ECOLOGICAL INVESTIGATIONS ON THE POTENTIAL OF THREE WOODLAND TREE SPECIES FOR AGROFORESTRY PRACTICES

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By
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To late Girma Abate, my brother who was everything to me.

May God bless his soul.

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ABSTRACT

Three indigenous tree species namely *Acacia tortilis* (Forssk.) Hayne, *Acacia senegal* (L.) Willd. and *Balanites aegyptiaca* (L.) Del. were studied to explore their potential for agroforestry practices. Studies on the ecology and growth characteristics of the three tree species and their influence on environment were conducted at three different sites; Adamitulu, Awash and Abajata Shalla National Parks in the rift valley.

A total of 15 relevès (50 x 50 m), five relevès in each of the sites were established. In each of the relevès presence and abscence and frequency of all tree species was recorded. From each site a total of 15 trees, five for each study tree, were randomly selected for detailed investigation. Tree characteristics which included tree height, diameter at breast height (DBH), canopy depth, canopy radius and canopy diameter of each of the study trees were measured. Cover of undercanopy vegetation was estimated for each of the study trees to assess the influence of trees on undercanopy species diversity. To investigate the influence of trees on undercanopy soil, samples were collected from 50, 250, and 450 cm distances at 0 - 2.5, 5.0 - 8.0, and 20 - 23 cm depths along the transect radiating from tree boles. Texture, pH, conductivity, organic carbon, total nitrogen, available phosphorus and exchangeable potassium of the soil samples were analyzed. For comparison purposes cover of vegetation outside tree canopies and soil physical and chemical properties beyond the canopies of trees were also investigated.

Of the three sites, Abijata Shalla area was characterized by high tree density (61/ 2500 m^2), followed by Awash National Park (36/ 2500 m^2) and Adamitulu area (17/ 2500 m^2). *Acacia tortilis* had the highest DBH (0.42 ± 0.12 m), canopy diameter (13.64 ± 2.25 m) and canopy radius (6.91 ± 0.79 m) whereas the highest tree height (5.18 ± 0.77 m) and canopy depth (2.14 ± 0.73 m) were recorded for *B. aegyptiaca*. Undercanopy vegetation diversity of *A. tortilis* was highest (2.13) followed by *A. senegal* (1.92) and *B. aegyptiaca* (1.78). In all sites undercanopy species diversity was significantly higher than vegetation diversity outside of tree canopies.

Texture and pH did not vary between under and outside canopy soils implying that tree canopies did not affect these soil properties. Surface soil conductivity, organic carbon, total nitrogen, available phosphorus and exchangeable potassium were significantly higher under tree canopies for all the study trees compared with outside canopy soils. Comparison of the study trees top soil nutrient contents indicated that under canopy soils of *A. tortilis* had higher values followed by *A. senegal* and *B. aegyptiaca*, respectively.

Acacia tortilis and *A. senegal* had comparable seedling growth rates whereas the former had a higher seedling emergence vigor.

The results showed that the study trees significantly enriched soil under their canopies and created a suitable environment for the growth of undercanopy vegetation. Over all *A.tortilis* had better growth characteristics and improved most undercanopy soil. The significance of the findings for agroforestry are discussed.

1 INTRODUCTION

1.1 Scope of the problem

Despite the fact that the area originally covered by closed forests in Ethiopia was estimated on poorly established facts (Anonymous, 1992; Tamrat, 1994), there is a general consensus that some 5,000 years ago, high forests covered 35% of the country (FAO, 1981; Wood and Stahl, 1990; Zerihun and Mesfin, 1990).

Deforestation in Ethiopia has been occurring prior to the 16th century (Zerihun, 1985). Nevertheless, its rate in the past few years was dramatic. In the early 1950's forests were reported to cover 16% of the country. This amount was reduced by 81% within 44 years resulting in a forest cover of less than 3% at the present time (Wood and Stahl, 1990).

High population growth accounts for the rapid rate of devegetation. When the first census was held in 1984 the population of the country was 42 million. The population growth rate was estimated to be 2.9% annually (CSA, 1991). At this rate of growth the population size in the year 1995 will reach 58 million. More surprisingly, World Bank (1987) anticipated annual growth rate of population greater than 3% after the year 1995.

High population growth means higher demands for more agricultural land and fuelwood. According to FAO (1988) sustainable fuelwood production for the year 1984 was 14.9 million m^3 from all types of forests and woodlands. However, the consumption in the same year was 24 million m^3 which was 60% in excess. More recent studies have suggested that consumption is 2.5 times greater than the level of sustainable production (UNDP/FAO/LUPRD, 1984). The shortage of fuelwood forces the rural population to resort to dung and crop residues. Domestic animal dungs and crop residues have become now the main household fuel for the rural people resulting in complete removal of biomass from the soil. The result is lower soil fertility, poor soil structure and decreased infiltration.

Loss of vegetation cover and soil degradation lead to higher rate of soil erosion. Current soil erosion from cultivated land averages to 42 tone ha^{-1} $year^{-1}$ (Barber, 1984). All in all, soil loss from slopes amounts to approximately 1,500 million tonnes per year with 45% from crop land alone (Hurni, 1988).

The impacts of deforestation are drastic. It is estimated that crop production decreases annually by 2% due to land deterioration alone (Hurni, 1988). This in turn contributes to continued rural poverty and famine.

Both governmental and non governmental organizations have been carrying afforestation and other soil conservation programs to curb the impacts of deforestation. In the years from 1976 to 1988, about 800,000 km of soil and stone bunds for terrace formation on crop land, about 600,000 km of hillside terraces for afforestation of steep slopes and some 100,000 hectares of closed areas for natural regeneration were made (Hurni, 1988; Wood and Stahl, 1990).

Conservation programs up to now largely concentrated on physical measures. It is obvious that terraces and bunds reduce erosion and improve infiltration. There are also areas which by their nature require such measures. However, physical measures alone can not give effective and relatively immediate solution to rural problems. Hurni (1988) estimated that using only physical measures, it will take 70 years until all land in Ethiopia in need of rehabilitation will have received a first treatment. This calls for better and acceptable strategies. A combination of agroforestry and physical measures haven been proved to be a better set of conservation measures (Wood and Stahl, 1990).

Agroforestry, involves the exploitation of ecologically and economically beneficial interaction between the woody and non woody components which lead to combined production of crop, fodder and fuelwood while at the same time providing protection against soil erosion (Karamchandani, 1989).

The practice of agroforestry is not new to Ethiopian farmers as many farmers grow trees and crops together on their farm fields. Despite the many advantages of agroforestry little attention has so far been given to it and very little scientific investigations have been made on agroforestry schemes compared with other conservation measures (Karamchandani, 1989; Wood and Stahl, 1990). This is inspite of the fact that the country posses a large number of multipurpose trees that could be used for agroforestry (De Vletter, 1991).

According to the report of Karamchandani (1989), so far only three plant species have been studied and proved to be important for agroforestry. These species are *Acacia albida, Sesbania spp.* and *Leucaena spp.* Before a tree can be recommended for agroforestry practices basic knowledge on the characteristics and potentials of the tree should be acquired. The present study was conducted with this in mind.

In this study the ecology of three indigenous woodland tree species namely *Acacia tortilis* (Forssk.) Hayne, *Acacia senegal* (L.) Willd. and *Balanites aegyptiaca* (L.) Del. were studied in order to evaluate their potential for use in agroforestry systems.

1.2 Objectives of the study

a. To investigate the growth characteristics of the tree species and their associated vegetation in their natural growing areas.

b. To investigate the effects of these species on the composition of understory vegetation.

c. To analyze the effect they have on understory soil physical and chemical properties.

d. To study some seedling establishment characteristics and

e. To evaluate their potential for use in agroforestry practices.

1.3 Description of the study areas

1.3.1 Location

The study was conducted at three different sites within the Ethiopian main 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) (Fig. 1). The altitude of site one and three ranges between 1680 - 1740 m above see level while the second site has an altitude of 970 m above see level.

1.3.2 Geology

Detailed accounts of the geology of the Rift System of Ethiopia was given by Mohr (1962, 1967a and 1967b). The Ethiopian Rift System separating the northwestern from the southeastern highlands comprises several units, the most important of which are the Lake Rudolf, the Lake Stefanie, Main Ethiopian and Afar rifts (Mohr, 1967a). The three study sites are located in the main Ethiopian rift. This rift is marked by a persistent belt of intense fresh faults which have been termed as the Wonji fault belt (Mohr, 1962). In the study sites this belt is associated with extensive basalt flows, cinder and spatter cones as well as silicilic flows and domes (Mohr, 1967b). Recent sediments of quaternary age which are composed of conglomerates, sands, silt, and clay represent non-volcanic rock units in the study sites.

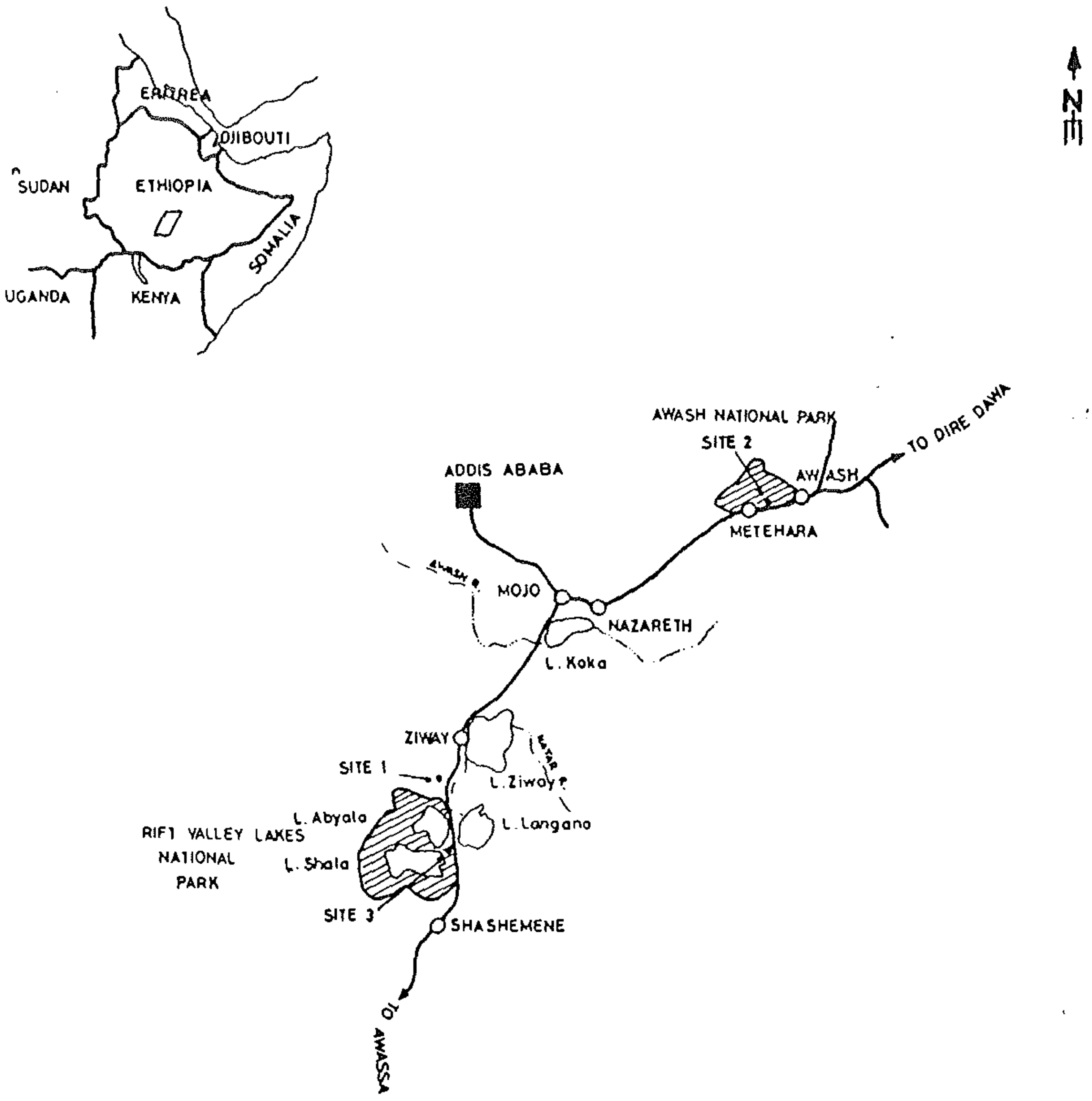

FIG. 1 MAP SHOWING LOCATIONS OF THE STUDY AREAS.DOTS SHOW THE APPROXIMATE AREAS WHERE THE VEGETATION AND EDAPHIC DATA WERE COLLECTED.

SCALE 1:3,000,000

SOURCE: NATIONAL ATLAS OF ETHIOPIA (EMA 1988)

1.3.3 Climate

1.3.3.1 Precipitation

The rainfall pattern in Ethiopia is governed by two moist wind systems, one coming from the Atlantic Ocean and the other from the Indian Ocean (Daniel, 1977). Based on the annual distribution of rainfall, four major regimes are identified. The rift valley experiences a nearly bimodal rainfall distribution. The small rains from February - March come from the Indian Ocean and the big rains from June - September come mainly from Atlantic Ocean and minor amount from the Indian Ocean. High concentration of rainfall occurs in July and August. According to EMA (1988) mean annual rain fall in the study areas ranges from
400 - 800 mm.

1.3.3.2 Temperature

The mean annual temperature in the study area ranges between 20 - 25 °C.

1.3.4 Vegetation

The vegetation of Ethiopia has been grouped into nine major zones (Ensermu *et al*, 1992). The vegetation of the study area belongs to *Acacia* - *Commiphora* woodland (Ensermu *et al*, 1992). This vegetation is characterized by small leafed deciduous tree species predominantly, *Acacia tortilis, A. senegal, A. seyal, A. mellifera, A. nilotica, A. sieberiana* and *Balanites aegyptiaca.* Other commonly occurring species include *Dichrostachys cinerea, Barleria spp., Aerva spp., Combretum spp., Commiphora spp. Albizia spp.* and *Entada spp.*

As indicated in the first part of the introduction, it is worth noting that Acacia - Commiphora woodlands have been severely deforested particularly in recent years due to intensification of agricultural activity and for the supply of fuelwood and charcoal to the major towns of Ethiopia (Anonymous, 1992).

1.4 Description of the Study Trees

Complete description of features of *A. tortilis, A. senegal* and *B. aegyptiaca* is provided in Hedberg and Edwards (1990). The followings include only major features of the study trees.

Acacia tortilis belongs to family Fabaceae subfamily Mimosoideae. It is a medium size tree ranging from 4 - 21 m in height. It grows between 600 and 1900 m above sea level. It has flat crown, white flowers contorted or spirally twisted pods. Based on the nature of the pods two subspecies are identified. *A. tortilis* subspecies *tortilis* has 3 - 5 mm wide, shortly pubescent eglandular pods and *A. tortilis* subspecies *spirocarpa* has pods 6 - 9 mm wide, appressed puberulous to tomentellous and with numerous dark red glands.

A. tortilis is an important shade and browse tree whose seeds are said to be edible and used as famine food. The wood has many uses.

A. senegal belongs to family Fabaceae subfamily Mimosoideae. It grows in the altitude range of 600 - 1700 m above sea level as shrub or tree species up to 10 (15) m in height. It has white or cream flowers and straight, yellowish brown to brown pods.

Three varieties are identified: *A. senegal* variety *Kerensis* is shrub whereas *A. senegal* variety *senegal* and variety *leiorhachis* are trees which can be distinguished by the nature of their branchlets, bark and inflorescence.

Acacia senegal is an important source of Gum Arabic for international trade and it is also found to be useful for agroforestry in semi - arid areas of Ethiopia and Sudan.

Balanites aegyptiaca belongs to family Balanitaceae. It is a small tree up to 8 m high growing in the range of 700 - 1800 m above sea level. It has foliage leaves only on the stem, elongated fruits in the early stage, becoming ovoid to ellipsoidal, usually rounded or truncate at both ends when matured. The fruits become yellow when ripen.

Two varieties are known: *B. aegyptiaca* variety *aegyptiaca* is characterized by leaflets indumentum usually sparse and or early glabrescent or minutely puberulous, inflorescences few to many flowered clusters often at spinous nodes. Where as *B. aegyptiaca* variety *pallida* has densely tomentellous leaflet indumentum, inflorescence always at spineless node with 1 -5 flowers.

Balanites aegyptiaca is used in many ways throughout its range. The fruit which is edible, yields a valuable oil and also contains saponins which are lethal to certain invertebrates and thus of value in eliminating the carriers of guinea-worm and schistosomiasis. It is a very useful, evergreen, shade tree in semi-arid areas.

In all of the sites, the study was conducted on *A. tortilis* variety *spirocarpa* and *B. aegyptiaca* variety *aegyptiaca*. *Acacia senegal* variety *senegal* was used in site 1 and 3. However, as this particular variety could not be found at site 2, it was replaced by *A. senegal* variety *kerensis*.

2 COLLECTION OF FIELD DATA AND LABORATORY STUDIES

2.1 Field data

Vegetation data and soil samples were collected from three selected tree species: *Acacia tortilis*, *Acacia senegal* and *Balanites aegyptiaca* (study trees). At every site canopy features and cover of undercanopy vegetation were recorded for five individuals from each study species. Soil samples were collected from only two individuals of each study tree in every site. Thus, a total of 15 tree species for vegetation study and six trees for undercanopy soil analysis were selected in each of the sites.

2.1.1 Vegetation data

Five relevès having an area of 2500 m^2 (50 x 50 m) were esablished in each of the sites. The relevès were established systematically to include all the three species at once. 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. Selection of trees for detailed studies was made on the basis that they were at least 10 m apart from the neighboring tree. In each of the relevè's the density of all tree species was recorded.

A meter tape was used to measure diameter at breast height, (DBH), approximately 1.5 m above the ground, canopy diameter, canopy radius, tree height and canopy depth. Canopy diameter was measured by stretching the meter tape from one edge of the canopy to another (Fig 2). Canopy radius refers to the distance from the tree bole to the edge of the canopy. Tree height was recorded by measuring the distance from the base of the tree to the tip of the tree. Canopy depth was measured from the bole where bifurcation of branches begin to the tip of the tree.

Under each of the study trees, cover of herbaceous vegetation was estimated visually. Cover of outside canopy (refers to the area where the effect of canopy is absent) herbaceous vegetation was also estimated from a (10 x 10 m) quadrat which was made at least 3 m away from the edge of the tree canopy. Figure 2 depicts the sampling design for vegetation and soil sample collection. Cover of outside canopy vegetation was compared with undercanopy vegetation to assess the effect of canopy on vegetation abundance and composition.

2.1.2 Environmental data

2.1.2.1 Temperature and Relative humidity

Air temperature and relative humidity were recorded using a thermometer and a sling Psychrometer, respectively.

2.1.2.2 Soil samples

Soil samples were taken from 0 - 2.5, 5.0 - 8.0 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. For comparison purposes soils were collected at a distance of at least 3 m outside the canopy of trees.

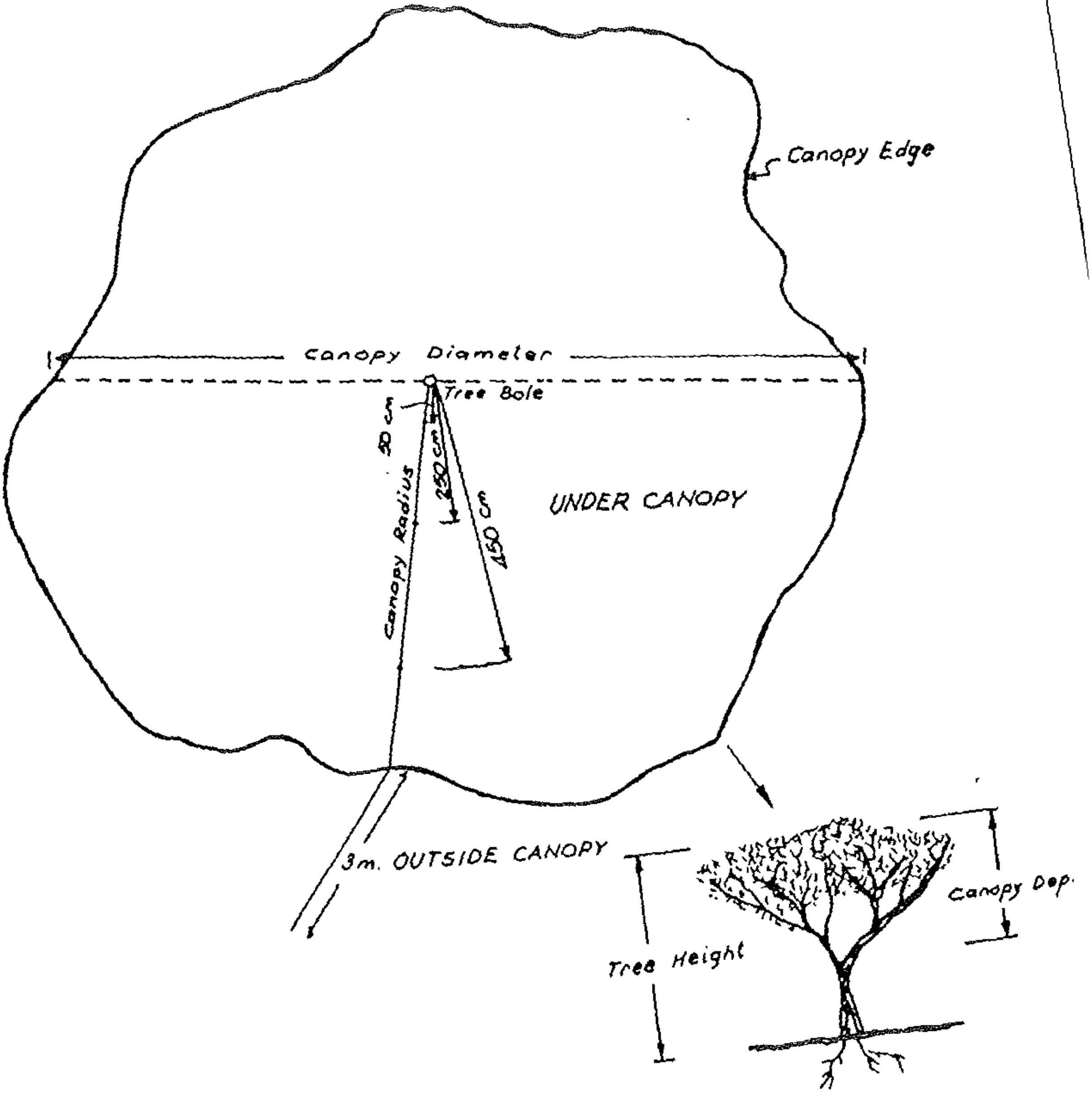

Fig 2. Aerial view of sampling design for soil and vegetation data collection.

2.2 Laboratory studies

2.2.1 Soil analysis

The textural classes of the soil samples were determined following hydrometer method of mechanical analysis (Juo, 1978; Tamirie, Heluf and Yohannes, 1986). Fifty gram of 2 mm sieved samples were added to 50 ml of 5% Sodium hexametaphosphate along with 100 ml of distilled water to remove the humus of the soil. After stirring, the suspension was allowed to stand for 30 minutes. The suspension was then stirred for 15 minutes using multi-mix machine and transferred to 1 liter measuring cylinder. The cylinder was filled to the mark and the first hydrometer and temperature readings were taken after 40 seconds. The second hydrometer and temperature readings were taken 3 hours later. The percentages of the various soil separates were determined by the following formulae (Juo, 1978):

$$Per\ cent\ sand = 100 - [H_1 + 0.2\ (T_1 - 68) - 2]\ x\ 2$$

$$Per\ cent\ clay = H_2 + [0.2\ (T_2 - 68\ -2\ ]\ x\ 2$$

$$Per\ cent\ silt = 100 - [\%sand + \%clay]$$

Where H_1 and H_2 are first and second Hydrometer readings and, T_1 and T_2 (in °F) are first and second temperature readings, respectively.

The per cent of the soil separates were used to determine the textural classes of soil samples.

For pH measurement a 1:1 soil water ratio was used (Juo, 1978). Twenty grams of soil was mixed with 20 ml of distilled water in 50 ml beaker. The suspension was stirred occasionally and then the pH was determined after 30 minutes using Beckman pH meter (Model CA 92634 - 3100, U.S.A) standardized by buffer solutions of pH 4 and 7.

Electrical conductivity of the soil solution which is mainly determined by soluble salts of chlorides, sulphates, carbonates and nitrates was analyzed by preparing a 1:2 soil/water suspension following Chopra and Kanwar (1976). Soil samples (50 gm) were mixed with 100 ml of distilled water in conical flasks and the mixtures shaken for 12 hours using mechanical shaker. The suspensions were then filtered and the specific conductance of the filtrates was determined by Crison Conductometer (Barcelona, Spain).

Organic carbon was determined following the Walkley and Black wet oxidation method (Juo, 1978; Cottenie, 1980). However, it is worth mentioning from the outset that this method yields 75 per cent of the total organic carbon present (Cottenie, 1980). Initially 0.2 gm soil samples were digested with 10 ml 1 N potassium dichromate and 10 ml concentrated sulphuric acid in Erlenmeyer flasks. After 30 minutes 10 ml of 85% phosphoric acid was added to complex the Fe^{+3} ions liberated together with 1 ml diphenylamine indicator and the resulting solutions were titrated with hydrated ferrous sulphate. The per cent carbon was calculated using the following formula (Chopra and Kanwar, 1980):

$$\text{Per cent carbon} = \frac{(X - Y) \times 0.003 \times 100}{W}$$

Where W = weight of soil sample in gram,

X = volume of 1 N ferrous sulphate used for reducing 10 ml potassium dichromate (blank) and

Y = volume of 1 N ferrous sulphate used for reducing the excess potassium dichromate in the sample.

Total nitrogen was determined following the micro-kjeldahl procedure (Cottenie, 1980). To one gram soil samples passed through a 0.5 mm sieve, a mixture of 7 gm potassium sulphate and 0.8 gm cupric sulphate was added. The mixtures were transferred into macro Kjeldahl flasks and 12 ml concentrated sulphric acid was added. The suspensions were digested until a blue clear solution developed. After cooling and adding 75 ml distilled water, the digest was distilled by dispensing 40% sodium hydroxide. The distillates were received in 25 ml of mixed boric acid indicator and titrated with 0.1 N hydrochloric acid till the green color of the distillate changed to red. The per cent of nitrogen in the samples was calculated as follows:

$$\text{Per cent nitrogen} = \frac{(T - B) \times N \times 14.007 \times 100}{\text{weight of sample(mg)}}$$

where, T = Titration Volume for the sample.

B = Titration volume for the blank.

N = Normality of the acid.

14.007 = Atomic weight of nitrogen.

To determine available phosphorus in the soil Bray No. 1 method was used following Juo (1978). One gram soil samples were extracted using 7 ml of extracting solution.

The extraction was facilitated by shaking the suspension with a mechanical shaker. The suspensions were then centrifuged at 2000 revolution per minute for 15 minutes and 2 ml of the supernatant pipetted into test tubes. Into the supernatant 5 ml distilled water along with 2 ml ammonium molybdate was added. After mixing the content properly 1 ml of diluted stannous chloride was added. The transmittance of the resulting complex was determined using spectrophotometer (Spectronic 1001, U.S.A) at 660 nm. The parts per million (ppm) of available phosphorus in the soil was calculated from the regression equation developed using transmittance readings of samples with known amounts of phosphorus.

Exchangeable potassium (K^+) was determined by Flamephotometer (Teklu, 1992). Five gram of soil samples passed through 2 mm sieve were soaked for 12 hours in 100 ml of ammonium acetate (pH 7). The suspensions were filtered and filled to 250 ml. Finally, flamephotmeter readings were taken for potassium. Potassium standards which were prepared by dissolving 1.097 g potassium chloride in one liter ammonium acetate was used to estimate the ppm of potassium in the soil samples. As exchangeable cations expressed in milli equivalent (meq.) the ppm was converted to the appropriate unit as follows:

$$\text{Exchangeable potassium meq./100 gm soil} = \frac{ppm \times 250 \times 100 \times M}{5 \times 1000 \times 39.1}$$

$$= ppm \times 0.128 \times M$$

where M = moisture correction factor.

2.3 Seedling emergence and relative growth rate

Seeds of *A. tortilis* and *A. senegal* were collected from a number of randomly selected trees and mixed. From each collection the weights of 100 seeds (for each species) were used to average the weight of a single seed. Healthy looking seeds were selected and treated with 0.35% commercial sodium hypochlorite as a disinfectant. After treatment the seeds were sown in plastic pots (having a length of 22 cm and diameter of 15 cm) which were kept in a greenhouse. A total of 48 pots were used for each species and 10 seeds were sown in each pot at a depth of 1 cm. Pots were observed for emerged seedlings daily until no further seedlings emerged. The seedling emergence index was calculated by following Jones and Peterson (1976):

$$\text{Emergence Index } (EI) = \sum_{n=o}^{t-1} X_n \frac{(t-n)}{t}$$

where x_n = number of emerged seedlings on the *nth* count

n = number of counts

t= total number of counts

Embryo weight for each species was calculated by subtracting the weight of the seed coat from seed weight.

Dry shoot and root weights of seedlings up-rooted at an interval of one month time after 15 days of sowing were used to calculate relative growth rates (Leopold and Kriedemann, 1964):

$$Relative\ Growth\ Rate = \frac{\ln_{w2} - \ln_{w1}}{t_2 - t_1}$$

where w_1 and w_2 refer to whole plant dry weight on two successive time t_1 and t_2

2.4 Data analysis

All tree canopies included in the study areas from which outside canopy vegetation sampling was made were considered as a stand. Visually estimated cover values from these stands were converted into a modified Domin scale (Goldsmith, Harrison and Mortan, 1976). The scale used is given in Table 1. The converted cover value was used to calculate the species diversity which measures species richness and relative abundance. The diversity in each stand was computed using the Shanon-Weaver diversity index (Goldsmith, Harrison and Mortan, 1976).

A total of 162 soil samples were collected from undercanopies of *A. tortilis, A. senegal* and *B. aegyptiaca* (study trees) and a total of 18 soil samples from outside tree canopies. Mean values of texture, pH, conductivity, organic carbon, 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. The mean values of results obtained by soil analysis were compared using t-test (Sanders, 1990).

Table 1. A modified Domin scale, used to convert the per cent cover estimated visually.

Percent cover	Domin scale
<5	1
5-20	2
21-40	3
41-60	4
61-80	5
>81	6

3 RESULTS

3.1 Vegetation

The dominant tree species in all the three sites investigated were *A. tortilis, A. senegal, B. aegyptiaca and A. seyal.* In addition the following trees were also present; *A. mellifera, A. nubica, A. nilotica* only in site two and *A. sieberiana* only in site three. Grass and herb species dominant in site one were *Cenchrus ciliaris, Hyparrhenia hirta, Chloris gayana, Cryptostegia grandiflora, Harpachne schimperi, Tagetes minuta, Solanum incanum, Bidens pilosa, Satureja abyssinica* and *Sida ovata.* Site two was dominated by grass species of *Ischaemum afrum, Bothriochloa radicans, Chrysopogon plumulosus, Dactyloctenium scindicum* and *Cymbopogon excavatus. Barleria quadrispina* was dominant among the herbs in site two. Grass and herb species dominant in site three were *Cenchrus setigerus, Cenchrus ciliaris, Harpachne schimperi, Hypoestes forskaolii, Satureja abyssinica* and *Solanum incanum.*

The mean density of the four dominant trees in the three sites is compared in Table 2. Site three had the highest tree density of the dominant species followed by site 2 and 1 with total mean values of 61, 36 and 17 per 2500 m^2, respectively. However, the study trees in site one were characterized by highest mean values of tree height, DBH and canopy diameter (Appendix 1) as well as diversity of under canopy herbaceous species compared with site 2 and 3 (Table 4).

Table 2 . Mean density (per 2500 m^2) of dominant tree species at each site.

Tree spp.	site 1	site 2	site 3
A. tortilis	8.2	9.8	30.4
A. senegal	2.4	23.4	6.6
B. aegyptiaca	<1	2.8	9.4
A. seyal	5.2	<1	14.2
Total	16.6	36	60.6

3.2 Characteristics of study trees

Taking tree characteristics in all sites together, the highest tree height was recorded for *B. aegyptiaca*. Trees of *A. tortilis* were relatively larger in size. They had the highest diameter at breast height (DBH), canopy radius and canopy diameter with means 0.42 ± 0.12 m, 6.91 ± 0.79 m and 13.64 ± 2.25 m, respectively (Tab. 3). However, as *A. tortilis* had more or less flat crowns they had the lowest canopy depths (1.71 ± 0.58 m). *B. aegyptiaca* had the highest canopy depth (2.14 ± 0.73 m).

Table 3. Mean Values of Tree Characteristics in m

(mean ± SE) (n = 15).

Tree Characteristics	*A. tortilis*	*A. senegal*	*B. aegyptiaca*
Tree Height	4.99 (0.58)	4.35 (0.64)	5.18 (0.77)
DBH	0.42 (0.36)	0.32 (0.10)	0.26 (0.06)
Canopy Depth	1.71 (0.58)	2.09 (0.58)	2.14 (0.73)
Canopy Radius	6.91 (0.79)	4.30 (0.62)	3.32 (0.51)
Canopy Diameter	13.64 (2.25)	8.54 (1.59)	6.46 (0.89)

3.3 Undercanopy Vegetation

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*, respectively (Tab. 4). Comparison of the mean diversity indices of the study trees indicated that the diversity index of *A. tortilis* (2.13) was significantly higher at 5% confidence level compared with *B. aegyptiaca* (1.78). Mean diversity indices of all the study trees were significantly higher than diversity indices of species outside the canopy (Tab.4).

Table 4. Mean diversity indices of undercanopy vegetation in each of the sites (n = 5) (OC = outsidecanopy).

Site no.	*A. tortilis*	*A. senegal*	*B. aegyptiaca*	OC
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}	1.09^{c}

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

3.4 Temperature and Relative humidity

Air temperature and relative humidity under and outside the canopies of the study trees in all the sites were alike ranged from 22 - 34 °C and 43 - 56%, respectively.

3.5 Texture

Per cent of sand fraction was highest under the canopies of all the study trees in site one. It ranged between 63 - 79% (Tab. 5.1). Soils under canopies of *A. tortilis* and *A. senegal* in the second site were characterized by more or less equal proportion of sand and silt particles that ranged from 38 - 52% and 33 - 49%, respectively (Tab. 5.2). Soils from *B. aegyptiaca* were different from the two other study species by having a higher fraction of sand particles which ranged from 66 - 81%.

Similarly as in the first site, soils in the third site had also higher fraction of sand particles under tree canopies. The sand fraction ranged from 65 - 79 % (Tab. 5.3). The difference in texture with depth and distance as well as between under and outside canopy (Tab. 5.4) soils was small.

3.6 Soil pH

The soil pH under *A. tortilis* and *A. senegal* was slightly alkaline. It ranged between 7.13 -7.38. The soil pH of *B. aegyptiaca* on the other hand was slightly acidic. It ranged between 6.43 and 6.82 (Table 6). The difference in soil pH between inside and outside canopy soils was insignificant in all the study trees.

Table 5.1 Per cent sand, clay and silt at each distance and depth in site one.
Distance and depth are given in cm. The percentages of soil particles are mean values (n = 2)

		A. tortilis				A. senegal				B. aegyptiaca			
distance	depth	sand	clay	silt	textural class	sand	clay	silt	textural class	sand	clay	silt	textural class
50	1.25	75	5	20	loamy sand	63	7	30	sandy loam	72	4	24	sandy loam
	6.5	79	7	14	loamy sand	63	6	31	sandy loam	68	6	26	sandy loam
	21.5	73	7	20	sandy loam	64	6	30	sandy loam	64	6	30	sandyloam
250	1.25	79	5	16	loamy sand	70	5	25	sandy loam	68	4	28	sandy loam
	6.5	74	5	21	loamy sand	65	7	28	sandy loam	64	6	30	sandy loam
	21.5	72	5	23	loamy sand	64	6	30	sandy loam	70	6	24	sandy loam
450	1.25	78	5	17	loamy sand	67	8	25	sandy loam	72	4	24	sandy loam
	6.5	76	4	20	loamy sand	67	6	27	sandy loam	68	6	26	sandy loam
	21.5	72	5	23	loamy sand	64	7	29	sandy loam	64	6	30	sandy loam

Table 5.2 Per cent sand, clay and silt at each distance and depth in site two.
Distance and depth are given in cm. The percentages of soil particles are mean values (n = 2)

		A. tortilis				A. senegal				B. aegyptiaca			
distance	depth	sand	clay	silt	textural class	sand	clay	silt	textural class	sand	clay	silt	textural class
50	1.25	42	11	47	loam	48	10	42	loam	66	7	27	sandy loam
	6.5	42	13	45	loam	42	11	47	loam	68	2	30	sandy loam
	21.5	52	15	33	loamy sand	47	12	41	loam	72	2	26	sandy loam
250	1.25	51	15	34	loam	42	9	49	loam	78	1	21	sandy loam
	6.5	42	16	42	loam	41	11	48	loam	61	1	18	sandy loam
	21.5	52	18	30	loam	50	8	42	loam	76	2	22	sandy loam
450	1.25	36	16	48	loam	42	10	48	loam	80	1	19	sandy loam
	6.5	40	17	43	loam	43	11	46	loam	76	2	22	sandy loam
	21.5	39	19	42	loam	41	7	52	silt loam	75	2	23	sandy loam

Table 5.3 Per cent sand, clay and silt at each distance and depth in site three.
Distance and depth are given in cm. The percentages of soil particles are mean values (n = 2)

		A. tortilis				A. senegal				B. aegyptiaca			
distance	depth	sand	clay	silt	textural class	sand	clay	silt	textural class	sand	clay	silt	textural class
	1.25	78	2	20	loamy sand	77	1	22	loamy sand	73	1	26	sandy loam
50	6.5	72	1	27	loamy sand	77	1	22	loamy sand	67	2	31	sandy loam
	21.5	73	1	26	loamy sand	79	1	20	loamy sand	66	2	32	sandy loam
										67	1	32	sandy loam
	1.25	72	1	27	loamy sand	77	1	22	loamy sand	65	3	32	sandy loam
250	6.5	73	1	26	loamy sand	74	1	25	loamy sand	66	1	31	sandy loam
	21.5	73	1	26	loamy sand	74	1	25	loamy sand				
	1.25	72	1	27	loamy sand	74	1	25	loamy sand	73	1	26	sandy loam
450	6.5	74	1	25	loamy sand	73	1	26	loamy sand	65	3	32	sandy loam
	21.5	71	2	27	loamy sand	71	2	24	loamy sand	66	2	32	sandy loam

Table 5.4 Per cent sand, clay and silt of outside canopy soils at all sites.
distance and depth are given in cm.
The percentages of soil particles are mean values (n = 6).

site	depth	sand	clay	silt	textural class
1	1 25	65	7	28	sandy loam
2	6.5	64	5	31	sandy loam
3	21.5	66	3	29	sandy loam

Table 6. Mean pH of undercanopy soils of the study trees in all the sites (n = 6) (OC = outside canopy).

Depth (cm)	*A. tortilis*	*A. senegal*	*B. aegyptiaca*	OC
1.25	7.13	7.28	6.82	6.51
6.50	7.23	7.38	6.78	6.43
21.50	7.38	7.38	6.79	6.62

3.7 Electrical Conductivity

Electrical conductance of soils under all the study trees was higher ranging from 0.05 - 0.80 m siemens m^{-1} and surface soils under *A. tortilis* had relatively higher values of electrical conductivity (Tab. 7). In all the sites mean conductance was significantly higher in surface soils compared to soils outside the tree canopies at 5% confidence level. 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* respectively (Fig. 3). However, their difference was not significant at 5% confidence level.

Table 7. Mean soil electrical conductivity (m siemens cm^{-1}) of the study trees in all the sites. (n=6) (OC = outside canopy).

	Distance from the bole									
	A. tortilis			*A. senegal*			*B. aegyptiaca*			
Depth (cm)	50	250	450	50	250	450	50	250	450	OC
1.25	0.80a*	0.73a	0.57a	0.71d	0.54db	0.18bc	0.76a	0.47a	0.47ab	0.08c
6.50	0.40c	0.31b	0.18a	0.32d	0.18b	0.10a	0.54a	0.22b	0.14b	0.11c
21.50	0.28c	0.23b	0.12a	0.17b	0.05b	0.11a	0.47a	0.32b	0.28b	0.17c

* Only means of pairs at each depth and top soils of all distances of each study tree were compared. Top soils of each study tree were compared with outside canopy soil. Means followed by different letters are significantly different at 5% confidence level.

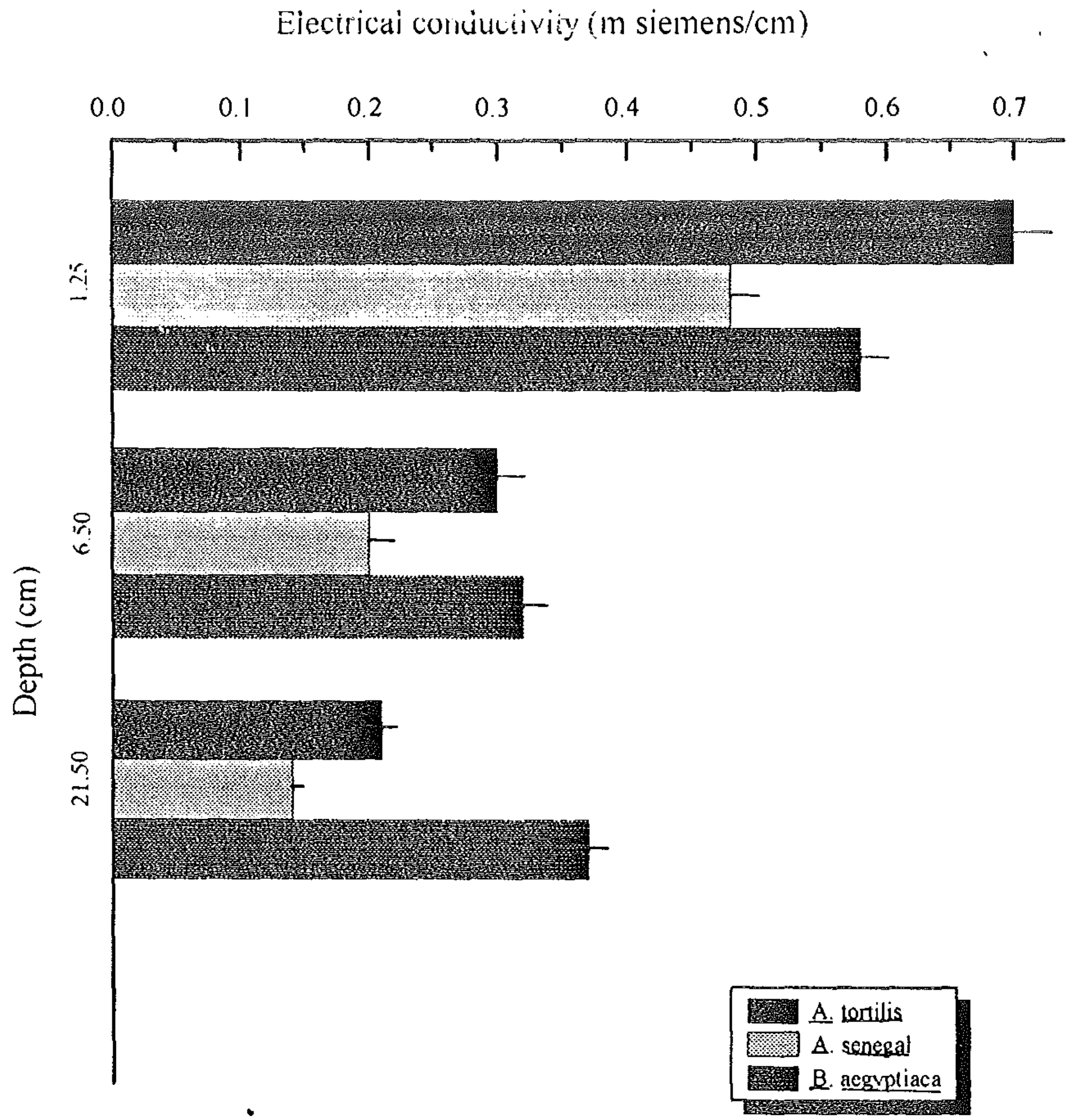

Fig. 3. Comparison of electrical conductivity among study trees (x̄ ± se; n = 18).

3.8 Organic carbon

Higher percentage of organic carbon was obtained from undercanopy surface soils of all the tree species. It ranged from 1.84 - 5.36%. In all the study trees organic carbon declined with depth. In addition, under canopy surface soils had significantly higher (at 5% confidence level) organic carbon compared to soils of outside tree canopies (Tab. 8).

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* at 5 % confidence level. The organic carbon of surface soil under *A. senegal* exceeded surface soil of *B. aegyptiaca*. However, per cent organic carbon of soils at depths of 6.5 and 21.5 cm under *B. aegyptiaca* were higher compared with soils under *A. senegal* of similar depths (Fig. 4).

Table 8. Mean organic carbon (%) of each of the study trees in all of the sites. (n = 6) (OC = outside canopy).

	Distance from the bole in cm									
	A. tortilis			*A. senegal*			*B. aegyptiaca*			
Depth (cm)	50	250	450	50	250	450	50	250	450	OC
1.25	4.10b	5.02b	5.36b	4.53b	3.42b	1.84a	2.41a	2.91a	4.24b	1.36a
6.50	2.10	2.54	2.12	2.46	1.83	1.53	2.77	1.79	1.58	1.23
21.50	2.00	1.81	1.92	2.22	1.50	1.17	1.35	2.57	1.64	0.99

* Top soils of each study trees were compared separetely. Means followed by different letters are significantly different at 5% confidence level

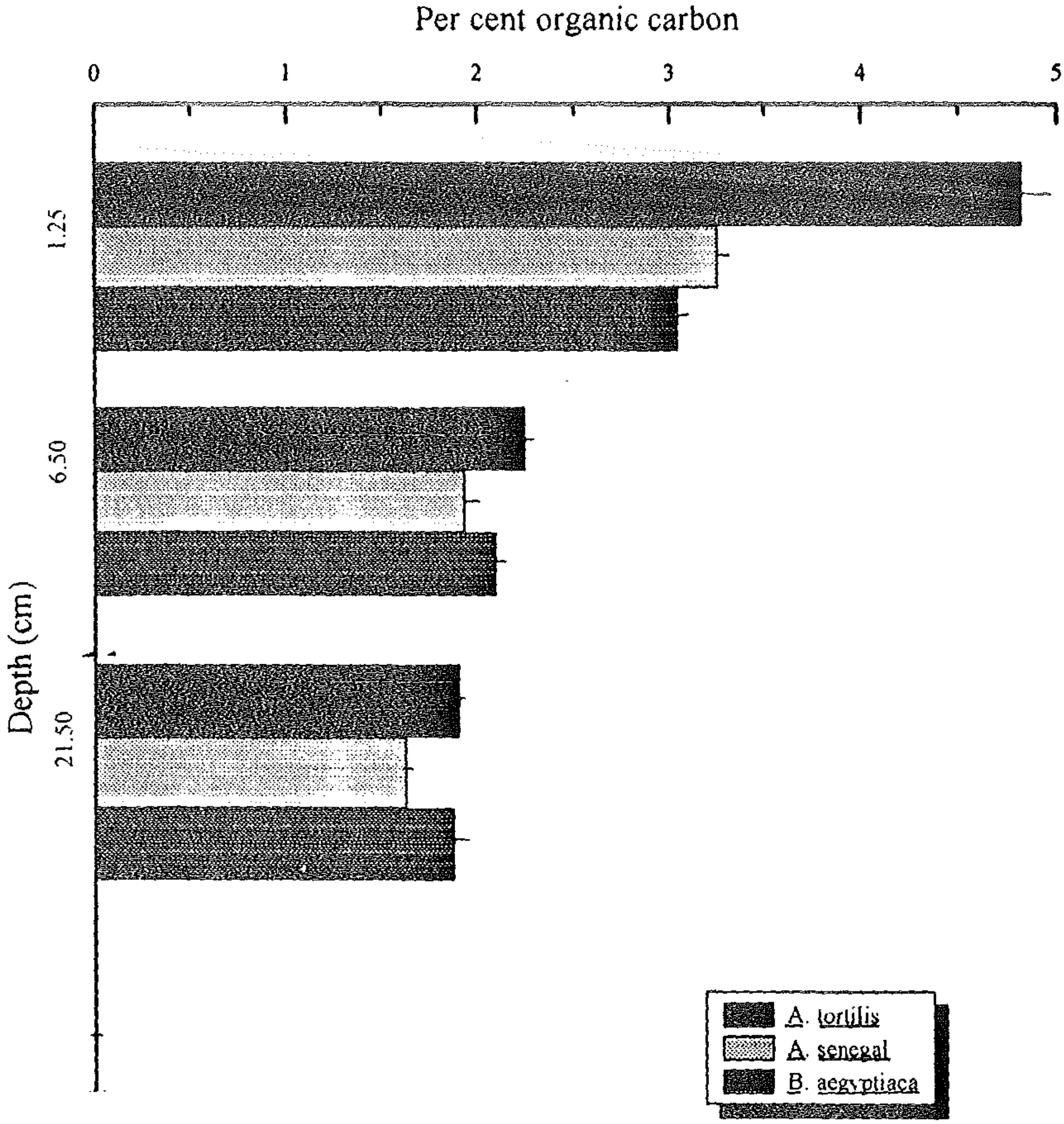

Fig. 4. Comparison of per cent organic carbon among study trees ($\bar{x} \pm$ se; n = 18).

3.9 Total nitrogen.

Like organic carbon, total nitrogen was higher in surface soil and declined with depth in all the study trees (Tab. 9). Total nitrogen in outside canopy soils was lowest compared with under canopy soils of all the study trees. However, the difference was not significant at 5% confidence level.

Total nitrogen of surface soils under *A. tortilis* was highest followed by *B. aegyptiaca* and *A. senegal* (Fig. 5). Surprisingly, total nitrogen of soils under *A. senegal* was lower than under the none legume *B. aegyptiaca.*

Table 9. Mean total nitrogen (%) of each of the study trees in all the sites.

(n = 6) (OC = outside canopy).

	Distance from the bole in cm									
	A. tortilis			*A. senegal*			*B. aegyptiaca*			
Depth(cm)	50	250	450	50	250	450	50	250	450	OC
1.25	0.16	0.35	0.34	0.13	0.11	0.05	0.27	0.15	0.37	0.09
6.50	0.12	0.14	0.08	0.05	0.07	0.05	0.09	0.12	0.16	0.06
21.5	0.11	0.14	0.08	0.06	0.05	0.04	0.04	0.09	0.22	0.05

3.10 Available Phosphorus.

Available phosphorus was also 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* (Tab. 10). In general available phosphorus declined with distance from the boles and soil depth.

Comparison of available phosphorus in the soils of study trees showed that available phosphorus in surface soil of *A. tortilis* was significantly higher at 5 % confidence level than surface soil of *B. aegyptiaca* (Fig. 6).

Table 10. Mean available phosphorus (ppm) of the study trees in all the sites. (n = 6) (OC = outside canopy).

	Distance from the bole in cm									
	A. tortilis			*A. senegal*			*B. aegyptiaca*			
Depth(cm)	50	250	450	50	250	450	50	250	450	OC
1.25	1.19	0.85	0.83	0.71	0.62	0.28	0.41	0.21	0.45	0.63
6.50	0.42	0.43	0.24	0.43	0.16	0.19	0.26	0.22	0.18	0.38
21.5	0.38	0.19	0.16	0.65	0.32	0.13	0.30	0.22	0.11	0.28

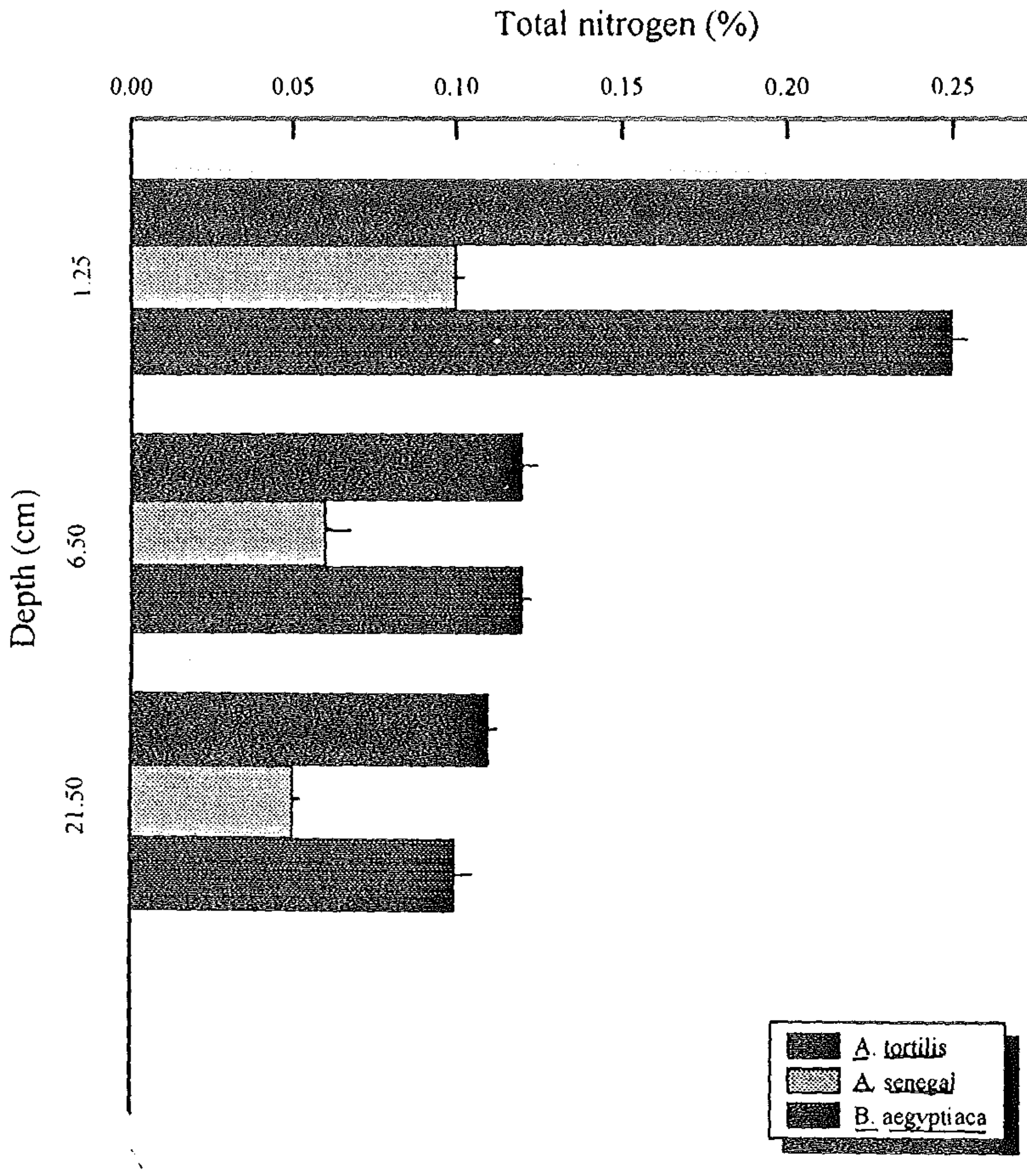

Fig. 5. Comparison of total nitrogen among study trees
($\bar{x} \pm$ se; n = 18).

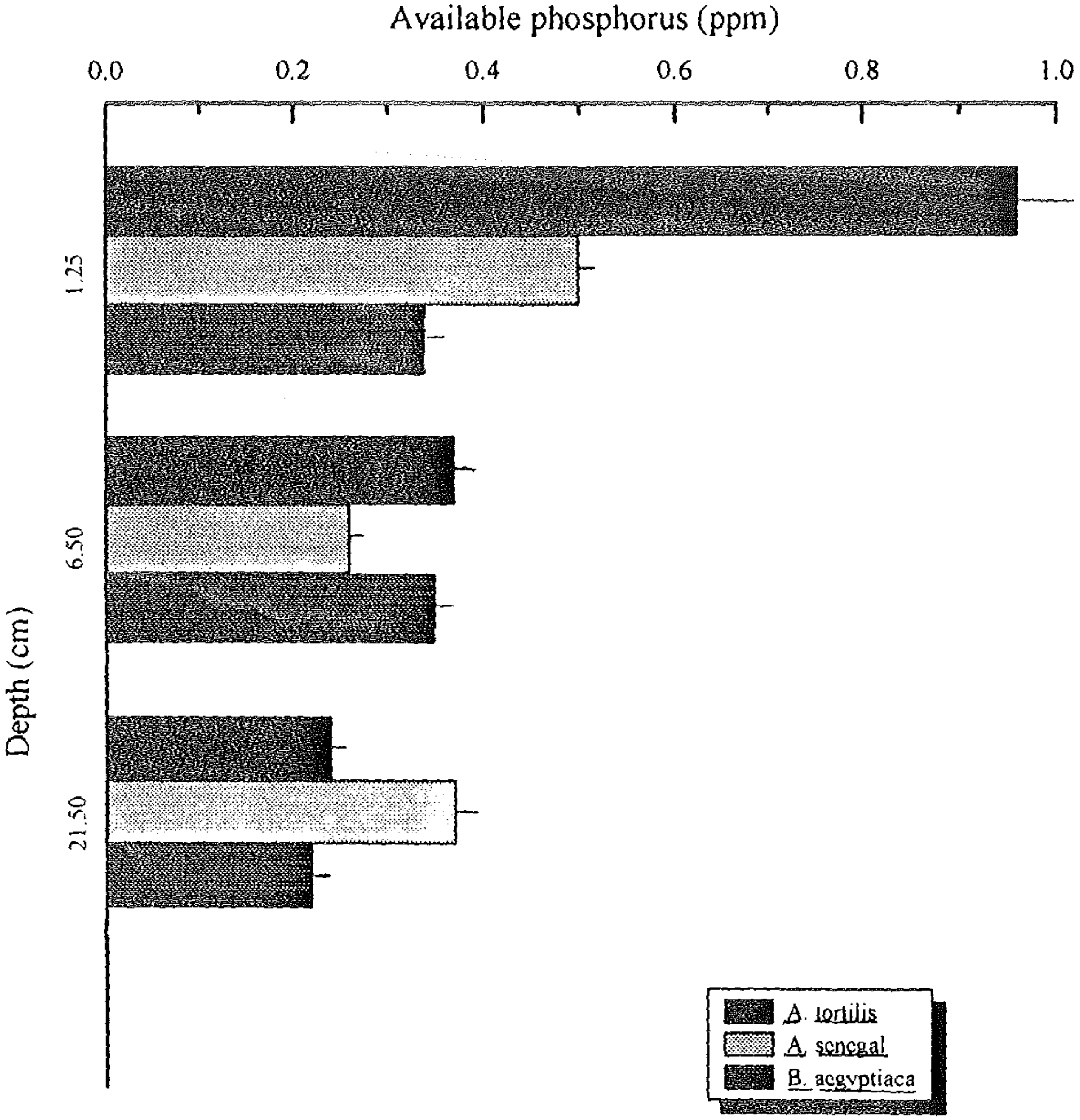

Fig. 6. Comparison of available phosphorus among the study trees
($\bar{x}$ ± se; n = 18).

3.11 Exchangeable potassium

Exchangeable potassium in undercanopy soils of *A. tortilis* and *A. senegal* ranged from 3.00 -4.82. Although not significantly, exchangeable potassium declined both with depth and distance from the bole under these trees. Exchangeable potassium undercanopy soils of *B. aegyptiaca* ranged between 1.81 - 5.11 (Tab. 11). Unlike in the other two study trees there was no regular pattern of change in exchangeable potassium with distance and depth. Surface soil outside the canopy had significantly (at 5% confidence level) lower exchangeable potassium compared with undercanopy soils of all the study trees. There was no significant variation in exchangeable potassium among the study trees.

Table 11. Mean exchangeable potassium (in milli equivalents) of all the study trees. (n = 6) (OC = outside canopy).

	Distance from the bole in (cm)									
	A. tortilis			*A. senegal*			*B. aegyptiaca*			
Depth (cm)	50	250	450	50	250	450	50	250	450	OC
1.25	4.42	4.23	4.15	4.82	4.66	3.80	4.42	5.11	2.78	1.52
6.50	4.42	3.39	4.05	4.38	3.86	3.54	4.39	4.32	1.81	4.18
21.5	4.43	3.10	3.10	3.90	3.61	3.00	4.59	3.98	1.24	2.43

3.12 Relative growth rate and root shoot ratio

The growth of seedlings of *A. tortilis* and *A. senegal* were followed for over six months (Fig. 7). Both *A. tortilis* and *A. senegal* had an exponential growth in the first eleven weeks. In the constant growth phase *A. tortilis* had a slightly higher growth rate compared with *A. senegal*. However the difference was not statistically significant.

Root shoot ratio in both species increased with time (Fig. 8). The root shoot ratio of *A. senegal* was higher towards the last weeks of measurement.

3.13 Seedling emergence

Of the two species compared, *A. senegal* had the highest seedling emergence. *Acacia senegal* had 28% emergence 7 days after sowing whereas *A. tortilis* had only 4% in the same period. There was also a significant difference in the total number of seeds that had emerged by the end of counting. Whereas 66% of seeds of *A. senegal* had emerged within 11 days only 22% of seeds of *A. tortilis* emerged after 17 days.

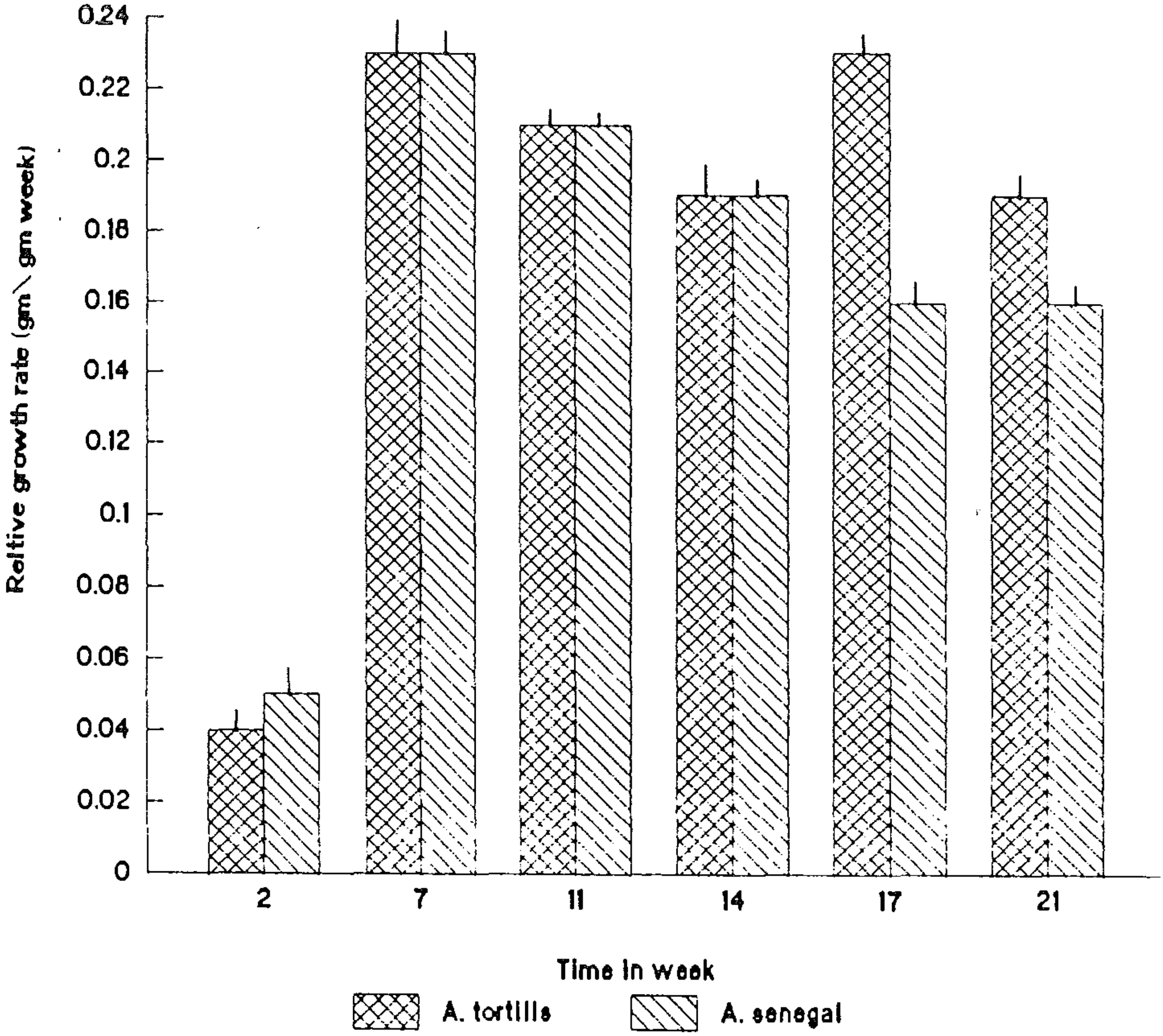

Fig. 7 Relative growth rate of *Acacia tortilis* and *A. senegal* $(\bar{x} \pm se;\ n = 6)$

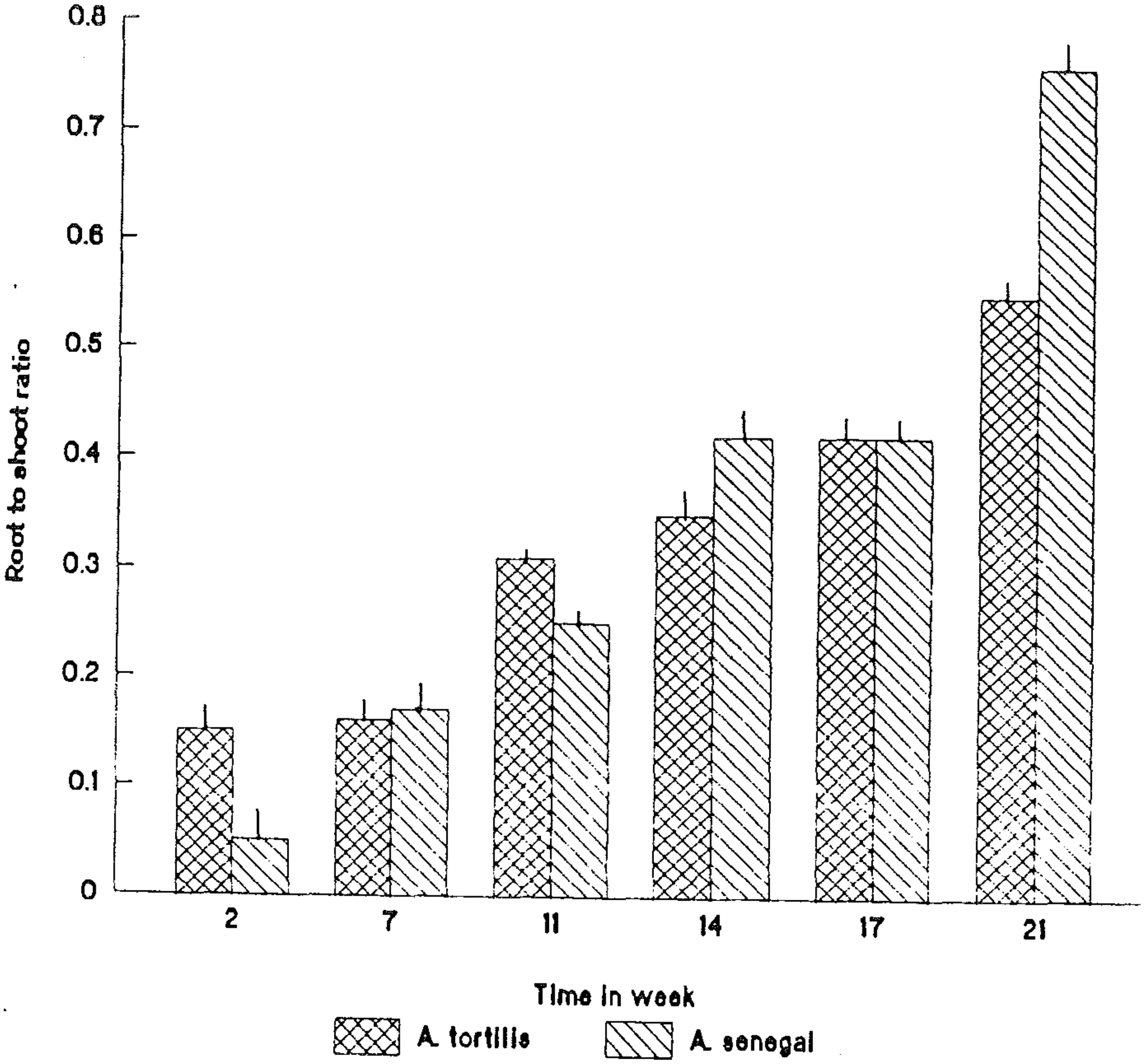

Fig. 8 Root to shoot ratio of *A. tortilis* and *A. senegal* $\left(\overline{x} \pm se;\ n = 6\right)$

4 DISCUSSION

Tree density was lower in site one whereas tree characteristics such as tree height, DBH, canopy depth, canopy diameter and canopy radius of the study trees in this site were highest, (Appendix 1). High values of tree characteristics in site one might be explained by the fact that high tree density could result in inter and intra competition of tree and herbs for soil moisture and nutrients which results in tree species with poor canopy features. 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. Besides, consideration of spatial arrangement and proximity of trees are also important factors (Karamchandani, 1980).

The difference between under and outside canopy temperature and relative humidity was insignificant. Perhaps the equipment used were not sensitive enough to measure the difference. Still the results show that there is little influence of canopies of the study trees on relative humidity and temperature. Similarly, Jaksic and Fuentes (1980) explained that microclimatic factors were relatively unimportant in affecting the abundance of herbs under tree canopies. Weltzin and Coughenour (1990) also reported that tree height and DBH of *A. tortilis* did not affect undercanopy soil nutrient. However, this does not mean that the above tree characteristics are unimportant, especially in terms of providing valuable fuelwood and forage for domestic animals. In addition high canopy diameter of *A.tortilis* is of crucial importance in providing more shade for domestic animals in the dry season.

High abundance and diversity of herbaceous species under *A. tortilis* might be due to its large canopy diameter which allows more favorable area for the abundant growth of various species. Large shade of the canopy also minimizes runoff by reducing the size and speed of raindrops which results in a negative effect of nutrient loss from undercanopy soils (Weltzin and Coughenour, 1990).

High per cent cover and diversity of species undercanopy vegetation compared to vegetation outside canopies clearly show that the species furnish favorable 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 understory vegetation revealed that availability of soil moisture and nutrient are the key factors (Walker and Noy-meir, 1982 cited in Skarpe; 1992; Ben-Shahar, 1991). Soil moisture was also found to be higher under tree canopies in the present study (data was not shown as it was not complete). This might support the importance of soil moisture for the abundance growth of undercanopy vegetation.

Soil moisture in undercanopy soil is a result of three main factors. Tree and shrub canopies intercept direct solar radiation and reduce the intensity of light reaching under the canopy. This may increase soil moisture content by lowering soil temperature and evapotranspiration. However, interception of rainfall may also counteract the effect of canopy shade on soil moisture (Vettas, 1992).

Trees and shrubs intercept rainfall with an amount dependent on the size of their canopies and redistribute it back to the atmosphere by evaporation and to the ground by throughfall and stemflow (Pressland, 1973, 1976). The redistribution is also dependent on the intensity and frequency of rainfall. Weltzin and Coughenour (1990), reported that as rainfall increased intercepted rainfall exceeded canopy storage capacity and most of the excess flowed down the stem with some throughfall. Glover, Glover and Gwynne (1962) on the contrary showed that even light rainfall wet the deeper soil by the stem flow.

Litter fall both from the canopy and understory 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 by nine times compared to bare ground. The net effect of these factors would be improving undercanopy soil moisture. Together with soil nutrient (see below) better soil moisture regime increase undercanopy vegetation abundance and diversity.

Texture did not vary significantly among the sites. Also there were no major differences between under and outside canopy soils (Tab. 5.1 - 5.4). The result depicted that the study trees did not have a significant effect on soil texture. Kamara and Haque (1992) found similar textural class of soils under and outside canopy of *Faidherbia albida*. The textural class of soils obtained in the present study might be a result of sediments of sands, silt and clay particles deposited in the study sites in the recent quaternary age (Mohr, 1967b).

As it can be noted from the Tables (5.1 - 5.4) the textural classes of the soils belonged to sandy loam, loam and loamy sand. These soils are less erodible compared to clay loam and silt loam (Kohnke, 1968). Moreover, such soil properties have been reported to be suitable for agriculture (Kohnke, 1968; Donahue, Miller and Shickluna, 1983).

The difference in pH among the study trees as well as under and outside canopy soils were insignificant (Tab. 6). This implies that, similar to soil texture the study trees had little impact on the pH of undercanopy soils. However, it is important to note that pH under and outside the canopy is in the range suitable for the growth of most agricultural crops and forages (Donahue, Miller and Shickluna, 1983).

All soils are in the normal range of concentration of soluble salts for most plant growth of about 0.4 m siemens m^{-1} (Donahue, Miller and Shickluna, 1983). High accumulation of soluble salts mostly cations such as sodium (Na^+) calcium (Ca^{++}) and magnesium (Mg^{++}) and anions such as chloride (Cl^-), sulphate ($SO4^{--}$) account for high electrical conductivity in the surface of undercanopy soils (Thompson and Frederick, 1978). Increased soil conductivity with 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. Thus, significant difference of mean conductance between under and outside canopy soils indicated the influence of the trees on soil conductivity.

Greater concentration of organic carbon, total nitrogen, available phosphorus and exchangeable potassium under the tree canopies implies the potential of the study trees to enrich undercanopy soils with essential soil nutrients. 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).

Higher presence of nutrients in undercanopy soils could be due to variable and complicated causes (Vettas, 1992). Weltzin and Coughenour (1990) suggested that leaf fall from trees might be the most likely nutrient source. This suggestion is supported by availability of higher soil nutrients in surface soils found under tree canopies in the present study.

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 may probably be important in nutrient concentration under the canopy (Kellmann, 1979). Knoop and Walker (1985) suggested that nutrient found in low concentration through out 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).

Higher concentration of nitrogen under *A. tortilis* could be a result of symbiotic nitrogen fixation. Tolsma *et al* (1987) showed that *Acacia* species litter were characterized by higher nitrogen compared to non legume tree and shrub species. The efficiency of nitrogen fixation is, however, dependent on many conditions out of which availability of phosphorus and moisture in the soil are essential (Allen and Allen, 1981).

Despite the fact that moisture and available phosphorus were higher in undercanopy soils of *A. senegal*, and suitability of the depths from where soil samples were collected for effective interaction of *rhizobium* species and legumes (Smith and Douglas, 1987) total nitrogen under *A. senegal* was lower compared to *B. aegyptiaca* supporting the idea that all the trees which have the potential for forming relation with the rhizobium may not necessarily fix atmospheric nitrogen (Garcia-Moya and Mckell, 1970).

In general, litter fall from trees, root system of trees, dust accumulated on trees and symbiotic nitrogen fixation (in nitrogen fixing species) might be the main factors that enrich under canopy soils with essential plant nutrients. This has got important implication for agroforestry.

Acacia senegal showed a higher seedling emergence index. Ingeneral embryo weight, seed shape, seed size and seed coat are responsible for determing rate of seedling emergence (Grime et al, 1983). Fenner (1983) stated that embryo weight and seed size are particularly important for high seedling emergence index of plants. Comparing seed characteristics of *A. senegal* with *A. tortilis*, it appears that *A. senegal* had relatively higher seed size and embryo weight. These features of *A. senegal* could be the main reasons for high emergence index of this species.

High root shoot ratio of *A. senegal* was found to be important in giving vertical seedling form to the species compared to the horizontal growth form of *A.tortilis*. This feature of *A. senegal* might be essential to ensure the strong hold of the plant to the ground which inturn increases the probability of the plant to reach to maturity.

Although no data on the relative growth rate, emergence index and root to shoot ratio of the two species have been reported previously, it is possible to suggest that their performance in the greenhouse (particularly, *A. senegal*) proved that they have good potential for fast regeneration. However, not many seedlings were observed in the field. Thus, to facilitate the growth of these species in their growing habitat factors responsible for checking their growth under field condition should be studied.

7. CONCLUSION

The results of the present study show that all the species investigated had remarkable features that qualify them for agroforestry use. Among the qualities the ability to ameliorate undercanopy soil conditions and the creation of favourable micro-climate for the growth of herbaceous vegetation were found to be important.

Each species investigated also had their distinguishing characteristics. *Acacia tortilis* had better tree qualities as well as large canopies. It can be, therefore recommended for growing crops and forage under its canopies at the same time providing fuelwood and protection for soil erosion. *Acacia senegal* is well known for its Gum Arabic. Thus, the tree can benefit the country by generating foreign currency if grown extensively. *Acacia senegal* was found in this study to have a high seedling emergence index and good seedling establishment. These findings could be important for an extensive planting of the tree with crops and forage. *Balanites aegyptiaca* is an ever green tree especially suited for dry semi-arid type areas. The green leaves of *Balanites* are liked by cattle while the fruits are edible and crucially important for their saponin content. The species can also be a good agroforestry tree as shown by its soil quality improving characteristics.

This investigation only dealt with the potentials of the trees for agroforestry concentrating on the tree qualities, canopy undergrowth and undercanopy soil. It is recommended that detailed agronomic studies such as optimum spacing, provenance trials and other relevant studies should be conducted for suggesting the best way for using the species for agroforestry.

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Appendix 1 Tree characteristics of the study trees in all the sites (measurements are given in m)

description: 1 = tree height 2 = DBH 3 = canopy depth
4 = canopy radius 5 = canopy diameter

A. tortilis, site 1

1	2	3	4	5
5.70	0.79	2.90	6.81	21.40
5.48	0.79	2.60	9.80	20.10
5.85	0.41	2.60	6.40	10.00
6.90	0.41	3.10	7.20	13.00
6.30	0.82	3.10	9.40	18.50

A. tortilis, site 2

1	2	3	4	5
4.10	0.25	1.00	5.20	10.00
5.48	0.28	2.00	8.80	18.40
5.70	0.26	1.40	5.70	9.20
5.20	0.28	1.60	6.60	12.90
5.20	–	2.60	4.90	10.60

A. tortilis, site 3

1	2	3	4	5
4.00	0.22	0.50	6.00	9.80
4.00	0.25	1.00	6.40	13.00
3.00	0.35	0.30	7.80	14.70
4.00	0.47	0.70	6.46	10.70
4.00	0.38	0.30	6.20	12.30

A. senegal, site 1

4.75	0.22	2.60	3.40	7.40
4.50	0.57	3.10	5.25	9.80
5.80	0.54	4.30	5.60	12.00
5.25	0.28	3.20	7.00	12.50
6.30	0.32	3.60	4.90	9.60

A. senegal, site 2

3.60	–	2.15	3.30	6.80
2.90	–	1.65	3.50	5.95
3.20	–	1.80	3.10	6.10
3.10	–	1.70	3.70	6.70
3.30	–	1.80	4.90	10.60

A. senegal,site 3

5.80	0.38	1.00	4.00	8.80
4.00	0.32	0.50	5.00	8.60
3.50	0.19	2.00	3.00	6.60
3.30	0.19	1.00	3.30	7.20
5.80	0.19	1.00	4.60	9.60

B. aegyptiaca, site 1

4.00	0.22	2.60	2.70	4.40
3.20	0.32	2.60	3.40	6.60
4.60	0.47	2.60	3.80	7.40
3.30	0.22	1.90	3.42	6.60
6.63	0.46	4.38	3.70	6.80

B. aegyptiaca, site 2

6.00	0.09	4.30	3.00	4.60
6.00	0.25	4.10	6.00	8.60
6.50	0.28	5.40	3.70	7.80
6.80	0.18	2.50	2.80	5.30
5.05	0.16	2.75	2.60	5.80

B. aegyptiaca, site 3

3.50	0.19	2.50	2.80	5.30
4.00	0.25	1.50	2.50	4.70
6.80	0.32	3.50	4.30	10.00
4.50	0.32	0.50	2.90	6.40
3.80	0.25	3.00	2.20	6.60