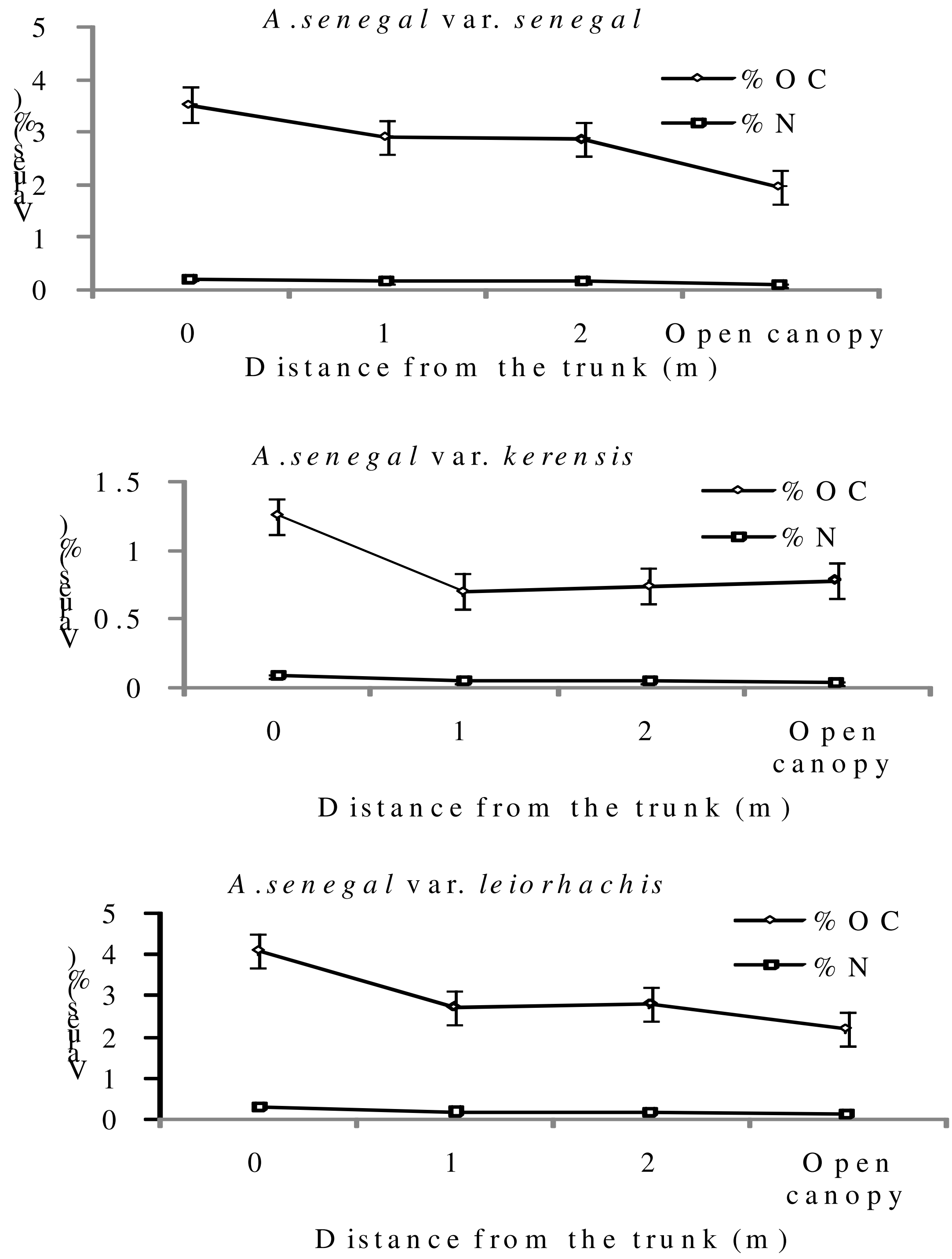

Figure 3. Soil organic carbon and nitrogen from soils collected at specified distances from the trunk and in the open grasslands.

that influence the gum Arabic production and quality and further research is needed especially on the effect of soil micronutrients on gum quality. Further research is necessary to identify the provenances with high gum production and quality under these agro-ecological zones for domestication and use in dryland agroforestry systems.

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