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INVESTIGATIONS ON CANOPY FEATURES OF THREE INDIGENOUS WOODLAND TREE SPECIES OF ETHIOPIA

Asferachew Abate[1], Masresha Fetene[2,*] and Zerihun Woldu[2]

[1] Ministry of Economic Development and Cooperation PO Box 1037
Addis Ababa, Ethiopia

[2] Department of Biology, Faculty of Science Addis Ababa University
PO Box 1176 Addis Ababa, Ethiopia

ABSTRACT: Canopy features, diversity of undercanopy vegetation, and undercanopy soil chemical characteristics of three indigenous woodland tree species namely: *Acacia tortilis* (Forssk.) Hayne, *Acacia senegal* (L.) Willd, *Balanites aegyptiaca* (L.) Del. were studied. The objective of the study was to explore the potential of the tree species for use in agroforestry systems. The study was conducted at three different sites within the Great Rift Valley at Adamitulu area, Abijata Shalla and Awash National Parks. At each site a total of 15 study trees were selected from 50 x 50 m relevès. From each tree, data on tree height, diameter at breast height (DBH), canopy depth and canopy diameter were collected. Effect of trees on undercanopy vegetation diversity was assessed by estimating cover of undercanopy herbaceous vegetation. Soil samples were collected beneath and outside tree canopies to investigate the influence of tree species on undercanopy soil. *A. tortilis* had the highest DBH (0.42 $\pm$ 0.12) and canopy diameter (13.64 $\pm$ 2.25) whereas the highest tree height (5.18 $\pm$ 0.77) and canopy depth (2.94 $\pm$ 0.73) were recorded for *B. aegyptiaca*. The highest undercanopy vegetation diversity was recorded for *A. tortilis* (2.13) followed by *A. senegal* (1.92) and *B. aegyptiaca* (1.78). In general, surface soil organic carbon, total nitrogen, available phosphorus, exchangeable potassium, and electrical conductivity were higher under tree canopies for all the study trees compared to outside canopy soils. Soil conductivity, organic carbon, total nitrogen and available phosphorus were found to be highest for surface soils, under *A. tortilis*. However, no difference in soil nutrient content among the tree species were found at greater soil depth. Implications of the findings for agroforestry systems are discussed.

Key words/phrases: *Acacia senegal, Acacia tortilis*, Agroforestry, *Balanites aegyptiaca*, undercanopy soil property

* Author to whom all correspondence should be addressed.

INTRODUCTION

The potential role woodland trees can play as multipurpose tree species has recently gained wider significance (Gutteridge and Shelton, 1993). This is more so in connection with the use of indigenous trees for agroforestry systems (Fagg and Stewart, 1994). To qualify for use as multipurpose species a tree should have a relatively fast growth rate and ability to improve soil fertility. It should also provide favourable microclimate for growing crops and forage under its canopy (Belsky *et al.*, 1989). Thus, before considering trees for use in agroforestry systems, their growth characteristics, canopy features and soil improving capacity need to be assessed.

Ethiopia is endowed with a number of woodland trees that could be used as multipurpose tree species (De Vletter, 1991). However, very few studies have been done on their actual potential. Although limited data may have been obtained on some species from studies in other countries (Belsky *et al.*, 1989; Belsky *et al.*, 1993), the large variability that exists, depending on sites and varieties in the country, necessitate specific studies. The following study was conducted with this in mind. Three indigenous woodland trees, *Acacia tortilis* (Forssk.) Hayne, subspecies *spirocarpa, Acacia senegal* (L.) Willd variety *senegal* and *Balanites aegyptiaca* (L.) Del. variety *aegyptiaca* were studied to investigate their potential for use in agroforestry systems.

MATERIALS AND METHODS

Sites

The study was conducted at three different sites within the Ethiopian Rift Valley: at Adamitulu, about 220 km south of Addis Ababa along the road to Awassa (site-1), in the Awash National Park at about 10 km on the left side of the road from the main gate to the Head Quarter (site-2), and in the Abijata Shalla National Park (site-3). The altitude of sites-1 and 3 ranges between 1680–1740 m while the second site was at an altitude of about 1000 m above see level. Mean annual rainfall and temperature in the study areas range between 400–800 mm and 20–25° C, respectively (EMA, 1988). All the sites were protected from livestock and based on information from the locality the sites had not been burnt at least for the past ten years. The effect of wildlife was also minimal.

Vegetation data and analysis

Five representative relevès, having an area of 2500 m^2 (50 x 50 m), were established in each of the three sites. Both establishment of relevès and data collection were performed in July, 1993. The relevès were established systematically to include *A. tortilis*, *A. senegal* and *B. aegyptiaca* at each relevè. When it was difficult to encompass all the trees within one relevè, a relevè was made to include at least two of the study trees and the third one was taken from the nearest possible distance from this relevè. In each of the relevè's the density of all tree species was recorded. Selection of trees for detailed studies was made on the basis that they were at least 10 m away from neighbouring trees. In each relevè one individual from each of the study trees was selected to measure tree height, diameter at breast height (DBH) approximately 1.5 m above the ground, canopy diameter and canopy depth. Canopy depth was measured as the distance between the bole, where bifurcation of branches begin, and the tip of the tree.

Under the canopies of each of the study trees, herbaceous vegetation was listed and their cover was estimated visually. Cover of outside canopy herbaceous vegetation was also estimated from 10 x 10 m quadrats, which were made at least 3 m away from the edge of the tree canopies. Cover of outside canopy vegetation was compared with undercanopy vegetation to assess the effect of canopy on vegetation abundance and composition.

Undercanopy areas of all study trees and the corresponding outside tree canopy areas were considered as stands. Visually estimated cover values from these stands were converted into a modified Domin scale (Goldsmith *et al.*, 1976). The converted cover values were used to calculate species diversity as a measure of species richness and relative abundance. The diversity in each stand was computed using the Shanon-Weaver diversity index (Goldsmith *et al.*, 1976).

Soil sample collection and analyses

Six species were selected from each of the study trees and undercanopy soil samples were collected from 0–3, 5–8 and 20–23 cm depths along a transect from the bole to the edge of the canopy at a distance of 50, 250, and 450 cm. Similarly, representative soil samples outside tree canopies, two from each site, were collected from an area where there was no vegetation. Electrical conductivity was determined by preparing a 1:2 soil/water suspension (Chopra and Kanwar, 1976). The Walkley and Black wet oxidation method was followed to determine organic carbon (Juo, 1978; Cottenie, 1980). Available phosphorus was determined following Bray No.1 procedure (Juo, 1978). Micro-Kjeldahl method was used to determine total nitrogen (Juo, 1978). Potassium was determined by extraction using ammonium acetate solution at pH 7 (Teklu Baissa, 1992).

Mean values of conductivity, organic carbon, total nitrogen, available phosphorus and exchangeable potassium were used to compare the influence of trees on canopy soils at different depth and distance from the tree bole. Comparison of variation in soil properties among study trees were made by using the overall mean of a particular soil property.

Statistical analysis

The mean values of tree characteristics and the results obtained by soil analysis were compared using a two way analysis of variance and Tukey's test of significance using the MINITAB statistical software (version 10) at 5% confidence level.

RESULTS

The dominant species in all the three sites investigated were *A. tortilis, A. senegal, B. aegyptiaca* and *A. seyal* (Table 1). In addition the following trees were also recorded; *A. mellifera, A. nubica, A. nilotica* (only in site-2) and *A. sieberiana* (only in site-3). Grass and herb species dominant in site-1 were *Cenchrus ciliaris, Hyparrhenia hirta, Chloris gayana, Cryptostegia grandiflora, Harpachne schimperi, Tagetes minuta, Solanum incanum, Bidens pilosa, Satureja abyssinica* and *Sida ovata*. A complete list of undercanopy species and their cover values is given in appendices 1 and 2.

Site-2 was dominated by the following grass species: *Ischaemum afrum, Bothriochloa radicans, Chrysopogon plumulosus, Dactyloctenium scindicum* and *Cymbopogon excavatus*. *Barleria quadrispina* was dominant among the herbs in site-2.

Grass and herb species dominant in site-3 were *Cenchrus setigerus, Cenchrus ciliaris, Harpachne schimperi, Hypoestes forskaolii, Satureja abyssinica* and *Solanum incanum*.

Table 1. Density of species in each of the Relevé.

Species	Relevé/Density				
	1	2	3	4	5
<u>Site-1</u>					
Acacia tortilis	13	9	4	8	7
A. senegal	5	2	2	0	0
Balanites aegyptiaca	3	1	0	0	0
A. seyal	13	9	1	0	0
<u>Site-2</u>					
A. tortilis	16	8	3	3	14
A. senegal	14	19	9	51	16
B. aegyptiaca	9	0	6	0	11
Cordia gharaf	5	17	2	0	3
Grewia vilosa	5	20	13	18	10
A. mellifera	0	0	0	0	8
A. nubica	0	0	137	0	18
A. nilotica	0	1	0	0	0
Dobera glabra	0	0	3	0	0
Grewia erythria	1	0	0	2	7
<u>Site-3</u>					
A. tortilis	37	26	39	25	25
A. senegal	6	5	10	10	0
B. aegyptiaca	8	18	12	7	2
A. seyal	26	3	15	10	17
A. sieberiana	0	0	0	4	3

Site-3 had the highest tree density of the dominant species followed by sites-2 and 1 with total mean values of 61, 36 and 17 per relevè, respectively. However, the study trees in site-1 were characterized by highest mean values of tree height, DBH and canopy diameter (Table 2) as well as diversity of undercanopy herbaceous species compared with sites-2 and 3.

Table 2. Mean values of tree characteristics (m) of the study trees at the different sites.

Characteristics	*A. tortilis*			*A. senegal*			*B. aegyptiaca*		
Sites	1	2	3	1	2	3	1	2	3
Height (m)	6.05 ± 0.56^a	5.14 ± 1.44^a	3.80 ± 0.45^b	5.32 ± 0.74^a	3.26 ± 0.34^b	4.48 ± 1.23^b	4.35 ± 1.39^b	6.07 ± 0.66^a	5.12 ± 1.57^a
DBH (m)	0.64 ± 0.02^a	0.27 ± 0.08^b	0.33 ± 0.18^b	0.39 ± 0.16^b	-	0.29 ± 0.09^b	0.34 ± 0.12^b	0.19 ± 0.09^c	0.27 ± 0.06^b
Canopy Depth (m)	2.86 ± 0.25^a	1.72 ± 0.61^b	0.56 ± 0.29^b	3.36 ± 0.63^a	1.82 ± 0.19^b	1.10 ± 0.55^c	2.82 ± 0.93^a	3.81 ± 1.19^a	2.20 ± 1.20^a
Canopy Diameter (m)	16.60 ± 4.88^a	12.22 ± 3.71^a	12.10 ± 1.93^a	10.26 ± 2.05^b	7.23 ± 1.92^c	8.14 ± 1.26^c	6.36 ± 1.14^c	6.42 ± 1.70^c	6.60 ± 2.06^c

Note: Means of each tree species were compared separately. Mean values followed by the same letters are not significantly different at 5% confidence interval.

Taking tree characteristics in all sites together, the highest tree height (5.18 ± 0.77) and canopy depth (2.94 ± 0.73) were recorded for *B. aegyptiaca*. Trees of *A. tortilis* were relatively larger in size. They had the highest DBH and canopy diameter with means 0.42 ± 0.12 m and 13.64 ± 2.25 m, respectively. Trees of *A. tortilis*, with their more or less flat crowns, had the lowest canopy depths (1.71 ± 0.58 m).

Cover of undercanopy vegetation was highest (124 ± 21 %) under *A. tortilis* followed by *A. senegal* (110 ± 21 %) and *B. aegyptiaca* (107 ± 16.77 %), respectively. *A. tortilis* had the highest diversity of species growing beneath its canopy in all the sites followed by *A. senegal* and *B. aegyptiaca* (Table 3). Comparison of the mean diversity indices of the study trees indicated that the diversity index of *A. tortilis* (2.13) was significantly higher compared with *B. aegyptiaca* (1.78). Mean diversity indices of all the study trees were significantly higher than diversity indices of species outside tree canopies (Table 3).

Electrical conductance of soils under the study trees ranged from 0.05–0.80 m siemens cm^{-1}. In all the sites, mean conductance was significantly higher in surface soils compared to soils outside tree canopies at 5% confidence level (Table 4). Comparison of undercanopy surface soils of the study trees revealed that mean conductance of *A. tortilis* was highest followed by *B. aegyptiaca* and *A. senegal* (Fig. 1). However, their difference was not significant at 5% confidence level.

Table 3. Mean diversity indices of undercanopy vegetation in each of the sites (n=5).

Site no.	*A. tortilis*	*A. senegal*	*B. aegyptiaca*	Outside canopy
1	2.44	2.27	2.12	1.18
2	1.91	1.84	1.70	0.76
3	2.05	1.64	1.51	1.32
Mean*	2.13^{a}	1.92^{ab}	1.78^{b}	1.05^{c}

* Mean diversity indices of the study trees in all sites (n=15). Means followed by the same letters are not significantly different at 5 % confidence interval.

Table 4. Mean soil electrical conductivity (m siemens cm^{-1}). Means followed by different letters are significantly different at 5% confidence level, (n=6) (OC, Outside Canopy).

Depth (cm) / Distance from the bole (cm)	*A. tortilis* 50	*A. tortilis* 250	*A. tortilis* 450	*A. senegal* 50	*A. senegal* 250	*A. senegal* 450	*B. aegyptiaca* 50	*B. aegyptiaca* 250	*B. aegyptiaca* 450	OC
0-3	0.80^a	0.73^a	0.57^a	0.71^d	0.54d^b	0.18b^c	0.76^a	0.47^a	0.47^{ab}	0.08^c
5-8	0.40^c	0.31^b	0.18^a	0.32^d	0.18^b	0.10^a	0.54^a	0.22^b	0.14^b	0.11^c
20-23	0.28^c	0.23^b	0.12^a	0.17^b	0.05^b	0.11^a	0.47^a	0.32^b	0.28^b	0.17^c

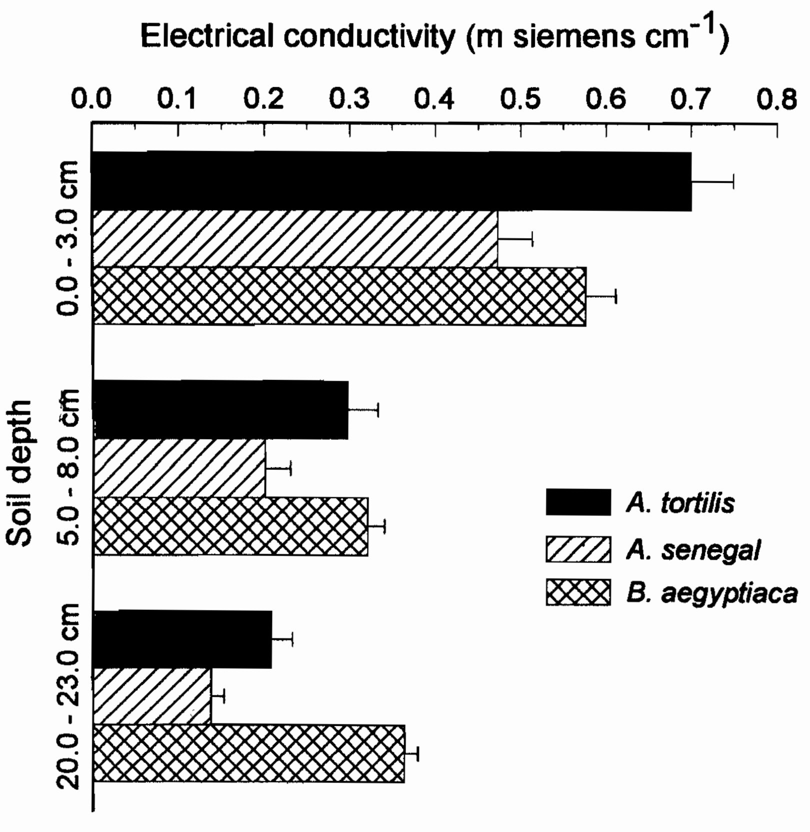

Fig. 1. Comparison of electrical conductivity of soils under the canopies of the tree species. ($\bar{x} \pm sd$, $n=18$).

Per cent organic carbon from undercanopy surface soils of all the tree species ranged from 1.84 to 5.36%. In all the study trees organic carbon declined with soil depth. In addition, undercanopy surface soils of *A. tortilis* and *A. senegal* had significantly higher organic carbon compared to surface soils of outside tree canopies (Table 5). Comparison of the study trees among themselves showed that organic carbon of surface soils under *A. tortilis* were significantly higher than the surface soil under *B. aegyptiaca*. The organic carbon of surface soil under *A. senegal* exceeded surface soil of *B. aegyptiaca*. However, per cent organic carbon of soil samples at depths of 6.5 and 21.5 cm under *B. aegyptiaca* tended to be higher compared with soil samples under *A. senegal* of similar depths (Fig. 2).

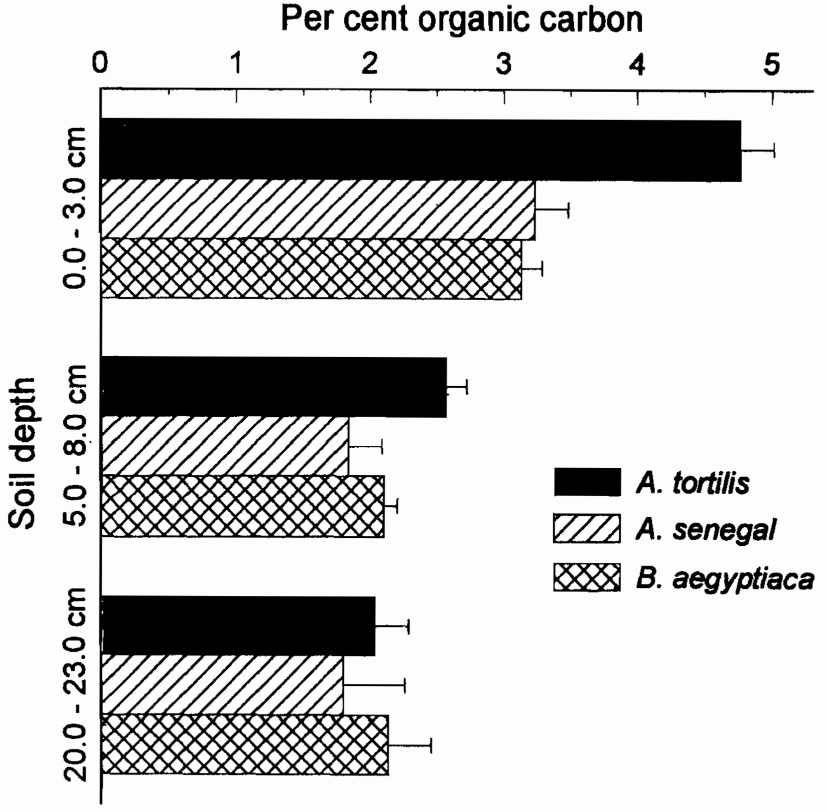

Fig. 2. Comparison of organic carbon of soils under the canopies of the tree species. ($\bar{x}$ ± *sd*, $n = 18$).

Like organic carbon, total nitrogen tended to be higher in surface soils and declined with depth in all the study trees (Table 6 and 8). Total nitrogen in outside canopy soils tended to be lowest compared with undercanopy soils of all the study trees. However, the difference was not significant. Total nitrogen of surface soils under *A. tortilis* tended to be highest followed by *B. aegyptiaca* and *A. senegal* (Fig. 3). Total nitrogen of soils under *A. senegal* tended to be lower than under the non-legume *B. aegyptiaca*.

Table 5. Mean organic carbon (%). Means followed by different letters are significantly different at 5% confidence interval, (n=6) (OC, outside canopy).

Depth (cm)	Distance from the bole (cm)	*A. tortilis*			*A. senegal*			*B. aegyptiaca*			
		50	250	450	50	250	450	50	250	450	OC
0–3		4.10^{b}	5.02^{b}	5.36^{b}	4.53^{b}	3.42^{b}	1.84^{b}	2.41^{a}	2.91^{a}	4.24^{b}	1.36^{a}
5–8		2.10	2.54	2.12	2.46	1.83	1.53	2.77	1.79	1.58	1.23
20–23		2.00	1.81	1.92	2.22	1.50	1.17	1.35	2.57	1.64	0.99

Table 6. Mean total nitrogen (%), (n=6) (OC, outside canopy).

Depth (cm)	Distance from the bole (cm)	*A. tortilis*			*A. senegal*			*B. aegyptiaca*			
		50	250	450	50	250	450	50	250	450	OC
0–3		0.16	0.35	0.34	0.13	0.11	0.05	0.27	0.15	0.37	0.09
5–8		0.12	0.14	0.08	0.05	0.07	0.05	0.09	0.12	0.16	0.06
20–23		0.11	0.14	0.08	0.06	0.05	0.04	0.04	0.09	0.22	0.05

Available phosphorus also tended to be highest in surface soils. It ranged from 0.83–1.19 ppm in *A. tortilis*, 0.28–0.71 ppm in *A. senegal* and 0.21–0.45 ppm in *B. aegyptiaca* (Tables 7 and 8). In general, available phosphorus declined with distance from the boles and with soil depth. Available phosphorus in surface soil collected under *A. tortilis* was significantly higher at 5 % confidence level than surface soils under *A. senegal* and *B. aegyptiaca* (Fig. 4).

Exchangeable potassium in undercanopy soils of *A. tortilis* and *A. senegal* ranged from 3.00–4.82 milli equivalent. Although not significantly, exchangeable potassium declined both with depth and distance from the bole under these trees. Unlike in the other two study trees, there was no regular pattern of change in exchangeable potassium with distance and depth for *B. aegyptiaca*. Surface soils of outside tree canopies had significantly lower exchangeable potassium compared with undercanopy soils of all the study trees. There was no significant variation in exchangeable potassium among the study trees.

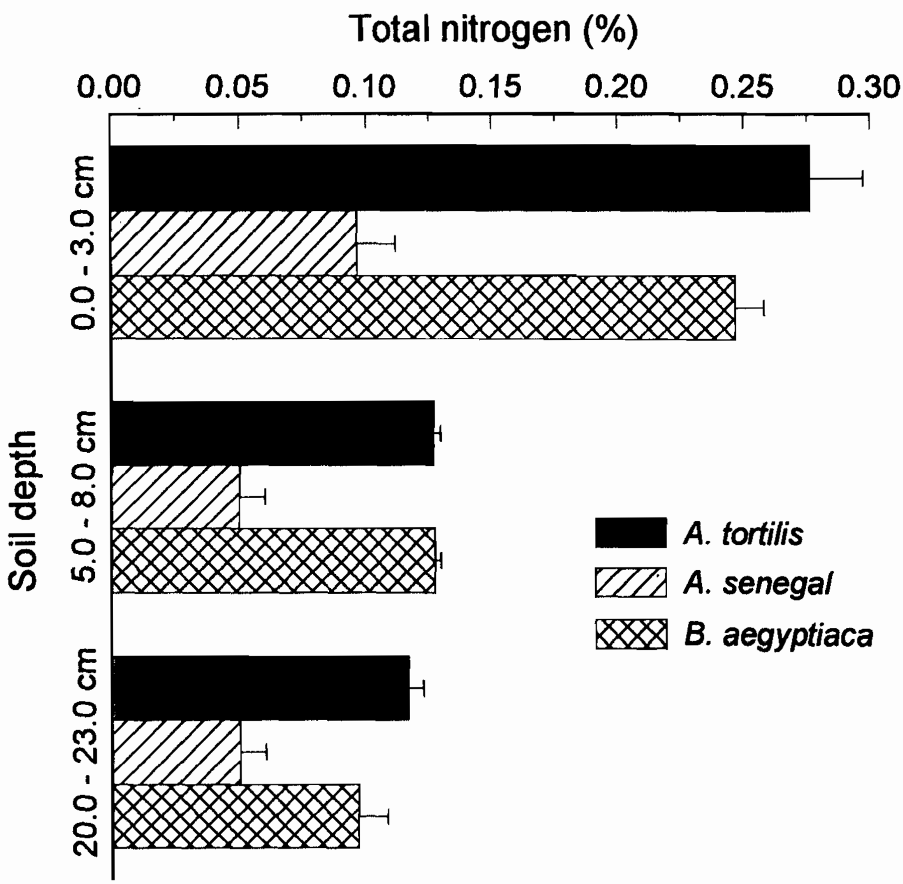

Fig. 3. Comparison of total nitrogen of soils under the canopies of the tree species. ($\bar{x} \pm sd$, $n = 18$).

Table 7. Mean available phosphorus (ppm), (n=6) (OC, outside canopy).

Depth (cm) / Distance from the bole (cm)	*A. tortilis*			*A. senegal*			*B. aegyptiaca*			
	50	250	450	50	250	450	50	250	450	OC
0–3	1.19	0.85	0.83	0.71	0.62	0.28	0.41	0.21	0.45	0.63
5–8	0.42	0.43	0.24	0.43	0.16	0.19	0.26	0.22	0.18	0.38
20–23	0.38	0.19	0.16	0.65	0.32	0.13	0.30	0.22	0.11	0.28

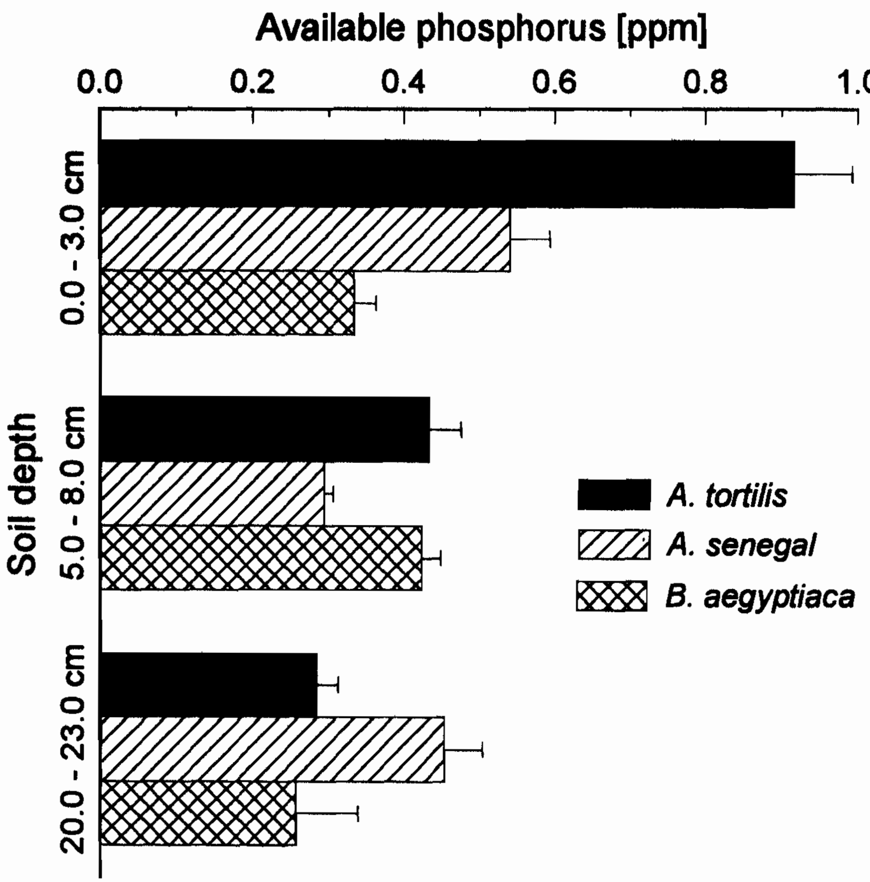

Fig. 4. **Comparison of available phosphorus of soils under the canopies of the tree species.** ($\bar{x}$ ± *sd*, *n*=18).

Table 8. Two way analysis of variance table for the interaction of soil depth and distance from the bole within tree canopies.

Species	Source	DF	MS	F_{ratio}	P
			Electrical conductivity		
Acacia tortilis	Depth	2	1.223	9.41	< 0.05
	Distance	2	0.191	1.47	> 0.05
	Dept. x Dist.	4	0.002	0.02	> 0.05
Acacia senegal	Depth	2	0.359	7.68	< 0.05
	Distance	2	0.298	6.38	< 0.05
	Dept. x Dist.	4	0.100	2.14	> 0.05
Balanities aegyptiaca	Depth	2	0.253	3.58	< 0.05
	Distance	2	0.575	8.16	< 0.05
	Dept. x Dust.	4	0.188	0.27	> 0.05
			Organic carbon		
A. tortilis	Depth	2	45.69	8.41	< 0.05
	Distance	2	0.93	0.17	> 0.05
	Dept. x Dist.	4	1.02	0.19	> 0.05
A. senegal	Depth	2	13.52	7.27	< 0.05
	Distance	2	10.87	5.84	< 0.05
	Dept. x Dist.	4	1.56	0.84	> 0.05
B. aegyptiaca	Depth	2	5.79	1.63	> 0.05
	Distance	2	1.10	0.31	> 0.05
	Dept. x Dist.	4	3.03	0.85	> 0.05
			Total nitrogen		
A. tortilis	Depth	2	0.183	3.69	< 0.05
	Distance	2	0.027	0.55	> 0.05
	Dept. x Dist.	4	0.024	0.49	> 0.05
A. senegal	Depth	2	0.011	1.76	> 0.05
	Distance	2	0.006	0.99	> 0.05
	Dept. x Dist.	4	0.003	0.53	> 0.05
B. aegyptiaca	Depth	2	0.083	4.10	< 0.05
	Distance	2	0.006	0.29	> 0.05
	Dept. x Dist	4	0.012	0.61	> 0.05
			Available phosphorus		
A. tortilis	Depth	2	2.557	6.69	< 0.05
	Distance	2	0.033	0.87	> 0.05
	Dept. x Dist.	4	0.039	0.10	> 0.05
A. senegal	Depth	2	0.342	2.55	> 0.05
	Distance	2	0.721	5.38	< 0.05
	Dept. x Dist.	4	0.072	0.54	> 0.05
B. aegyptiaca	Depth	2	0.047	0.73	> 0.05
	Distance	2	0.062	0.96	> 0.05
	Dept. x Dist.	4	0.012	1.18	> 0.05

DISCUSSION

This study revealed that a site with a high tree density may not necessarily have trees with desirable characteristics. Adamitulu area (site-1) had the lowest tree density while it contained trees with the highest height, the largest DBH, canopy depth, canopy diameter and canopy radius. On the other hand, Awash National Park (site-2) had the highest tree density whereas the lowest tree characteristics were recorded from this site. Both tree characteristics and tree density are influenced by inter- and intra-species competition. Thus, to effectively utilize the interaction of trees and herbs for crop and forage production as well as wood products from the trees, it might be necessary to optimize the number of tree species to be used per unit area (Karamchandani, 1989).

High abundance and diversity of herbaceous species under *A. tortilis* might be due to its large canopy diameter which allows for abundant growth of various species in the favourable undercanopy microclimate. Large shade of the canopy also minimizes run off by reducing the size and speed of raindrops which otherwise would result in loss of top soil from undercanopy.

High per cent vegetation cover and diversity of species under tree canopies compared to vegetation of outside canopies clearly showed that the species provide favourable environmental conditions which encourage higher growth of herbs and grasses beneath their canopies. Studies conducted so far to assess the important factors determining the abundance of understorey vegetation revealed that availability of soil moisture and nutrients are the key factors (Ben-Shahar, 1991).

Litter fall both from the canopy and understorey vegetation improves infiltration of precipitation by altering the physical and chemical properties of the soil and minimizing evapotranspiration. Kelly and Walker (1976) demonstrated that litter fall can improve the rate of infiltration compared to bare ground. The net effect of these factors would be improving undercanopy soil moisture. Together with soil nutrient content (see below) better soil moisture regime increase under-canopy vegetation abundance and diversity.

Soils are said to be in the normal range of concentration for soluble salts for most plant growth if their electrical conductances do not exceed 0.4 m siemens cm^{-1} (Donahue *et al.*, 1983). Electrical conductivity well above 0.4 m siemens

cm^{-1} were found from surface soils of most of the studied tree canopies. Although individual soluble salts were not quantified in the present study, it is possible that the high electrical conductivity values might be due to accumulation of Na^{+}, Ca^{++}, Mg^{++}, Cl^{-} and SO_4^{--} (Thompson and Frederick, 1978). The values of electrical conductivity in the present study decreased with depth except for *B. aegyptiaca*. Increased soil conductivity with soil depth under *B. aegyptiaca* (20 cm) might be due to leaching facilitated by the cylindrical shape of its canopy allowing much throughfall during the rainy season. Increase in conductivity with depth of outside canopy soil might also be attributed to leaching by rain that falls directly on the ground uninterrupted. Thus, significant difference of mean conductance between under and outside canopy soils indicated the influence of the trees on soil conductivity.

The relatively higher content of soil organic carbon under tree canopies indicated the soil enriching capacity of the trees. Although the values for nitrogen and phosphorus were not high, relatively more of these nutrients were found within tree canopies compared to outside canopy soils. Similar reports have been made by a number of workers who investigated the effect of tree canopies on plant nutrients (Garcia-Moya and Mckell, 1970; Charley and West, 1975; Kellman, 1979; Weltzin and Coughenour, 1990; Kamara and Haque, 1992).

The reason for higher content in the undercanopy soils could be complex (Vettas, 1992). Weltzin and Coughenour (1990) suggested that leaf fall from trees might be the most likely nutrient source. Dust accumulated on tree leaves and branches by wind blowing from the surroundings could also be a good source of mineral nutrients as it is washed down to undercanopy soil during stemflow and throughfall (Kellmann, 1979).

Woody species have deeper tap roots and extensive spreading lateral roots. Such root systems are probably important in concentrating nutrients under the canopy (Kellmann, 1979). Knoop and Walker (1985) suggested that nutrients found in low concentration throughout the soil profile may be taken up by the root system of mature trees and shrubs. These nutrients return back to undercanopy soil when tree leaves fall and decompose (Garcia-Moya and McKell, 1970).

Comparing the nitrogen content of undercanopy soils of the three trees (Fig. 3), soil under *A. tortilis* had more nitrogen followed by *B. aegyptiaca* and *A.*

senegal. That the legume tree *A. senegal* had less nitrogen compared to the non-legume tree *B. aegyptiaca* is surprising. Perhaps this might support the finding that not all trees that have the potential to fix atmospheric nitrogen actually do so (Garcia-Moya and McKell, 1970).

This study showed that all three species investigated had some qualities as agroforestry species, especially as related to their soil improving quality. From the study, it could be suggested that *A. tortilis* may be the choice tree for agroforestry in Adamitulu area whereas in the lower and more drier Awash National Park area *Balanites aegyptiaca* may be the better choice. However, more detailed studies on crop tree interactions, spacing, etc. are needed. Currently, seed germination and seedling establishment characteristics of these trees are under investigation in our laboratory.

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Appendix 1. Tree and herbaceous undercanopy species occurring in the three study sites — Adamitulu, Awash and Abijata Shalla. The tree species are in five replicates A-E and the undercanopy species are represented by numbers with their per cent cover in parenthesis. The list of undercanopy species corresponding to the numbers are given in Appendix 2.

		A	2	(5.0)	4	(1.0)	6	(80.0)	11	(1.0)	13	(2.0)		
			18	(2.0)	25	(1.0)	26	(10.0)	34	(2.0)	35	(2.0)		
Adamitulu			36	(1.0)										
		B	2	(20.0)	4	(1.0)	5	(2.0)	6	(60.0)	10	(2.0)		
			11	(5.0)	26	(6.0)	34	(5.0)	37	(5.0)	38	(20.0)		
			39	(1.0)										
	A. tortilis	C	2	(10.0)	5	(2.0)	6	(10.0)	9	(1.0)	11	(1.0)		
			34	(5.0)	36	(1.0)	38	(20.0)	39	(1.0)	40	(20.0)		
			41	(1.0)										
		D	2	(20.0)	5	(1.0)	6	(30.0)	9	(1.0)	10	(10.0)		
			11	(5.0)	13	(5.0)	25	(1.0)	26	(5.0)	34	(5.0)		
			35	(1.0)	36	(1.0)	37	(10.0)	38	(40.0)	42	(15.0)		
		E	2	(40.0)	5	(1.0)	6	(65.0)	9	(15.0)	10	(5.0)		
			11	(1.0)	25	(1.0)	27	(20.0)	33	(20.0)	34	(5.0)		
			35	(5.0)	38	(15.0)	43	(20.0)						
		A	2	(10.0)	6	(5.0)	7	(4.0)	10	(5.0)	13	(15.0)		
			26	(10.0)	34	(5.0)	38	(20.0)						
		B	1	(1.0)	2	(40.0)	6	(40.0)	9	(50.0)	26	(10.0)		
			34	(5.0)	35	(5.0)	38	(40.0)	39	(1.0)	44	(1.0)		
			49	(10.0)										
	A. senegal	C	2	(40.0)	5	(1.0)	6	(10.0)	7	(30.0)	10	(1.0)		
			11	(2.0)	13	(2.0)	26	(5.0)	34	(5.0)	36	(1.0)		
			38	(20.0)	39	(1.0)	44	(1.0)						
		D	2	(40.0)	6	(3.0)	10	(10.0)	11	(1.0)	13	(20.0)		
			26	(5.0)	34	(5.0)	38	(40.0)	41	(10.0)				
		E	1	(1.0)	2	(20.0)	5	(1.0)	6	(5.0)	10	(15.0)		
			11	(1.0)	26	(5.0)	34	(15.0)	38	(60.0)				
		A	2	(1.0)	6	(30.0)	9	(30.0)	11	(1.0)	13	(2.0)		
			26	(10.0)	34	(5.0)	37	(1.0)	38	(1.0)	39	(1.0)		
			45	(2.0)	49	(20.0)								
	B. aegyptiaca	B	5	(1.0)	6	(55.0)	10	(5.0)	26	(5.0)	34	(5.0)		
			38	(20.0)	39	(1.0)	42	(1.0)						
		C	2	(10.0)	5	(5.0)	6	(25.0)	9	(70.0)	26	(5.0)		
			38	(5.0)										
		D	6	(1.0)	9	(5.0)	13	(20.0)	32	(10.0)	34	(1.0)		
			38	(30.0)	41	(1.0)								
		E	7	(2.0)	9	(30.0)	10	(2.0)	13	(10.0)	18	(5.0)		
			26	(5.0)	29	(10.0)	37	(2.0)	38	(10.0)	45	(10.0)		

Awash	*A. tortilis*	A	8	(10.0)	12	(5.0)	14	(30.0)	15	(20.0)	16	(5.0)
			32	(10.0)	46	(5.0)						
		B	12	(20.0)	14	(10.0)	15	(20.0)	16	(5.0)	17	(5.0)
			27	(10.0)	47	(1.0)	48	(2.0)				
		C	12	(5.0)	14	(50.0)	15	(20.0)	16	(5.0)	19	(5.0)
			21	(5.0)	29	(10.0)	47	(1.0)	50	(10.0)	51	(2.0)
		D	12	(2.0)	14	(2.0)	16	(20.0)	52	(60.0)		
		E	8	(5.0)	12	(5.0)	14	(10.0)	16	(60.0)	17	(10.0)
	A. senegal	A	8	(5.0)	12	(5.0)	14	(10.0)	15	(20.0)	16	(5.0)
			19	(5.0)	29	(10.0)						
		B	14	(20.0)	16	(5.0)	19	(5.0)	22	(5.0)	47	(5.0)
			48	(10.0)								
		C	12	(10.0)	14	(10.0)	15	(20.0)	16	(10.0)	19	(5.0)
			47	(5.0)								
		D	12	1(5.0)	14	(2.0)	15	(10.0)	16	(50.0)	17	(20.0)
			24	(2.0)	27	(10.0)						
		E	16	(70.0)	23	(20.0)						
	B. aegyptiaca	A	15	(10.0)	19	(10.0)	20	(30.0)	29	(10.0)	32	(5.0)
		B	16	(2.0)	19	(10.0)	21	(5.0)	23	(10.0)	29	(20.0)
			32	(40.0)	50	(75.0)						
		C	19	(10.0)	23	(20.0)	24	(5.0)	48	(5.0)	50	(10.0)
			53	(2.0)								
		D	12	(10.0)	16	(15.0)	23	(2.0)	50	(40.0)		
		E	12	(40.0)	14	(5.0)	15	(30.0)	47	(2.0)	50	(10.0)
			54	(10.0)	55	(20.0)						
Abijata Shalla	*A. tortilis*	A	2	(40.0)	3	(10.0)	9	(1.0)	25	(1.0)	26	(10.0)
			30	(10.0)	56	(50.0)	57	(20.0)	58	(2.0)	59	(1.0)
		B	2	(1.0)	3	(60.0)	10	(40.0)	25	(1.0)	26	(5.0)
			31	(5.0)	41	(1.0)	60	(1.0)	62	(5.0)		
		C	2	(30.0)	3	(5.0)	9	(25.0)	26	(40.0)	28	(1.0)
			29	(15.0)	31	(5.0)	58	(2.0)	60	(1.0)		
		D	3	(80.0)	9	(20.0)	13	(10.0)	26	(10.0)	28	(5.0)
			38	(5.0)	63	(5.0)						
		E	2	(60.0)	3	(50.0)	9	(5.0)	26	(50.0)	61	(10.0)
	A. senegal	A	2	(1.0)	9	(5.0)	10	(4.0)	26	(5.0)	29	(20.0)
			31	(1.0)	38	(2.0)	56	(70.0)	58	(1.0)		
		B	2	(5.0)	3	(60.0)	9	(5.0)	26	(10.0)	28	(5.0)
			29	(50.0)	31	(5.0)	35	(5.0)	61	(5.0)	62	(5.0)
		C	3	(60.0)	26	(50.0)						
		D	3	(70.0)	9	(20.0)	26	(50.0)				
		E	1	(2.0)	3	(1.0)	9	(10.0)	18	(1.0)	26	(90.0)
			61	(5.0)	62	(60.0)						
	B. aegyptiaca	A	1	(1.0)	3	(80.0)	9	(1.0)	26	(10.0)	64	(1.0)
		B	9	(1.0)	26	(20.0)						
		C	29	(15.0)	60	(1.0)	61	(5.0)	64	(5.0)		
		D	2	(5.0)	3	(70.0)	25	(10.0)	26	(10.0)	36	(20.0)
			37	(5.0)	43	(10.0)	65	(5.0)				
		E	1	(1.0)	9	(2.0)	26	(90.0)	43	(1.0)	61	(10.0)

Appendix 2. List of undercanopy species recorded from the three sites.

No.	Species name	No.	Species name
1.	*Lippia trifolia*	33.	*Acacia seyal* Del.
2.	*Solanum incanum* L.	34.	*Bidens pilosa*
3.	*Hypoestes forskaolii* (Vagk.) R. B.	35.	*Setaria verticillata*
4.	*Achyranthes aspera* L.	36.	*Commelina benghalensis* L.
5.	*Galinsoga parviflora* Cav.	37.	*Solanum schimperi*
6.	*Tagetes minuta* L.	38.	*Chloris gayana* Kunth
7.	*Solanum nigrum* L.	39.	*Euphorbia petitiana* A. Rich.
8.	*Vernonia* sp.	40.	*Acacia sieberiana* DC.
9.	*Satureja abyssinica* (Benth.) Briq.	41.	*Erucastrum* sp.
10.	*Harpachne schimperi* Hochst. ex A. Rich.	42.	*Cineraia abyssinica*
11.	*Cryptostegia grandiflora* R. Br.	43.	*Sida* sp.
12.	*Grewia villosa* Willd.	44.	*Erucastrum abyssinica*
13.	*Hyperrhenia hirta* (L.) Stapf.	45.	*Eragrostis tenuifolia* (A. Rich.) Steud.
14.	*Bothriochloa radicans* (Lehm.) A. Camus	46.	*Digitaria rivae* (Chiov.) Stapf.
15.	*Chrysopogon plumulosus* Hochst.	47.	*Pupalia lappacea* Juss.
16.	*Ischaemum afrum* (J.F. Gmel) Dandy	48.	*Seddera latifolia* Hochst & Steud.
17.	*Cordia gharaf* (Forssk.) Ehrenb ex Ashers.	49.	*Enteropogon macrostachys* (A. Rich.) Benth
18.	*Sida ovata* Forssk.	50.	*Cymbopogon* sp.
19.	*Barleria quadrispina* Lindau	51.	*Seddera lancolata*
20.	*Cymbopogon excavatus* (Hochst.) Stapf.	52.	*Lintonia nutans* Stapf.
21.	*Vernonia cinerea* (L.) Less	53.	*Solanum benderaianum* Engl
22.	*Dactyloctenium scindicum* Boiss	54.	*Hibiscus triona*
23.	*Acacia nubica* Benth	55.	*Grewia tricolata* (SP.)
24.	*Vernonia cinerea* (L.) Less	56.	*Cenchrus setigerus* Vahl
25.	*Abutilon bidentatum* (Hochst.) A. Rich.	57.	*Ceropegia cufodritii* Chiov.
26.	*Cenchrus ciliaris* L.	58.	*Sida rhombitolia* L.
27.	*Acacia tortilis* (Forssk.) Hayne	59.	*Leptadinia arborea*
28.	*Pavonia arabica* Boiss	60.	*Notonia abyssinica* A. Rich.
29.	*Acacia senegal* (L.) Willd	61.	*Ischaemum* sp.
30.	*Abutilon figarianum* Webb.	62.	*Heteropogon contortus* (L.) Roem. & Shult.
31.	*Eragrostis papposa* (Roem. & Schult.) Steud	63.	*Cypholepis yemenica* (Schweinf.) Chiov.
		64.	*Sonchus asper* (L.) Hill
32.	*Balanites aegyptiaca* (L.) Del.	65.	*Cordia* sp.