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Soil properties and carbon sequestration under desert date (*Balanites aegyptiaca*) in the lowlands of Northern Ethiopia

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This study assessed the effect of *Balanites aegyptiaca* on soil properties and carbon sequestration. A 100 × 100 m plot of entirely the same biophysical setting was delineated. Nine trees of relatively the same diameter at breast height (DBH) were selected to study the effect of the tree on soil properties. In total, 81 soil samples were collected from three radii distances from each tree, that is 0 - 2, 2 - 4, and 4 – 8 m at three soil depths of 0 - 20, 21 - 50 and 51 – 100 cm. Soil analysis was carried out following routine laboratory procedures. The carbon sequestration potential of the tree was determined by taking 0.5 g sample specimen from each tree. The highest productivity was observed at the radial distance of 0 - 2 followed by 2 - 4 and 4 – 8 m with the productivity indices of 0.74, 0.63 and 0.58, respectively. The highest amount of CO_2^-e (235.7 kg $tree^{-1}$) was sequestered in older trees with a DBH range of 17 - 19 cm as compared to younger ones (56.9 kg $tree^{-1}$) with the DBH range of 8 - 10 cm. Therefore, this tree has a significant effect on soil fertility improvement and climate change mitigation through carbon sequestration and as a result, it is important to retain *B. agyptiaca* on farmlands.

Key words: *Balanites aegyptiaca*, soil properties, carbon sequestration, Kafta Humera Woreda.

INTRODUCTION

Parkland agroforestry is one of the agrosilvicultural systems known in agroforestry systems. It is defined as the integration of scattered trees in a cultivated land or rangeland where trees are deliberately associated with the agricultural environment because of their specific use (ICRAF 2008). It is one of the three types of agroforestry systems that are known in the drylands of Ethiopia Involving mixed cereal-tree-livestock, cereal-trees and tree-livestock systems as described by Kindeya (2004). Therefore, parkland agroforestry system can be characterized as a cereal-tree agroforestry system. There are often both economic and ecological interactions between trees and other components of the system. The ecological interaction can be understood as the existence of trees on farms that help maintain soil nutrient status through protection against leaching, translocation of

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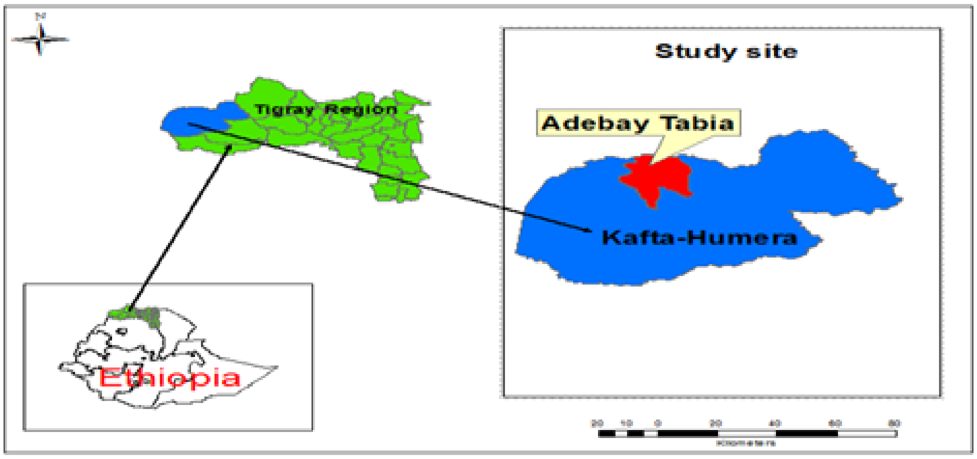

Figure 1. Geographical location of *Kafta Humera.*

nutrients from deeper soil layers to the surface and accumulation of plant litter, which creates a temporary nutrient pool at the soil surface below the canopies (Nair et al., 2009). The tree shades its leaves during the peak growing season and plays a great role in organic matter improvement and stays evergreen the whole year (Terra 2009). *Balanites aegyptiaca,* commonly known as desert date, is a small to medium sized dryland tree, which belongs to the family Zygophyllaceae (Clement, 2011).

It is found in most African countries stretching from arid and semi arid regions to sub humid Savannah (Orwa 2009). As a multi-purpose tree, *B. aegiptiaca* plays an important role in soil fertility maintenance, providing food, medicine, cosmetics, fodder, fuel wood and pesticides (Mansor et al., 2004). In lowlands of Tigray, *B. aegyptiaca* is traditionally retained on farmlands to get ecosystem benefits such as shading as described by Teklehaimanot (2011).

Small-scale farmers in *Kafta Humera Woreda* have long been experienced retaining *B.aegyptiaca* on their farmlands. However, due to the inadequate information available on the role of *B. aegyptiaca* in soil fertility management and climate change mitigation, farmers are clearing the tree for other socioeconomic uses like fuelwood and construction. Therefore, this study come up with clear findings that could help understand the role of *B. aegyptiaca* in soil properties and carbon sequestration, which at the same time enhances their awareness in retaining the existing trees and planting new seedlings on their farmlands.

MATERIALS AND METHODS

Study area description

The study was conducted in *Kafta Humera Woreda* located between 13° 40′′ to 14° 27′′ N latitude and 36°27′ to 37° 32′′ E longitude, Western Tigrayzone (Figure 1). It is located about 570 km northwest of *Mekelle* town. It is bordered with the Sudan in the West, *Tahitay Adyabo* in the East, *Wolkayt* and the *Amhara* region in the South and Eritrea in the North.

Study site selection criteria

In selecting the study site, the natures of *B. aegyptiaca* dominated environment of all farmlands enabled understand the paramount significance of the tree. Secondly, the number of trees retained in each farms ranged from 23 to 55 where taking 47 trees for the purpose of this study was found representative. Finally, the proximity of the study site to access labor force and necessary materials was the other criteria used.

Experiment I: Examining the effect of *B. aegyptica* on soil properties

Experimental design and layout

In the experiment, a 100 × 100 m (1 ha) plot was laid out first where the total number of trees inside it were found to be 47. The DBH of all trees were measured and four DBH classes were then identified, namely 8 - 10, 11 - 13, 14 - 16 and 17 – 19 cm to study the effect of *B. aegyptiaca* on soil properties. DBH classification was made to minimize the variability in the desired variable due to wider age differences and make tree sampling easier.

A total of nine trees, which also were replications, were then randomly selected from the same diameter class. The two factors identified to cause variability in the response variable were tree radial distances (that is, 0 - 2, 2 - 4 and 4-8 m) and soil depths (that is, 0 - 20, 21 - 50 and 51 - 100 cm). As a result, complete randomized factorial design (CRFD) was used for laying out the experiment.

Soil sampling methods

A total of 81 composite soil samples were collected from three radii; namely 0 - 2, 2 - 4 and 4 - 8 m at three soil depths that is, 0 - 20; 21 - 50 and 51 - 90 cm. All the soil samples were air-dried, ground and passed through a 2 mm sieve for soil physico-chemical analysis.

Table 1. Effect of *B. aegyptiaca* on physical soil properties.

S/N	Factors	Physical soil properties						
		BD (Mg m^{-3})	MC (%)	AWC (cm cm^{-1})	Clay (%)	Sand (%)	Silt (%)	Texture
1	**Radii (m)**							
	0 - 2	1.26^b	16.3^a	0.14^b	57^b	20^a	20^a	Clay
	2 - 4	1.43^a	15.0^b	0.16^{ab}	59^{ab}	19^a	23^b	Clay
	4 - 8	1.46^a	9.0^c	0.17^a	60^a	19^a	24^b	Clay
	S (±)	0.15	2.3	0.04	4.3	4.3	5.5	
	P-value	< 0.001	< 0.001	0.01	0.024	0.911	0.125	
2	**Depth (cm)**							
	0 - 20	1.23^c	11.4^c	0.13^b	56^c	20^a	24^a	Clay
	21 - 50	1.37^b	13.4^b	0.16^a	59^b	20^a	21^{ab}	Clay
	51 - 100	1.54^a	15.5^a	0.18^a	63^a	19^a	18^b	Clay
	S (±)	0.12	3.5	0.03	3.5	4.4	5.1	
	P-value	< 0.001	< 0.001	< 0.001	< 0.001	0.557	0.001	
3	**Depth * Radii**							
	P-value	0.001	0.987	0.148	0.992	0.962	0.986	
	Rep.	9	9	9	9	9	9	
	DF	80	80	80	80	80	80	

BD = Bulk density; Mc = moisture content; AWC = available water holding capacity and values with the same superscript letter were not significantly different at (P < 0.05).

Laboratory soil analyses procedure

Total Nitrogen was analyzed using Kjeldahl procedure as described in Jackson (1958) by using oxidation method. Soil pH was measured in a 1:2.5 suspension of soil salt solution of 1 M $CaCl_2$ by using pH meter (Schofield and Taylor, 1955). Available phosphorus was determined by Olson method (Olsen and Sommers, 1982). Exchangeable potassium was measured using Flame Photometer following ammonium acetate extraction method (Jackson, 1958). The total organic carbon content of the soil was determined by wet oxidation method as described by Black and Walkley (1934). Electrical conductivity was determined using an EC meter in 1:5 soil water suspensions (Houba et al., 1989). The cation excange capacity of the soil was analyzed through ammonium acetate extraction with a pH adjusted to 7.0 by using Flame Photometer (Houba et al., 1989).

The bulk density was determined using a core sampler and the moisture content was measured gravimetrically (Blake and Hartge, 1986). Soil texture was measured using a Bouyoucos hydrometer as indicated in Gee and Bauder (1982). Water holding capacity of the soil was analyzed using 10 Ka for field capacity and 1500 Kpa for permanent wilting point (Stolte 1998).

Soil productivity index calculation

The productivity index is an algorithm based on the idea that crop yield is a function of root growth, including rooting depth, which is controlled by the soil environment (Nwite et al., 2008). The productivity index was calculated using normalized sufficiency factors of pH, bulk density, electrical conductivity and available water holding capacity as described by Nwite et al. (2008), for the three soil layers, namely 0 - 20, 21 - 50, and 51 - 100 cm (Equation 1).

$$PI = \sum_{i=1}^{n} (A_i \text{ x } B_i \text{ x } C_i \text{ x } D_i \text{ x } WF) \quad (1)$$

Where PI = Productivity Index of the soil, I = 1, 2, 3…..n^{th} soil layers, Ai = sufficiency factor for available water holding capacity, B_i = the sufficiency factor for bulk density, Ci = the sufficiency factor of pH, D_i = the sufficiency factor for electrical conductivity of the i^{th} soil layer. The four sufficiency factors were retrieved from Table 1. WF is the root weighting factor at different rooting depths given by Equation (2) and B is average tree biomass where the soil sample was taken.

$$WFi = (RD_m – D_1)^2 – (RD_m – D_2)^2 / RD_m^2 \quad (2)$$

Where RD_m = maximum depth of root system (100 cm), D1 = depth of the upper boundary (cm) and D2 = depth of the lower boundary (cm).

Statistical analysis

All the soil data were first checked for normality and equality of variance using Anderson Darling normality test and Bartlett's test for equality of variance, respectively. Then, a two-way analysis of variance (ANOVA) with a fixed effect model at P < 0.05 was used to see the effect of *B. aegyptiaca* (both at three radii and soil depths) on selected soil properties using JMP Version 5 and MINITAB Version 14. Treatments were further compared using LSD Tukey (Least square means difference Tukey test) for their average values at 5% level of probability. A simple correlation analysis was also employed to see the relationship between different soil properties.

The statistical model, used for data analysis of the two factors experiment (Radial distance and soil depth effect) and one factor experiment (soil depth) for SPI were:

$Y_{ijk} = \mu + A_i + B_j + AB_{ij} + e_{ijk}$

And

$Y_{ik} = \mu + A_i + e_{ik}$

Where: Y = the response variable, μ = overall mean, A_i = i^{th} level treatment effect of factor A (that is, soil depth), B_j = j^{th} level treatment effect of factor B (that is, Radii), AB_{ij} = ij^{th} interaction effect of A and B, e_{ijk} = the random error effect.

Experiment II: Assessing the carbon sequestration potential of *B.aegyptiaca*

Experimental design and layout

A 100 × 100 m (1 ha) plot, which was also used for experiment-I, was delineated to measure tree characteristics, where 47 *B. aegyptiaca* were counted. Then, all the *B. aegyptiaca* in one hectare area were measured for their DBH using a caliper, tree height using clinometers and crown height using a measuring tape (Abebe, 2001).

Tree selection procedure

DBH was considered as tree selection criteria. Hence, the DBH of all the forty-seven trees were measured using a Caliper. These trees were then classified in to four DBH classes, namely 8-10; 11-13, 14-16 and 17-19 cm to see the effect of DBH on total biomass production and carbon sequestration as well as carbon trading potential.

Total tree biomass estimation

Total tree biomass here was considered as the sum of the above ground biomass (AGB) and belowground biomass (BGB). The above ground biomass of the forty-seven trees was estimated using the allometric equation specific to *B. aegyptiaca* (Equation 3) as developed by Matieu et al. (2011):

$$\log10Y = (2.55 \times \log10(X)) + 0.07 \quad (3)$$

Where, Y = above ground biomass (AGB) in kg, x = diameter at breast height (cm), 2.55 and 0.07 = constants.

The below ground biomass of each tree was estimated from the AGB by multiplying it with a factor of 0.27 (root/shoot ratio) as described by IPCC (2003), which is summarized in Equation (4):

$$\text{BGB tree}^{-1} = 0.27 \times \text{AGB tree}^{-1} \quad (4)$$

Determination of carbon fraction in B. aegyptiaca

Three trees with different DBH classes were randomly selected from the total of forty-seven trees. They were felled using chainsaw. Then, composite specimens were taken from the leaf, branches, stems and roots. Then after, the specimens were oven dried at 65°C and weighed repeatedly until a constant reading was obtained. Further, specimens of each tree sample were then ground (milled) using a grinding machine and a 0.5 g sieved sample was weighed for ashing. It was done after burning the sample in a muffle furnace at 550°C for 8 h until a white ash was obtained (Ullah et al., 2008). Finally, the ash content and carbon fraction were calculated using Equations (5) and (6), respectively:

$$\text{Ash (\%)} = (W_3 - W_1) / (W_2 - W_1) * 100 \quad (5)$$

$$\text{CF (\%)} = (100 - \%\text{ash}) * 0.58 \quad (6)$$

Where; W_1 = weight of crucibles; W_2 = weight of oven dried tree samples + empty crucible weight; W_3 = weight of ash + empty crucible weight; CF = carbon fraction and 0.58 = a conversion factor.

Estimation of carbon stock in B. aegyptiaca

The carbon stock of both the above ground and below ground biomass was estimated by multiplying total biomass by the carbon fraction as described by IPCC (2003) and given in Equations (7) and (8):

$$C_{AGB} = AGB * CF \quad (7)$$

$$C_{BGB} = BGB * CF \quad (8)$$

Where, C_{AGB} = the carbon stock in the above ground biomass; C_{BGB} = carbon stock in the below ground biomass and CF = carbon fraction as described in Equation (6).

The total carbon stock of the tree is the sum of both the above ground and below ground carbon as described IPCC (2003) indicated in Equation (10).

$$TCS_T = B_{Total} \times CF \quad (9)$$

Where, TCS_T = total carbon stock of the tree; B_{Total} = total biomass; CF = carbon fraction.

Soil carbon stock estimation

Three composite soil samples were collected from each radii of 0 - 2, 2 - 4 and 4 - 8 m at 0 - 20, 21 -50 and 51 – 100 cm soil depths for total organic carbon (TOC) determination according to Black and Walkley (1934). Besides, undisturbed soil samples were collected using a core sampler to determine soil bulk density (Blake and Hartge, 1986). The coarse fragment proportion of the soil was determined as the ratio of weight of coarse fragment to the weight of the sum of both the coarse fragment and fine soil of the i^{th} soil layer in gm. At last, the soil carbon stock was calculated using Equation (10) as described by Andreas et al. (2012).

$$C_{soil} = \sum_{i=1}^{n} d_i * \rho b_i * OC_i * CFpi \quad (10)$$

Where, C_{soil} = soil carbon stock (t ha^{-1}); d = soil layer thickness in (cm), ρb = bulk density in (g cm^{-3}) of each sample depth, OC = carbon concentration (g g^{-1}) of each soil sample and CF_{pi} = correction factor for coarse fragments of the i^{th} layer > 2 mm.

The total carbon stock of the parkland agroforestry system was calculated by summing up the total carbon stock of the tree and the soil by using Equation (11) (IPCC, 2003).

$$TCS_{system} = CS_T + C_{soil} \quad (11)$$

Where, TCS_{system} = total carbon stock of the parkland agroforestry system; CS_T = carbon stock of the tree and C_{soil} = soil carbon stock. Then, the CO_2 $^{-e}$ of the system was calculated by multiplying the total carbon stock of the system by a factor of 3.66 Equation (12) (IPCC, 2003).

$$CO_2^{-e} = TCSs_{ystem} \times 3.66 \quad (12)$$

The carbon price, which according to the European Union Emission Trading Scheme (*EU ETS*) is planned in three phases. Phase I was from 2005 to 2007, phase II from 2008 to 2012 and phase III from 2013 to 2020 where the carbon pricing was set to be 30, 10, and € 30 for one tone CO_2 for the three phases respectively. But the current (2013/2014) price rate is equivalent to € 4.94 tone^{-1} (Elina, 2013). As a result, the carbon trading potential of the parkland agroforestry system of the *Tabia* was estimated using Equation (13) as described by Lal (2002).

$$C_{benefit} = CO_2^{-e} \times C_{price} \times \text{total area of the parkland} \quad (13)$$

Statistical analysis

A one way analysis of variance (ANOVA) was used with LSD (Least square means difference Tukey test) to compare the mean carbon stocks at different radii with a fixed effect model at (P<0.05). JMP version 5 was used for data analysis. The linear model used was:

$$Y_i = \mu + A_i + e_i,$$

Where, Y_i = is the response variable (that is, SCS), μ = overall mean, A_i = ith treatment effect of factor A (that is, radii), and e_i = random variable error.

RESULTS AND DISCUSSION

Effect of *B. aegyptiaca* on physical soil properties

As presented in Table 1, the effect of *B. aegyptiaca* on bulk density showed a significant difference (P< 0.05) across the three radii and three soil depths. The highest BD was found in the open field (1.46 Mg m^{-3}), followed by the radial distances first at 0 - 2 m and then at 2 - 4 m where the respective BD were 1.26 and 1.43 Mg m^{-3}. Disturbance of the soil by livestock and organic matter availability contributed for the difference in BD both for the three radii and soil depths. Linnea (2006) reported that under tree canopies, lower bulk density was found than in the outside.

The moisture content of the soil was significantly different (P < 0.05) for the three radii (Table 1). The moisture content of the soil was found higher with increase in soil depth, which is due to a higher initial infiltration rate during the rainy season and relatively lower loss of moisture via evaporation and the mulching effect of the soil during the dry season. A study conducted by Bekelle (2003) also reported that, deeper soils under agroforestry systems have higher moisture content than the upper horizons.

The AWC was significantly different both across its radii and along soil depths. AWC ranged between 0.13 to 0.18 cm cm^{-1}. Open fields (0.17 cm cm^{-1}) held much water as compared to the soils under the tree canopy (0.14 cm cm^{-1}). This might be due to the higher water infiltrated in the open field than the amount trickled under the canopy. Furthermore, the highest AWC was obtained with increasing the soil depth. The highest AWC (0.18 cm cm^{-1}) was found in the deepest layer whereas the lowest AWC (0.13 cm cm^{-1}) was observed in the upper most layers. Nair et al. (2009) also concluded that a 15% increase in AWC was observed at deeper horizon (30-60 cm) than in the top soil (0 - 30 cm).

The clay proportion of the soil was found to be significantly different (P < 0.05) for the three radii and the three soil layers. The result clay content was 57 and 60% for 0 - 2 and 4 - 8 m radii, respectively which was by far 3% higher than in the soils under the tree canopy. High proportions of clay particles might have been trapped by cracks of vertisols during the dry season that is accumulated due to wind erosion. Migration of clay particles down the soil profile might also have contributed for the increase in clay particles deep the soil horizon.

Effect of *B.aegyptiaca* on chemical soil properties

Table 2 presents the effect of *B. aegyptiaca* on the soil chemical property. *B. aegyptiaca* effect on TN, Av. P, OC, CEC and EC were significant at (P < 0.05) both along with the soil depth and radii. The pH was not significantly different at (P > 0.05) in both the three radii and three soil layers (Table 2). This could be due to the Calcareous nature of the parent material.

The total nitrogen content was highly significant at (P < 0.05) both at the three radii and soil layers (Table 2). The highest N content (0.1%) at 0 - 2 m radial distance, which was by 50% greater than in the open field (0.05%) that was located at 4 - 8 m radius. This was apparently due to *B. aegyptiaca* effect on increasing the organic matter through liter fall.

The available phosphorus was only significantly different between the three radii (P < 0.05). The available P was decreased with increasing the radial distance. It exhibited a 23% increase at a radius of 0 - 2 m and 16% increase at 2 - 4 m radius as compared to the open field (4 - 8 m). The available P content was rated as low as described by Marx et al. (1999). P availability in the soil depends on the soil pH where it is most available within the pH range of 6 to 7 and absorbed primarily by plants as orthophosphates. Accordingly, the available P decreased with increasing the radial distances. Issam

Table 2. Effect of *B. aegyptiaca* on chemical soil properties.

S/N	Factors	Chemical soil properties						
		pH	TN (%)	Av. P (ppm)	Ex. K (C. mol kg^{-1})	OC (%)	CEC (C. mol kg^{-1} soil)	EC (dS m^{-1})
1	**Radii (m)**							
	0 - 2	7.4^{a}	0.10^{a}	6.8^{a}	2.11^{a}	0.7^{a}	46.6^{a}	0.16^{a}
	2 - 4	7.4^{a}	0.09^{b}	6.1^{a}	1.99^{a}	0.7^{a}	45.8^{ab}	0.15^{ab}
	4 - 8	7.5^{a}	0.05^{c}	4.5^{b}	2.09^{a}	0.4^{b}	43.6^{b}	0.14^{b}
	S (±)	0.28	0.02	1.02	0.33	0.21	4.4	0.03
	P-value	0.142	< 0.001	< 0.001	0.170	< 0.001	0.009	0.015
2	**Depth (cm)**							
	0 - 20	7.5^{a}	0.10^{a}	5.7^{a}	1.72^{c}	0.8^{a}	46.6^{a}	0.13^{c}
	21 - 50	7.5^{a}	0.08^{b}	5.6^{a}	2.14^{b}	0.6^{b}	47.1^{a}	0.15^{b}
	51 - 100	7.4^{a}	0.06^{c}	6.1^{a}	2.33^{a}	0.4^{c}	42.3^{b}	0.18^{a}
	S (±)	0.28	0.03	1.4	0.25	0.19	4.02	0.02
	P-value	0.609	< 0.001	0.241	< 0.001	< 0.001	< 0.001	< 0.001
3	**Depth * Radii**							
	P-value	0.089	0.0002	0.856	0.978	0.039	0.013	0.273
	Rep.	9	9	9	9	9	9	9
	DF	80	80	80	80	80	80	80
	Range	1.5	0.13	5.9	1.5	1.04	20.3	0.12

pH = Acidity and alkalinity of the soil; TN = total nitrogen; Av.P = available phosphorus, Ex. K = exchangeable potassium, OC = organic carbon; CEC = cation exchange capacity; EC = electrical conductivity. Values with the same superscript letter were not significantly different at (P < 0.05).

(2007) also confirmed that arid and semi-arid soils have relatively low available phosphorus.

A significant difference was observed in exchangeable K between three soil depths at (P < 0.05). The deepest layer (51-100 cm) had 2.33 C. mol kg^{-1} and was found to be higher than the surface horizon (0- 20 cm), which had only 1.27 C.mol kg^{-1}. Exchangeable K increased with increasing the soil depth. The highest exchangeable K was observed in the deepest horizon, which could be due to the pumping effect of the deep root.

As presented in Table 2, the effect of *B. aegyptiaca* on OC was significantly different at (P<0.05) both for the three radii and soil depths. The open field constituted only 0.4% of organic carbon as compared to soils under the tree canopy of the two radii that had 0.7% for both. Similarly, the top soil constituted a higher organic carbon than the deeper soil profile which was due to the accumulation of higher organic matter under the canopy.

The CEC was significantly different at (P < 0.05) for the three radii and soil depths (Table 2). As Fassil and Charles (2009) reported that the CEC of Vertisols of the highlands of Ethiopia ranged from 25 to 45 C. mol kg^{-1}, this study revealed a lower CEC on open fields (43.6 C. mol kg^{-1} soil) than under the tree canopy with 46.6 C. mol kg^{-1} soil at 0 - 2 m radii where the difference could be due to the lower organic matter in open fields.

Electrical conductivity (EC) was significantly different (P < 0.05) for both the three radii and soil depths (Table 2). Across the radii, the highest EC was obtained under the tree crown at 0 - 2 m with a value 0.16 dS m^{-1} than in the open fields (0.14 dS m^{-1}), which was about 2% greater than in the open field soils. Depth wise also, a 5% increase in EC was observed in the third soil horizon (51-100 cm) having a value of 0.18 dS m^{-1} as compared to the first layer (0 - 20 cm) that had only 0.13 dS m^{-1}.

The highest EC in the deepest soil horizon might be due the basaltic parent material of the soil, the root pumping effect and leaching of soluble salts deep into the soil. The highest EC at a radius of 0-2 m could be due to the availability of old leaves on the surface of the soil, which are rich in calcium. The EC was therefore ranged between 0.1 to 0.2 dS m^{-1}, which according to Marx et al. (1999) was rated as low.

Correlation of major soil properties

As seen in Table 3, a simple correlation test between the relevant soil properties indicated that soil fertility under *B. eagyptica* was significant (P < 0.05). The soil organic carbon was positively and significantly correlated with total nitrogen (r = 0.982*; P = 0.04) and significantly contributed to available phosphorus (r = 0.955*; P < 0.05) across the three radii indicating total N and available P

Table 3. Correlation matrix between major soil properties at P<0.05 and n=81.

Correlation across radii	pH	TN (%)	AV.P (ppm)	Ex.K (C. mol kg^{-1})	OC (%)	CEC (C. mol kg^{-1} soil)	AWC (cm cm^{-1})	Clay (%)
pH	1.000							
TN (%)	-0.982	1.000						
Av. P (ppm)	-0.955	0.994*	1.000					
Ex. K (cmol kg^{-1})	0.359	-0.176	-0.066	1.000				
OC (%)	-0.987*	0.982*	0.955*	-0.359	1.000			
CEC	-0.966	0.998*	0.999*	-0.107	0.966	1.000		
AWC (cm cm^{-1})	0.866	-0.945*	-0.975	-0.156	-0.866	-0.966	1.000	
Clay (%)	-0.945	0.990	0.999*	-0.034	0.945	0.997*	-0.982	1.000
Correlation (depth)								
pH	1.000							
TN (%)	0.866	1.000						
Av. P (ppm)	-0.982	-0.756	1.000					
Ex. K (cmol kg^{-1})	-0.740	-0.136	0.599	1.000				
OC (%)	0.866	0.998*	-0.756	-0.977	1.000			
CEC	0.996	0.815	-0.995	-0.673	0.815	1.000		
AWC (cm cm^{-1})	-0.803	-0.993	0.676	0.995	-0.993	-0.743	1.000	
Clay (%)	-0.904	-0.997	0.807	0.956	-0.997	-0.860	0.981	1.000

*Significant at P < 0.05 otherwise no.

were increased as the soil organic matter increased. Available P was strongly and significantly correlated with CEC (r = 0.999*; P < 0.05) and the clay content of the soil (r = 0.999; p < 0.05) across the three radii. The CEC also had a positive and strong correlation with the clay content (r = 0.997*; P < 0.05) across the three radii. Whereas, the total N was strongly and negatively correlated with the available water holding capacity (r = -0.945*; P < 0.05) indicating that with increase in soil depth, total nitrogen was decreased and available water holding capacity was increased. However, along the soil depth, total nitrogen was strongly and positively correlated with organic carbon (r = 0.998*; P < 0.05) that showed an increase in organic matter increased the total N of the soil.

Effect of *B. aegyptiaca* on soil productivity Index

Table 4 presented the effect of *B. aegyptiaca* on soil productivity index. The result revealed that the PI ranged from 0.67 to 0.75 in the open fields at 4 - 8 m and at 0 - 2 m radius, respectively. However, PI was significantly different at P < 0.05 at the three radii. Nevertheless, a relatively higher PI was observed under the tree canopy at 0 - 2 m than the open fields (4 - 8 m), which could be due to the availability of optimum pH, lower EC, higher AWC and lower BD. All the soil productivity indices were rated as very high as described in Table 4. Hence, *B. aegyptiaca* positively affected the soil productivity.

Biomass of *B. aegyptiaca*as affected by age

The biomass of *B. aegyptiaca* at different age classes was significantly different (P < 0.05) as presented in Table 5. Trees with an age class of 3 to 4 years had an average above ground biomass (AGB) of 24.99 kg tree^{-1}and those older than 7 and 8 years had an average AGB of 103.47 kg tree^{-1}. Similarly, an increase in the below ground biomass (BGB) of *B. aegyptiaca* was observed. This clearly indicates that older aged trees produce higher biomass as compared to younger ones.

In addition, the total aboveground biomass was 2936.78 kg ha^{-1} while the total belowground biomass of *B. aegyptiaca* was 792.62 kg ha^{-1} yielding a total biomass of 3729.4 kg ha^{-1}.

Carbon stock of *B. aegyptiaca*

The effect of *B. aegyptiaca* age on carbon stock was significantly different at (P < 0.05). Age classes of 5.1 to 7 and 7.1 to 8 years had the capacity to sequester more carbon in kg tree^{-1} than the younger ones (3 to 4 and 4.1 to 5 yrs.). An age class of 3 to 4 yrs. had a total carbon stock of 15.55 kg tree^{-1} and the oldest age class of 7.1 to8 years was able to sequester 64.39 kg C tree^{-1} with a48.8% increase over the first age class (3 to 4 years.).

Table 4. Effect of *B. aegyptiaca* on soil productivity index.

Soil depth (cm)	PI (0-2 m)	PI (2-4 m)	PI (4-8 m)	S (±)	P-value
0-20	0.28[a]	0.20[b]	0.24[ab]	0.062	0.05
21-50	0.29[a]	0.23[b]	0.22[c]	0.068	0.01
51-100	0.17[ab]	0.20[a]	0.12[b]	0.066	0.02
PI	0.74[a]	0.63[b]	0.58[c]	0.16	0.002

PI = Productivity index; S (±) = plus or minus deviation of each observation from the average value; P-value = significance level of rejection at (P<0.05).

Table 5. Age effect on tree biomass.

DBH class (cm)	Age class (years)	AGB (kg tree^{-1})	BGB (kg tree^{-1})	Total Biomass (kg tree^{-1})
8 - 10	3 - 4	24.99[d]	6.74[d]	31.73[d]
11 - 13	4.1 - 5	46.43[c]	12.53[c]	58.97[c]
14 - 16	5.1 - 7	72.47[b]	19.56[b]	92.04[b]
17 - 19	7.1 - 8	103.47[a]	27.93[a]	131.41[a]
S (±)		26.7	7.21	33.92
R^2		91	91	91
P-value		< 0.001	< 0.001	< 0.001
DF		46	46	46

R^2 = total variability of the response variable; DF = degree of freedom; values designated by the same letter were not significantly different and P-value= significant level at (P<0.05).

Therefore, this study concluded that an older tree could be able to capture more carbon from the atmosphere than the younger ones and this could be due to variation in biomass weight (Table 6).

The total carbon stock in the aboveground biomass was 1.438 t ha^{-1} showing differences among different age classes where older trees (7.1 - 8 years) could capture more carbon than younger ones. The higher biomass production in older trees might have contributed to the difference. Similarly, the belowground biomass was able to sequester 0.388 t ha^{-1}. The total carbon stock of *B. aegyptiaca* of the study site was then 1.826 t ha^{-1} (Table 7).

Soil carbon stock

The total soil carbon stock was significantly different (P < 0.05) at the three radial distances as presented on Table 8. It ranged from 10.15 to 14.73 t ha^{-1}. In the open field (that is, 4-8 m) the smallest carbon stock (10.15 t ha^{-1}) was observed as compared to the radii at 0 - 2 m (14.32 t ha^{-1}) and at 2 - 4 m (13.23 t ha^{-1}). The difference could be due to the availability of higher organic matter under the tree canopy than outside it. This finding is supported by Asako (2007) that confirmed an increase in soil carbon stock around trees and three reasons were given for this evidence. Firstly, it has an effect on physical stabilization by micro-aggregation; secondly, the intimate association through soil particles and finally, biochemical stabilization by formation of resistant soil organic compounds.

CO_2 equivalents and C benefits of *B. aegyptiaca*

As seen in Tables 6 and 8, the soil could sequester more carbon (12.57 t ha^{-1}) comparing to the tree, which was only 1.83 t ha^{-1}. Therefore, although the soil carbon was larger than the carbon stock of *B. aegyptiaca*, the existence of the tree contributed to the higher carbon pool of the soil as explained previously. The total carbon stock of the parkland agroforestry system was then 14.4 t ha^{-1}.

The carbon trading potential of the parkland agroforestry system of the study site was estimated to be € 260.3. However, in total, € 1,457,680 could be obtained from the total of 5600 ha land of the parkland agroforestry system of the selected study area (Table 9). This is therefore an indication that, besides the environmental services, parkland agroforestry systems could serve as a source of money by trading carbon.

Conclusion

This study concludes that *B . aegyptiaca* significantly improved soil properties such as total nitrogen, available

Table 6. Tree age effects on Carbon stock in *B. aegyptiaca.*

DBH class (cm)	Age class (years)	No. of trees	TC_{AGB} (t. ha^{-1})	TC_{BGB} (t. ha^{-1})	TC (t. ha^{-1})
8 - 10	3 - 4	7	0.086	0.023	0.109
11 - 13	4.1 - 5	12	0.273	0.074	0.347
14 - 16	5.1 - 7	19	0.674	0.182	0.856
17 - 19	7.1 - 8	8	0.405	0.109	0.514
Total C stock(t ha^{-1})			1.438	0.388	1.826

TC_{AGB} = total carbon in the above ground biomass, TC_{BGB} = total carbon in the below ground biomass, TOC = total carbon stock of *B. aegyptiaca.*

Table 7. Total carbon stock of *B. aegyptiaca* of the study site.

DBH class (cm)	Age class (years)	C_{AGB} (kg $tree^{-1}$)	C_{BGB} (kg $tree^{-1}$)	TOC (kg $tree^{-1}$)	CO_2^-e
8 - 10	3 - 4	12.24[d]	3.31[d]	15.55[d]	56.9
11 - 13	4.1 - 5	22.75[c]	6.14[c]	28.89[c]	105.7
14 - 16	5.1 - 7	35.51[b]	9.58[b]	45.09[b]	165.0
17 - 19	7.1 - 8	50.70[a]	13.68[a]	64.39[a]	235.7
S (±)		13.09	3.533	16.62	3.4
R^2		91	91	91	91
P-value		< 0.001	< 0.001	< 0.001	<0.001
DF.		46	46	46	46

TC_{AGB} = Total carbon stock in the above ground biomass; TC_{BGB} = total carbon stock in the below ground biomass; TOC = total carbon stock; t ha^{-1} = tone per hectare.

Table 8. Effect of *B. aegyptiaca* on soil carbon stock.

Variable	Radii(m)			S (±)	P-value
	0-2	2-4	4-8		
SCS (t ha^{-1})	14.32[a]	13.23[b]	10.15[a]	3.87	0.001

SCS = soil carbon stock; S = standard; P-value = significance level. Average values with the same superscript letters were not significantly different at (P<0.05).

Table 9. Carbon benefits of the parkland agroforestry system.

TCS_{tree} (t ha^{-1})	TCS_{soil} (t ha^{-1})	TCS_{PAS} (t ha^{-1})	CO_2^{-e} (t ha^{-1})	C price of the study site (€)	C price of the system (€)
1.83	12.57	14.4	52.7	260.3	1,457,680.00

TCS = total carbon stock; CO_2^{-e} = carbon dioxide equivalents; C = Carbon; € = Euro.

phosphorus, exchangeable potassium, organic carbon, pH, bulk density and CEC. A very high productivity index (PI) of the soil has also been found under the tree canopy than outside it. The tree was able to contribute 5 and 2% of the available N that could have been supplied by Dap and Urea to the soil, respectively.

It also contributed in clean development mechanism through storing carbon in its biomass both through its above ground biomass and below ground biomass. A significant amount of carbon was also stored in the soil from respiration of microorganisms and decomposition of organic matter under the tree canopy.

The carbon benefit of the parkland agroforestry system was also paramount. With the current carbon price developed by EU ETS, the total amount of money generated from the parkland agroforestry system of the *Tabia* was € 1,457,680.

RECOMMENDATIONS

B. aegyptiaca is widely grown through natural regeneration in the Northern lowlands of Ethiopia. Hence, due to the lack of knowledge by local farmers, it is usually cleared during cultivation from farmlands. Therefore, awareness creation for concerned stakeholders on the role of the tree in soil fertility improvement and climate change mitigation needs to be done. In addition, farmland based seedling raising and micro-propagation is recommended. It can be recommended for all African countries of the same agroecological zones where no trees exist. More scientific researches on the tree physiology, anatomy, biology and adaptation must be conducted to maximize the benefits both economically and ecologically.

Conflict of Interest

The authors have not declared any conflict of interest.

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