Journal of Soil Science and Environmental Management Vol. 1(6), pp. 107-114, August 2010
Available online at http://www.academicjournals.org/JSSEM
ISSN 2141-2391 ©2010 Academic Journals

Full Length Research Paper

Balanites aegyptiaca, a potential tree for parkland agroforestry systems with sorghum in Northern Ethiopia

Hailemariam Kassa[1], Kindeya Gebrehiwet[2] and Charles Yamoah[3]*

[1]Tigray Agricultural Research Institute, Humera Agricultural Research Centre, Humera, P. O. Box 230 Tigray, Ethiopia.
[2]Department of Land Resource Management and Environmental Protection, Faculty of Dryland Agriculture,
Mekelle University, P. O. Box 231, Ethiopia.
[3]Faculty of Renewable Natural Resources, University of Development Studies, P. O. Box TL 1350 Tamale, Ghana.

Accepted 1 July, 2010

Balanites aegyptiaca* tree is preferred by farmers in Tigray region of Ethiopia for fuel wood, provision of shade, fodder and as a medicinal plant. This study was conducted to assess soil properties and sorghum yields on farm fields (Limat, Goblel and Korbebite and Endakeshe), where *B. aegyptiaca* are traditionally retained. At each site, six trees were randomly selected and soil properties and sorghum yields were compared 1) under the tree canopy (0 – 4 m), designated as zone D1; 2) near the tree, (4 – 6 m, D2) and 3) far away from the tree (8 – 12 m, D3). At the Limat site, results indicated that % clay and available P were significantly higher ($p < 0.05$) at D1 (under the canopy) than D3 (further away from the canopy). Also at the same site, % silt was significantly lower ($p < 0.05$) at D1 than D3. At Goblel and Korbebite sites, pH was significantly lower ($p < 0.05$) at D1 and D2 than D3. Apart from these, exchangeable Ca, exchangeable K, organic carbon (OC), cation exchange capacity (CEC), electrical conductivity (EC) and yields were non-significant among the three zones at the sites. Mean moisture levels of all sites at sowing period at D1 (14.36%) was significantly ($p < 0.05$) lower than D3 (16.32%), but yields were unaffected. Pot studies using soils from the above sites and zones demonstrated similar soil and yields' patterns. Thus, it may be appropriate to integrate sorghum crops with *B. aegyptiaca* trees on the same field in a parkland agroforestry system with minimal risk of crop failure.

Key words: *Balanites aegyptiaca,* parkland agroforestry*,* sorghum.

INTRODUCTION

A major reason for practicing agroforestry land use systems is domestication of soil-improving trees for enhancing soil productivity through a combination of selected trees and food crops on the same farm field (ICRAF, 2000). Scattered trees are characteristics of a large part of the African agriculture landscape. The so-called parkland savanna may be defined as the regular presence of well-grown trees scattered on cultivated or recently fallowed fields. The trees are deliberately associated with the agricultural environment because of their specific use (ICRAF, 2000). *Sorghum bicolor* is the second dominant food crop cultivated in Tigray region (EARO, 2002).

Balanitus aegyptiaca is one of the dominant tree species deliberately retained on farm fields in the Tigray region of Ethiopia. It is useful as a medicinal plant, food, fodder, fuel wood, construction material and provision of shade (Kindeya, 2004).

Soil fertility depletion and low crops' yields are widespread in the Tigray region (EARO, 2002). The use of supplementary inorganic fertilizers has become less affordable for many Ethiopian farmers, following the removal of fertilizer subsidies. Consequently, improved fallows such as *Sesbania sesban,* is used to address low fertility problems of small holders fields in the region (EARO, 2002). Additionally, it is important to combine plant biomass with inorganic fertilizers so as to increase fertilizer-use efficiency or both (Juo and Franzluebbers,

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*Corresponding author. E-mail: yamoahcf@yahoo.com.

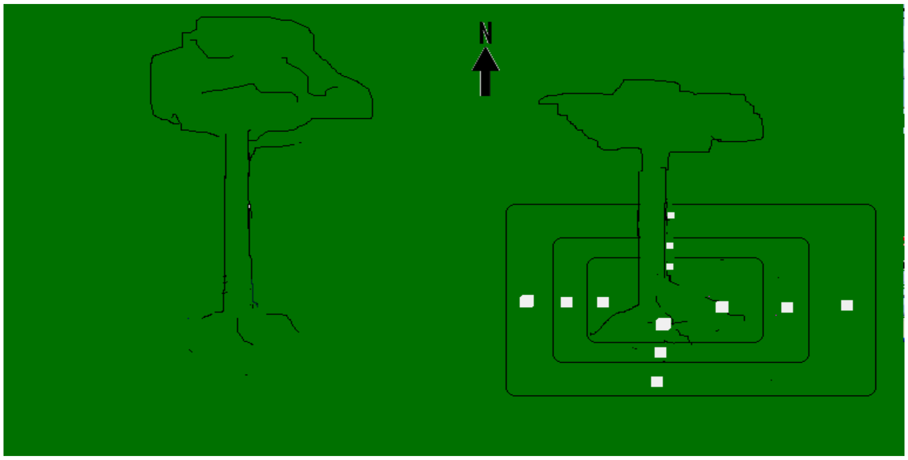

Figure 1. Design of soil sampling and measurement of sorghum plant height and yield from *B. aegyptiaca* tree.

2003). Usually, the rapid-decomposing biomass with low carbon to nitrogen ratios (C:N < 10) may be used as fertilizers to supply nutrients in a shorter time frame. On the contrary, the slow-decomposing biomass could be used as mulch to improve soil physical conditions (Tian et al., 1995).

There are a number of agroforestry options in drylands of Eastern Africa that are available for the purpose of both resources conservation and economic development for sustainable livelihoods (Jama and Zeila, 2005). There are many indigenous tree species including *B. agyptiaca* that have a potential of maintaining the ecology and economic development (Kindeya, 2004). Dispersed trees on farms, that is, parkland agroforestry systems, are typical in Tigray region of Ethiopia (Tesfay, 2004) covering large tract of agricultural land. However, despite their significance in contributing to the livelihood of rural people, they have been largely ignored in the research domain. Rather, the impact of trees like *Faidherbia albida*; *Cordia africana,* and *Crotton macrostachyus* (Poschen, 1986) on soil properties and yields have been extensively researched. Our objective is to determine the effects of *B. agyptiaca* on soil properties and sorghum yield in order to assess the tree's potential and suitability for use in parkland agroforestry systems.

MATERIALS AND METHODS

Description of the study sites

This study was conducted at Humera district located at (13°42' - 14°28'N, 36°20' - 37°31'E), Tigray region of Ethiopia, bordering Eritrea. Specific villages selected were Lemat, Goblel, Korbebit, and Endakashe, because of the sorghum-based cropping systems and *B. aegyptiaca* trees present on farm fields at these villages. The dominant soil type is Vertisol (USDA, 2006) characterized by deep soils (> 150 cm), clay content of 40 - 60%, electrical conductivity of 0.047 - 0.179 mmohs/cm, organic matter content of <2% and CEC ranging from 37 – 77 meq/100 g soil (Mitiku et al., 2006). The mean annual rainfall is 581.2 mm mostly occurring from June to September. The maximum temperature varies from 42°C in April to 33°C in August, while minimum temperature is from 22.2°C in May to17.5°C in July (EARO, 2002).

Experimental design

At each village, six *B. aegyptiaca* trees were randomly selected based on DBH (diameter at breast height), crown diameter and heights. Soil samples (0 - 20 cm) were taken at three distances from *B. aegyptiaca* designated as zones (D) were: 1) 0 to 4 m (D1), 2) 4 m to 6 m (D2) and 3) 8 to 12 m (D3) all from the base or zero cm of the tree. The six trees acted as replications. The test crop was an improved *S. bicolor* variety "Gobye" ,which is released to farmers by government to resist striga weeds (EARO, 2002). Data collection included height and biomass and grain yields from 8 quadrants of 0.5 m × 0.5 m taken from four directions from the tree as shown in Figure 1. The data were analyzed using a one-way analysis of variance.

Soil analyses

Soil samples were analyzed for total nitrogen (N) by Keldahl method (Jackson, 1958); available phosphorus (P) (Olsen and Sommers, 1982); exchangeable K by ammonium acetate (Jackson, 1958); organic carbon (OC) (Walkley and Black, 1934), electrical conductivity (EC) and cation exchange capacity (CEC) by (Houba et al., 1989); and pH, (1:2.5 soils to water ratio) by Jackson (1958). Texture was determined by hydrometer method (Gee and Bauder, 1982) and bulk density by the core method. Gravimetric moisture contents (Blake and Hartge, 1986) were determined at the beginning of rains to the flowering stage of sorghum that is, two months later.

Pot experiment

Soil samples collected from six trees on four sites (24 trees) and three distances or zones were used for the plastic pot experiments. The plastic pots were 25 cm high and a diameter of 10 cm and contained 2.5 kg soil. The experimental design was complete randomized (CRD) with 5 replications. Sorghum was the test crop. Three seeds were sown and thinned to one plant after germination. Plant height was measured at two weekly intervals and yield was

Table 1. Effect of *Balanites aegyptiaca* tree on soil properties at Limat site.

Soil property	Under the canopy (D1)	Near the canopy (D2)	Far from the canopy (D3)
OC %	0.60^{a} ±0.027	0.55^{a} ± 0.068	0.47^{a} ± 0.6
Total N %	0.07^{a} ±0.004	0.07^{a} ± 0.004	0.06^{a} ± 0.004
Available P (ppm)	1.28^{ab} ± 0.08	1.37^{a} ± 0.23	0.75^{b} ± 0.10
Exchangeable K (ppm)	320.21^{a} ± 20.10	305.47^{a} ± 23.85	289.00^{a} ± 14.15
EC ds/m	0.29^{a} ± 0.04	0.17^{a} ± 0.03	0.31^{a} ± 0.07
CEC meq/100 g soil	51.45^{a} ± 5.23	49.62^{a} ± 1.29	53.59^{a} ± 1.83
pH	8.17^{a} ± 0.08	8.15^{a} ± 0.09	8.40^{a} ± 0.03
Clay %	45.24^{a} ± 3.96	37.09^{ab} ± 2.36	30.90^{b} ± 3.12
	LSD = 11.81		
Silt %	16.76^{b} ± 4.45	22.91^{ab} ± 0.63	29.09^{a} ± 3.57

Rows with the same superscript letters are not significantly different at $P < 0.05$. OC % = Organic carbon percent. EC ds/m = electrical conductivity; Total N% = total nitrogen; CEC meq/100 g = Cation exchange capacity; Available P (ppm) = available Phosphorus; Exchangeable K (ppm) = exchangeable Potassium.

Table 2. Effect of *Balanites aegyptiaca tree* on soil properties at Goblel site.

Soil property	Under the canopy (D1)	Near the canopy (D2)	Far from the canopy (D3)
OC %	0.81^{a} ±0.04	0.77^{a} ±0.03	0.77^{a} ±0.01
Total N %	0.047^{a} ±0.01	0.05^{a} ±0.00	0.04^{a} ±0.01
Available P (ppm)	1.77^{a} ±1.04	1.06^{a} ±0.39	0.33^{a} ±0.13
Exchangeable K (ppm)	295.88^{a} ±29.66	276.91^{a} ±13.9	262.59^{a} ±11.19
EC ds/m	0.38^{a} ±0.03	0.34^{a} ±0.07	0.28^{a} ±0.023
CEC meq/100 g soil	50.56^{a} ±2.91	50.63^{a} ±1.54	50.89^{a} ±2.56
pH	7.96^{b} ±0.04	8.33^{a} ±0.06	8.22^{a} ±0.06
	LSD = 0.188		
Clay %	36.51^{a} ±2.41	31.75^{a} ±1.86	32.81^{a} ±2.23
Silt %	23.64^{a} ±1.66	25.20^{a} ±1.59	25.44^{a} ±2.41

Rows with the same superscript letters are not significantly different at $p < 0.05$. OC %= Organic carbon percent EC ds/m = electrical conductivity; Total N% = total nitrogen; CEC meq/100 g = Cation exchange capacity; Available P (ppm) = available Phosphorus; Exchangeable K (ppm) = exchangeable Potassium.

determined at harvest. Plant height, yield and soil analytical data were subjected to statistical analysis using JMP version 0.5. Duncan multiple range test (DMRT) was used for treatment mean separation.

RESULTS AND DISCUSSION

Effects of *B. aegyptiaca* tree on soil properties at the Limat site

Available phosphorus, clay and silt percentages were significant ($P < 0.05$) at Limat. Available P was higher at D1 (1.28 ppm) and D2 (1.37 ppm) than D3 (0.75 ppm), representing an increase by 82.7%. With available P of less than 10 ppm (Sanchez et al., 1982; Marx et al., 1999), the soils at Limat were deficient in available P. Percent clay was higher at D1 (45%) than D3 (31%), showing an increase of 45%. However, silt percent was the reverse that is,17% at D1 and 29% at D3, showing a decrease of 41 % (Table 1). Contrary to our expectation, there was no significance ($P > 0.05$) difference in OC among D1 (0.60%), D2 and D3 (0.47%). This range of OC is often what is encountered in soils of the semiarid areas, which is >1% (Bationo et al., 1993). Similarly, there was no significance difference in total nitrogen, exchangeable potassium, EC, CEC and pH among the three zones, that is, D1, D2 and D3 (Table 1).

Effect of *B. aegyptiaca* on soil properties at Goblel, Korbebit and Endakashe sites

Soil pH is the only parameter that was significantly different at Goblel and Korbebit sites (Tables 2 and 3). At

Table 3. Effect of *Balanites aegyptiaca tree* on soil properties at Korbebit.

Site parameter	Under the canopy	Near the canopy	Far from the canopy
OC%	$0.75^a \pm 0.03$	$0.69^a \pm 0.02$	$0.72^a \pm 0.03$
Total N %	$0.02^a \pm 0.00$	$0.03^a \pm 0.01$	$0.03^a \pm 0.02$
Available P (ppm)	$1.47^a \pm 0.42$	$1.10^a \pm 0.14$	$0.92^a \pm 0.15$
Exchangeable K (ppm)	$199.34^a \pm 8.83$	$217.12^a \pm 9.58$	$212.83^a \pm 10.91$
EC ds/m	$0.24^a \pm 0.044$	$0.180^a \pm 0.03$	$0.18^a \pm 0.03$
CEC meq/100 g soil	$34.32^a \pm 1.97$	$37.60^a \pm 4.01$	$43.15^a \pm 4.61$
pH	$8.46^a \pm 0.07$	$8.08^b \pm 0.11$	$8.49^a \pm 0.02$
Clay %	$41.03^a \pm 1.12$	$41.03^a \pm 0.84$	$40.36^a \pm 0.77$
Silt %	$29.28^a \pm 0.73$	$28.28^a \pm 2.24$	$28.61^a \pm 1.12$

Rows with the same superscript letters are not significantly different at $p < 0.05$. OC %= Organic carbon percent EC ds/m = electrical conductivity; Total N% = total nitrogen; CEC meq/100 g = Cation exchange capacity; Available P (ppm) = available phosphorus; Exchangeable K (ppm) = exchangeable potassium.

Table 4. Effect of *Balanites aegyptiaca tree* on soil properties at Endakeshe.

Site parameter	Under canopy (D1)	Near canopy (D2)	Far from canopy (D3)
OC %	$0.77^a \pm 0.06$	$0.77^a \pm 0.04$	$0.77^a \pm 0.05$
Total N %	$0.03^a \pm 0.00$	$0.03^a \pm 0.00$	$0.02^a \pm 0.00$
Available P(ppm)	$0.66^a \pm 0.11$	$0.46^a \pm 0.06$	$0.79^a \pm 0.15$
Exchangeable K(ppm)	$214.79^a \pm 15.30$	$186.11^a \pm 16.17$	$194.80^a \pm 7.91$
EC (ds/m)	$0.22^a \pm 0.02$	$0.21^a \pm 0.03$	$0.22^a \pm 0.03$
CEC (meq/100 g soil)	$53.50^a \pm 1.59$	$53.56^a \pm 1.44$	$51.65^a \pm 3.29$
pH	$8.14^a \pm 0.16$	$8.44^a \pm 0.04$	$7.95^a \pm 0.19$
Clay %	$32.693^a \pm 1.74$	$32.08^a \pm 1.41$	$32.36^a \pm 2.06$
Silt %	$22.28^a \pm 0.86$	$22.20^a \pm 0.66$	$24.61^a \pm 1.69$

Rows with the same superscript letters are not significantly different at $p < 0.05$. OC %= Organic carbon percent EC ds/m = electrical conductivity; Total N % = total nitrogen; CEC meq/100 g = Cation exchange capacity; Available P (ppm) = available phosphorus; Exchangeable K (ppm) = exchangeable potassium.

Goblel, pH was lower at D1 (7.96) than D3 (8.22) showing a decrease of 3.1% (Table 2). The pH range reflects the calcareous nature of the $CaCO_3$ parent material (Sharma and Gupta, 1989). Like the Limat site, there was no significant difference in OC among the three zones. The non-significant difference of organic carbon supports the assumption regarding the rapid mineralization of OC in the semiarid environment in Ethiopia (Tesfy, 2004). At Korbebit site, soil pH was significantly lower at D2 (8.08) than D1 (8.46) and D3 (Table 3).

According to Marx et al. (1999) and Sanchez et al. (1982), the soils were slightly alkaline, and that would not normally create an unfavorable condition for growth of common cereals and legumes. The same holds true for exchangeable potassium and EC. Cation exchange capacity of > 40 meq/100 g is above average. Total nitrogen value was >0.05 in the study area which is of the lower side of common soils. Even though total N is not a good measure of plant available N, typical agricultural soils has percent total N of 0.1 - 0.15 (Marx et al., 1999). Since OC, available P and total N are limiting (Tables 1, 2, 3 and 4), there is a need for supplementary inorganic fertilizers (e.g. DAP (diammonium phosphate) in addition to litter fall of *B. aegyptiaca* and possibly biomass of *S. sesban* to sustain increase sorghum yields. Diammonium phosphate is the recommended fertilizer by the Ministry of Agriculture for the Tigray region and *B. aegyptiaca and S. sesban* are indigenous shrubs in the region. At Endakashe, there was no significant difference in pH, organic carbon, total nitrogen, available phosphorus, exchangeable potassium, EC, CEC, clay and silt among the three zones (Table 4).

Combination soil chemical properties of the four sites

The combined OC of the four sites was not significantly different ($p > 0.05$) among the three zones from the base

Table 5. Combined all sites soil properties.

Site parameter	Under canopy (D1)	Near canopy (D2)	Far from canopy (D3)
OC %	0.72^{a} ±0.02	0.69^{a} ±0.03	0.68^{a} ±0.03
Total N %	0.04^{a} ±0.00	0.04^{a} ±0.00	0.04^{a} ±0.01
Available P(ppm)	1.29^{a} ± 0.28	0.99^{a} ±0.13	0.70^{a} ±0.08
Exchangeable K(ppm)	257.55^{a} ±14.21	245.76^{a} ±12.57	239.81^{a} ±9.46
EC (ds/m)	0.28^{a} ±0.02	0.22 ^{a} ±0.02	0.25^{a} ±0.02
CEC (meq/100 g soil)	47.46^{a}±2.20	47.96^{a} ±1.67	49.82^{a} ±1.72
pH	8.17^{a}±0.01	8.30^{a} ±0.050	8.24^{a} ±0.06
Clay %	38.87^{a} ±1.54	35.40^{ab} ±1.12	34.11 ^{b} ±1.29
	LSD 4.4987		
Silt %	22.99^{a} ± 1.47	24.40^{a} ±0.83	26.94 ^{a} ±1.18

Rows with the same superscript letters are not significantly different at $p < 0.05$. OC% = Organic carbon percent EC ds/m = electrical conductivity; Total N% = total nitrogen; CEC meq/100 g = Cation exchange capacity; Available P (ppm) = available Phosphorus; Exchangeable K (ppm) = exchangeable Potassium.

of *B. aegyptiaca* tree (Table 5). This may be due to low litter fall during the period of the experiment and the existing organic matter might have readily decomposed due to elevated temperatures often observed in the arid ecozone. The increase in soil organic matter under the canopy of different tree species has also been reported. For example, Abebe et al. (2001) reported an average increase of about 13% organic matter under canopy of Cordial Africana trees. Similarly, Felker (1978), Bernard-Reversat (1982), Tadesse (1997) and Yeshanew et al. (1999), all reported significantly higher organic matter under different trees' canopy than the corresponding open area. In addition, Jonsson (1995) found nearly three times higher percent organic carbon near the bole of the *Vitvaria paradoa* tree than at 150 cm away from the bole of the tree. Correspondingly, Tadesse (1997) and Zebene (2003) all reported significantly higher organic carbon under different trees canopy than the corresponding open area, which disagrees with the result of the present study. This study is similar to that of Kindeya's (1995) who found no difference in OC under and outside the canopy of *B. aegyptiaca* sp. as reported in the present study.

Also, total nitrogen content (%) of the topsoil did not show significant differences among the three zones (Table 5). The highest was observed near the canopy zone showing an increase of 8.2% over the control, that is, further away from the tree. Low N under the canopy may be due to low organic matter and rapid decomposition of already low OC that release N which were tapped by the trees roots or might have leached down the soil profile. In on-farm field experiment in Niger under the *F. albida* canopy, nitrogen availability under trees was estimated to be more than 200% higher than in the open field causing a 26% production increase (Elseed et al., 2002).

The concentration of available phosphorus was 2.29 ppm at D1, 0.99 ppm at D2 and 0.7 ppm at D3, and was statistically insignificant (Table 5). The highest concentration of available phosphorus under the canopy of *B. aegyptiaca* may be due to the release of available organic P during the decomposition of animal manure in addition to low native organic matter. In the semi-arid environment, livestock like cattle, sheep, goats and chicken etc hide under trees to avoid the scorching sun. The livestock litter and urinate whilst resting under the trees. The concentration of exchangeable potassium in the soil was higher under the canopy (257.55 ppm,) than far from the canopy 239.81 ppm (Table 5). However, exchangeable K was not significant ($p > 0.05$). The same pattern was noted for EC and CEC.

As regards to soil physical properties, percent clay of the four sites was higher under canopy (38.37%) was significantly different ($p < 0.05$) than further away from the canopy (34.11%). This agrees with the study of Pandey et al. (2000). In the Indian subcontinent they noted that under *Acacia nilotica,* canopy sand particles declined by 10 and 9% whereas clay particles increased by 14 and 10% respectively. Silt percent did not show significant difference between the treatments, but decreased 14.6% under canopy than far from canopy (Table 5).

Bulk density and soil moisture content

The moisture content at the beginning of rainy season when crops are sown was significantly lower than that at flowering stage two months later. The moisture content at both periods showed a gradual decrease towards the trees. However, sorghum yields were unaffected by the differential decrease in moisture levels (Tables 6). Findings of Sursh and Rao (1998) substantiated our observation by reporting that soil moisture content at different growth stages of sorghum was lower under *A. lebbeck* at all depths, indicating rapid depletion of soil moisture under this species. Sorghum growth under

Table 6. Effect of *Balanites aegyptiaca tree* on soil moisture and bulk density.

Parameter	Under canopy (D1)	Near canopy (D2)	Far from canopy (D3)
Soil moisture (%)			
At sowing	14.36^{b} ± 0.79	15.87^{ab} ± 0.35	16.32^{a} ± 0.42
After 2 months	21.08^{a} ± 2.58	24.40 ^{a} ± 0.83	26.61^{a} ± 3.20
Bulk density (gm/cm^{3})	1.36^{a} ± 0.05	1.24^{a} ±0.1	1.36^{a} ±0.06

Rows with the same superscript letters are not significantly different at $P < 0.05$.

Table 7. Effects of *Balanites aegyptiaca* on sorghum plant height, grain and biomass yields at Limat's field and potted soils from the same site.

Type of experiment	Parameter	Under canopy (D1)	Near canopy (D2)	Far from canopy (D3)
Field	Plant height	1.20^{a} ±0.05	1.36^{a}±0.06	1.27^{a} ±0.04
	Grain yield	172.80^{a} ±32.65	210.3^{a} ±36.77	221.1^{a} ±38.40
	Biomass yield	464.34^{a}±49.52	508.94^{a} ±64.86	492.86^{a}±72.94
Pot	Plant height	0.65^{a} ±0.03	0.58^{a}±0.04	0.63^{a} ±0.03
	Grain yield	135.4 ^{a}±26.55	117.3 ^{a}±30.8	159.8 ^{a}±27.4
	Biomass yield	481.5 ^{a}±84.9	403.55 ^{a}±90.25	434.6 ^{a}±53.25

Rows with the same superscript letters are not significantly different at $P < 0.05$

Table 8. Effect of *Balanites aegyptiaca tree* on sorghum plant height (m), grain and biomass weight (gm^{-2}) on farm field at Goblel .

Type of experiment	Parameter	Under the canopy (D1)	Near the canopy (D2)	Far from the canopy (D3)
Field	Plant height	1.10^{a} ± 0.05	1.09^{a} ± 0.02	1.09^{a} ± 0.03
	Grain yield	202.55^{a} ± 32.4	135.64^{a} ± 21.04	195.01^{a} ± 22.55
	Biomass weight	414.70^{a} ± 44.03	385.85^{a}±75.45	377.53^{a}±47.49
Pot	Plant height	0.60^{a} ±0.04	0.64^{a} ±0.04	0.57^{a} ±0.02
	Grain yield	134.6 ^{a} ±19.25	186.5 ^{a} ±41.10	149.15 ^{a} ±45.35
	Biomass weight	436.05 ^{a} ±53.7	485.8 ^{a} ±67.15	352.7 ^{a} ±15.85

Rows with the same superscript letters are not significantly different at $P < 0.05$.

A.ferruginea faced similar effects but of a lower magnitude compared to *A. lebbeck* (Sursh and Rao, 1998).

There was no significance difference in bulk density among the three zones, probably because of lack of differences in organic carbon levels (Tables 5 and 6). It is well known that incorporation of organic matter in soil improves physical (aggregate stability, bulk density, water retention, etc.) and biological properties (nutrients availability, cation exchange capacity, reduction of toxic elements etc.) of soils (Lal, 1989).

Effects of *B. aegyptiaca* on sorghum plant height (m), grain and biomass yields (gm^{-2}) at Limat, Goblel, Korbebit and Endakashe sites

Sorghum height, grain and biomass yields were not significantly different among the three zones (Tables 7, 8, 9, 10). Sorghum yields at Limat were 172.80 gm^{-2} at D1 (under canopy) and 221.1 gm^{-2} at D3 (further from canopy), that is, a decrease of 22% relative to D3. However, at Goblel, there was an increase of 3.87 and 9.85% in grain and biomass yields, respectively under the canopy. At Korbebit, there was an increase of 16.8% in plant height and decrease of 9% in biomass yields under canopy. Endakashe experienced an increase of 4.6% in plant height, a decrease of 2.0% in grain and 6.82% in biomass yields. Sorghum plant height, grain and biomass yields for the pot experiment at Limat are presented in Table 7. Evidently, there is no difference in sorghum performance, that is, height, biomass and grain yields when all the four sites were combined (data not shown). The patterns of sorghum plant height, grain and biomass yields in the field and the pots experiments were comparable in the four sites (Tables 7, 8, 9, 10). It is suspected that shading and nutrients competition may be

Table 9. Effects of *Balanites aegyptiaca tree* sorghum plant height (m), grain and biomass weight (gm^{-2}) on farm field at Korbebit .

Type of experiment	Parameter	Under the canopy (D1)	Near to the canopy (D2)	Far from the canopy (D3)
Field	Plant height	$1.46^{a} \pm 0.06$	$1.33^{a} \pm 0.05$	$1.25^{a} \pm 0.1$
	Grain yield	$210.25^{a} \pm 24.79$	$195.22^{a} \pm 25.23$	$210.81^{a} \pm 22.37$
	Biomass weight	$408.22^{a} \pm 28.66$	$404.88^{a} \pm 57.96$	$445.32^{a} \pm 31.98$
Pot	Plant height	$0.65^{a} \pm 0.04$	$0.66^{a} \pm 0.05$	$0.64^{a} \pm 0.06$
	Grain yield	$184.8^{a} \pm 26.7$	$163.55^{a} \pm 29.65$	$160.4^{a} \pm 23.35$
	Biomass weight	$508.75^{a} \pm 34.95$	$572.5^{a} \pm 42.4$	$487.7^{a} \pm 21.65$

Rows with the same superscript letters are not significantly different at $P < 0.05$.

Table 10. Effects of *Balanites aegyptiaca tree* on sorghum plant height (m), grain and biomass yields (gm^{-2}) on farm field at Endakeshe.

Type of experiment	Parameter	Under the canopy (D1)	Near to the canopy (D2)	Far from the canopy (D3)
Field	Plant height	$1.14^{a} \pm 0.17$	$1.13^{a} \pm 0.05$	$1.09^{a} \pm 0.06$
	Grain yield	$117.48^{a} \pm 10.46$	$107.39^{a} \pm 16.04$	$119.88^{a} \pm 11.17$
	Biomass weight	$268.24^{a} \pm 21.23$	$242.03^{a} \pm 29.63$	$287.86^{a} \pm 14.32$
Pot	Plant height	$0.55^{a} \pm 0.03$	$0.57^{a} \pm 0.06$	$0.56^{a} \pm 0.04$
	Grain yield	$36.95^{a} \pm 5.3$	$32.7^{a} \pm 5.90$	$32.1^{a} \pm 4.65$
	Biomass weight	$562.3^{a} \pm 103.05$	$533.75^{a} \pm 64.4$	$597.3^{a} \pm 110.$

Rows with the same superscript letters are not significantly different at $P < 0.05$.

the primary factors that are responsible for the observed yield reduction in the fields (Yamoah et al., 1986; Yamoah, 1991).

CONCLUSIONS AND RECOMMENDATIONS

The study concluded that there were no significant differences in total N, EC, CEC, exchangeable K and organic carbon among the three zones. However, available P on Limat site, pH at Goblel and Korbebite were significantly different. Apart from the Limat site, clay, silt and bulk density were not significant. *B. aegyptiaca* depletes soil moisture under canopy during the first two months, however, sorghum performance was not significantly affected. Indeed, *B. aegyptiaca* did not affect plant height, grain and biomass yields of sorghum. It is recommended to retain and protect *B. aegyptiaca* trees on sorghum farm fields in parkland agroforestry systems so as to attract multiple benefits namely additional incomes from the sale of wood and improved sorghum yields. Furthermore, farmers are advised to maintain *S. sesban* which is native to the highland alongside *B. aegyptiaca* on their farm fields of Ethiopia in order to capture the multiple benefits of agroforestry.

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