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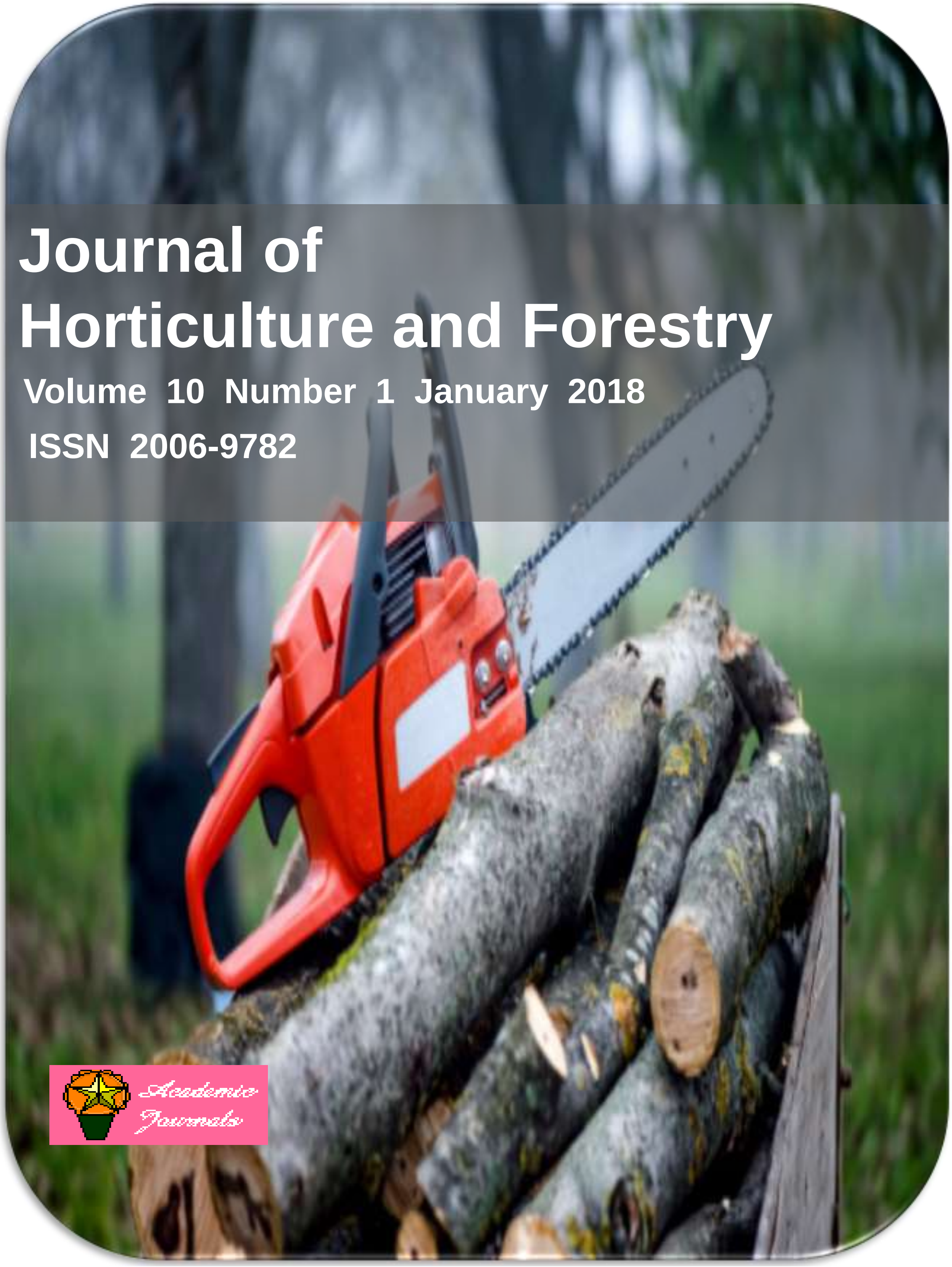

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Journal of Horticulture and Forestry

Full Length Research Paper

Physico-chemical properties of soil under the canopies of *Faidherbia albida* (Delile) A. Chev and *Acacia tortilis* (Forssk.) Hayen in park land agroforestry system in Central Rift Valley, Ethiopia

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This study was conducted to evaluate the effect of *Faidherbia albida* and *Acacia tortilis* on soil physico-chemical properties at Langano and Tuka in farm fields of Bora District where both trees are traditionally retained on the farm. At each site, four *F. albida* and four *A. tortilis* trees were purposively selected and soil sample collected from four directions at three distances (1.35, 3.35 and 26.35 m) from tree trunk and composite soil samples was taken for both physico-chemical analyses. Collected data was analyzed by two way ANOVA and mean separation with LSD (%). Mean moisture levels of all sites, 1.35 (14.32%) were significantly ($p < 0.05$) greater than that of openland (10.79%) at 26.35 m from tree trunk. Bulk density was also significantly affected by tree canopies ($p<0.05$). It increased from 1.20 g/cm^3 under canopy to 1.29 g/cm^3 in the openland. At both sites, pH was significantly lower ($p < 0.05$) under the canopy than out of the canopy (it was reduced from 6.05 under canopy to 7.00 at open land). Soil organic matter, total nitrogen available phosphorus, exchangeable calcium, exchangeable magnesium and cation exchange capacity were significantly higher ($p < 0.05$) under the canopy of trees as compared to openland. Apart from these, the recorded values of exchangeable sodium, potassium and electrical conductivity revealed statistically non-significant difference among the treatments. The research finding showed that trees have positive relation with availability of soil nutrient and to enhance these trees in the farm, farmers knowledge improvement and further research regarding tree age class should be conducted.

Key words: Parkland agroforestry, canopy position, soil physicochemical properties.

INTRODUCTION

The definition of agroforestry used by ICRAF is: "a dynamic, ecologically based, natural resources management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and

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sustains production for increased social, economic and environmental benefits" (Leakey, 1996). Agroforestry is one of the most conspicuous land use systems across landscapes and agroecological zones in Africa. With food shortages and increased threats of climate change, interest in agroforestry is gathering for its potential to address various on-farm adaptation needs, and fulfill many roles in agriculture, forestry and other land use-related mitigation pathways. Agroforestry provides assets and income from carbon, wood energy, improved soil fertility and enhanced local climate conditions; it provides ecosystem services and reduces human impacts on natural forests (Cheikh et al., 2013).

Agroforestry has potential to improve soil fertility. This is mainly based on the increase of soil organic matter and biological nitrogen fixation by leguminous trees. Trees on farms also facilitate tighter nutrient cycling than monoculture systems, and enrich the soil with nutrients and organic matter (Lehmann et al., 1998), while improving soil structural properties. Scattered trees on farm characterize a large part of the Ethiopian agricultural landscapes today, while tree species differ depending on their agro-ecological suitability such as rainfall, altitude and soil and natural distribution patterns.

The central rift valley in Ethiopia is being remarked for a shift in the use of land from dense woodland with palatable pasture to a farm land with scattered trees for growing agricultural crops to feed the growing population. The system is described as agroforestry parkland where naturally regenerated and scattered individual trees occur in the cultivated fields (Agena et al., 2014). In the study area, *Faidherbia albida and Acacia tortilis* trees are scattered on the farmland with different crops for different purposes like fodder for livestock, fuel wood, fencing material and soil conservation.

Central rift valley faced problems of soil fertility due to different reasons. Even rural poor households are using cow dung for earning income by collecting and selling them. Additionally, in the study area, most of the farmers remove trees from their farm for charcoal production and to reduce shading effect instead of retaining and improving soil fertility. Thus, this research can be fundamental to provide crucial information on the effect of *F. albida and A. tortilis* on soil fertility improvement and therefore to enhance trees on the farm. The objectives of this study were to assess physico-chemical properties of soil under the canopies of *F. albida* and *A. tortilis* in parkland agroforestry system in Central Rift Valley, Ethiopia.

MATERIALS AND METHODS

Description of the study area

The study site is located in Dugda district, East Shewa Zone, Oromia Regional State in Central Rift Valley of Ethiopia in geographical location between 8° 6'30"N - 8° 25'30 N" and 38°45'0" E - 39°4'0" E and 110 km south east of, Addis Ababa, capital city of Ethiopia (Figure 1).

Geology and soil

The area falls within the semi-arid climatic zone, and according to the agro climatic zonation in Ethiopia, it is classified as "Dry Weyna Dega" The study site is situated in Ethiopia's Rift Valley where the geology is dominated by basalt, ignimbrite, lava, volcanic ash, pumice, reverie and lacustrine alluvium that gives rise to pale color, coarse textured and freely drained light soils. The soil was developed from lake deposits inter-bedded with pumice and classified as Andosols (Makin et al., 1975). The soil fertility of the area is maintained by living crop residuals on the farm and animal dung used by the farmer. Additionally, farmers of the study area are retaining trees on their farm to improve soil fertility and reduce soil erosion.

Sampling design and data collection

Selection of agroforestry trees and treatment

F. albida and *A. tortilis* trees that are traditionally grown on croplands were selected independently for the study. Four scattered trees of *F.albida* and four *A. tortilis* growing on similar site condition at Tuka, that is, eight (8) trees at one location and total of sixteen (16) at both locations were randomly selected in the blocked area. Each tree was replicated four times at both location. The selection of trees for each species was based on the similarity of their canopy cover, diameter, height and age. Average diameter of eight *F. albida* and *A.tortilis* was 43.31 and 47.71 cm, respectively. The two longest canopy radii perpendicular to each other and parallel to the ground were measured and used to calculate canopy area, using Equation 1 (Vora, 1988). Relatively homogenous site conditions in terms of slope, aspect and topography and growth and vigor of the trees were also considered in the selection of the trees of each species. As indicated in Figure 2, the canopies coverage of each of 4 trees was divided into two radial transects and three plots (0.7 x 0.7 m), two under the canopy with distance of 1.35 and 3.35 m and one out of the canopy 26 .35 m from tree trunk as control for each radial were established (Belay and Abdu, 2004). Total sample size is number of treatments (3)* number of replicates (4)* tree species (2) * location (2). In this case, radial distance from the tree trunks was considered as treatment with three levels: 1.35, 3.35 and 26.35 m, while as location, tree species were taken as factors. Area around the tree trunks with 26.35 m radius is considered as block.

Soil sampling

Soil samples were collected from all experimental plots after harvest. Replicated soil samples were taken from 0 to 20 cm soil depth for both tree species, composite soil samples from each plot was taken under the tree canopy and out of the canopy at three distances in four different directions. 2 kg of composite soil samples for each treatment were collected and transported to the laboratory for analyses.

Analysis of soil physical properties

Soil moisture content at the time of sampling was determined gravimetrically through oven drying at 105°C to a constant weight from known mass and volume of soil sample collected using soil moisture cans (Blake and Hartge, 1986). Bulk density was determined in undisturbed soil clods collected in cylinders (core

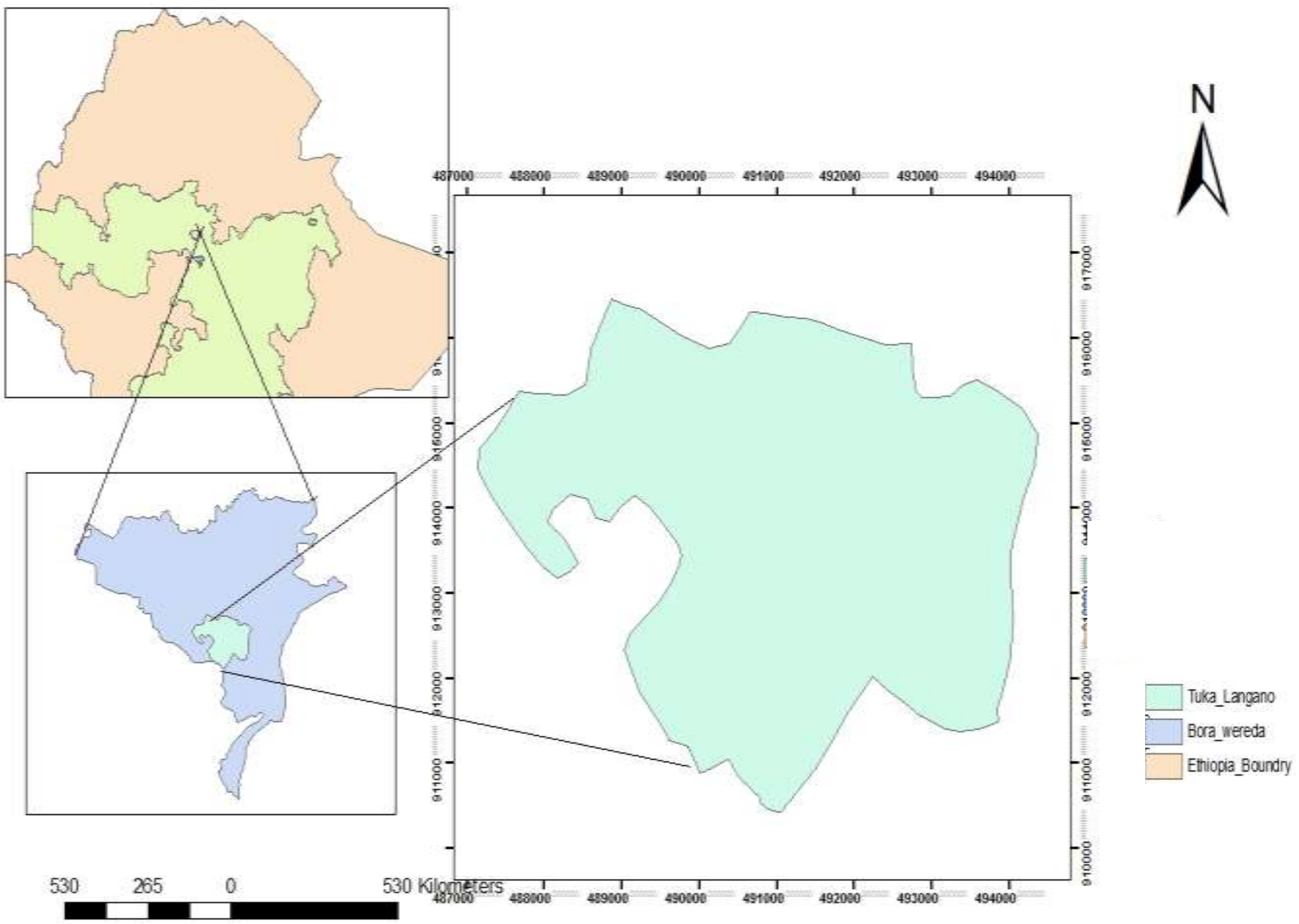

Figure 1. Map of the study area.

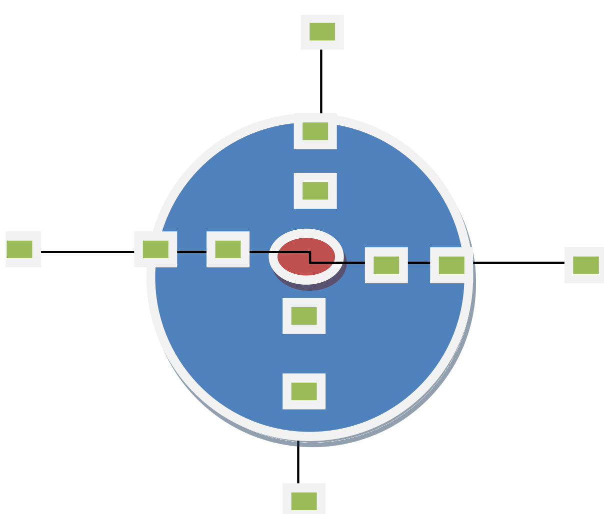

Figure 2. Data collection design. 1. Circle represents canopy of the tree and center is single tree trunk; 2: Plot on equal distance from the tree, considered as one treatment; 3. Soil sample at 0 to 20 cm depth was taken from each plot for analysis.

samplers) of known dimensions (length and diameter) from each soil sampling depth as described by Robert et al. (2002). Soil texture was determined by hydrometer method (Gee and Bauder, 1982).

Analysis of soil chemical properties

pH was analyzed using pH meter Van Reeuwijk (1992); EC, by electro conductivity meter; soil organic carbon, by Walkley and Black (1934); available phosphorus, by Olsen and Sommers (1982); cation exchange capacity (CEC), by ammonium acetate (1 M NH_4OAC) Houba et al. (1986); exchangeable K and Na, by flame photometer (Jackson, 1958); exchangeable Ca and Mg, by atomic absorption spectrophotometer (Jackson, 1958); exchangeable K by ammonium acetate (Jackson,1958); total nitrogen (TN), by Kjeldahl method (Jackson, 1958).

Statistical analysis

Randomized complete block design (RCBD) with two ways (ANOVA) were carried out to statistically compare the difference among treatments using SAS computer software SAS Institute version 8.1, Vol.1. (SAS, 1999) Statistical differences were tested using the least significant difference (at 0.05%).

Table 1. Effect of *F. albida* and *A. tortilis* on texture with radial distance from tree trunks at both locations.

Tree species	Radius	Tuka			Langano		
		Sandy (%)	**Silte (%)**	**Clay (%)**	**Sandy (%)**	**Silte (%)**	**Clay (%)**
Faidherbia	1.35	38.5	35.25	19.01	42.25	39.00	19.00
	3.35	39.5	39.5	19.10	43.50	38.50	17.50
	26.35	38.5	39.1	18.02	44.00	38.25	17.50
	CV %	12.47	15.47	12.37	8.85	9.29	9.44
	LSD %	7.75	9.38	3.69	6.1201	5.7365	2.7188
Tortilis	1.35	41.5	34.5	19.50	46.50	36.50	15.50
	3.35	40.5	38.00	18.50	47.00	35.00	16.00
	26.35	40.5	36.25	19.00	44.50	36.00	16.50
	CV %	16.18	8.00	7.44	6.69	8.27	9.77
	LSD %	10.57	4.6406	2.2622	2.72	4.74	2.50

Table 2. Moisture content as influenced by *F. albida* and *A. tortilis.*

Tree species	Radius (m)	Tuka			Langano
		Moisture content	**Bulk density**	**Moisture content**	**Bulk density**
Faidherbia	1.35	14.04^{a}	1.15^{b}	14.53	1.22^{b}
	3.35	12.38^{b}	1.19^{a}	11.94	1.28^{a}
	26.35	10.64^{b}	1.19^{a}	11.95	1.28^{a}
	CV %	25.65	7.21	41.64	9.22
	LSD %	5.07	0.136	8.53	0.19
Tortilis	1.35	15.41^{a}	1.13	13.294^{a}	1.15^{b}
	3.35	13.53^{ab}	1.18	7.36^{b}	1.13^{a}
	26.35	10.88^{b}	1.17	7.96^{b}	1.22^{a}
	CV %	15.50	5.536203	19.33	5.59619
	LSD %	3.29	0.1026	2.95	0.1045

RESULTS

Soil physical properties per tree species and location

Soil texture per tree species and location

As analysis of variance indicate, there was no significant ($p > 0.05$) difference between soil texture along the radial distance from the tree trunk of both trees at both locations (Table 1).

Moisture content and bulk density

Statistical analysis showed that moisture content and bulk density significantly varied ($p<0.05$) (Table 2) under *F. albida* as radial distance from tree trunk increases at Tuka location, whereas, only bulk density showed significant variation with radial distance under *Faidherbia* at Langano. Under *A. tortilis*, moisture content was significantly different ($p< 0.05$) at both locations. But bulk density significantly varied only at Langano.

Effect of *F. albida* and *A. tortilis* on soil chemical properties per location as radius from the trunk increase

Soil pH and electrical conductivity

Result showed that, pH was significantly ($p< 0.05$, Table 3) increased as radial distance from tree trunk increased under *F. albida* at Tuka location and EC did not significantly vary under both trees and both locations. However, it was not significant ($p> 0.05$) statistically; the measured means of soil pH increased with increasing distance away from the tree trunk, that is, it was lower beneath the trees and slightly higher in the open cultivated land under both trees at both locations.

Table 3. Effect of *F. albida* and *A. tortilis* on soil pH along radial distance.

Tree species	Radius	Tuka		Langano	
		pH	EC	Ph	EC
Faidherbia	1.35	6.05[b]	0.15	6.09	0.14
	3.35	7.03[a]	0.14	6.95	0.15
	26.35	7.08[a]	0.14	7.02	0.14
	CV %	7.90	7.45	7.94	10.53
	LSD %	0.85	0.02	0.85	0.02
Tortilis	1.35	5.82	0.15	6.26	0.133
	3.35	6.98	0.15	6.72	0.136
	26.35	7.25	0.14	6.94	0.13
	CV %	11.08	6.57	5.82	9.59
	LSD %	1.18	0.02	0.62	0.02

Soil organic carbon, total nitrogen and available phosphorus

Organic matter, total nitrogen and available phosphorus were significantly ($p<0.05$) affected by radial distance from the tree trunk under both trees at both locations. However, it was not significant ($p< 0.05$), the figure showed that Oc under *Faidherbia* at Tuka and Av. P under *Faidherbia* at Langano decreased with increased distance from the tree trunks. The result showed that TN significantly varied between the three distances (1.35, 3.35 and 26.35 m) from the tree base of both *F. albida and A. tortilis* at both locations.

Cation exchange capacity and exchangeable bases (Ca, Mg, Na and K)

The study result indicated that cation exchange capacity (CEC) and concentration of base cations (Ca^{++}, Mg^{++}, Na^{+} and K^{+}) were significantly ($p< 0.05$) (Table 5) affected by canopy position of both trees at Tuka and Langano except for sodium and potassium which were not significant ($p> 0.05$) (Table 5) under both trees and location. CEC and Mg were not significant ($p< 0.05$) under *A. tortilis* at langano and Mg was also not significant under *A. tortilis* at Tuka location.

DISCUSSION

Soil texture per tree species and location

The non-significance of textural distribution along the radial distance could be due to the fact that, texture depends on parent materials from which it is made up. In contrast to this finding, Mohammed et al. (2016) reported that soil texture was significantly different between *A. senegal* and Balanite *aegyptica.* According to this result, soil texture was not affected by both tree species and at both locations since soil texture is mainly dependent on parent material of the soil (Agena et al., 2014).

Moisture content and bulk density

The value of moisture decreased from 14.04% under canopy to 10.64% in open field at Tuka and in reverse, bulk density increased from 1.15 under the canopy to 1.19 gm/cm^3 out of the canopy as indicated in Table 5. Greater moisture content under the canopy might have resulted from higher organic accumulation under the tree as compared to the open plot which in turn increases water holding capacity of the soil. Similarly, both moisture content and bulk density significantly varied under *A. tortilis*. The lower BD under the canopy could be due to high differences in organic matter levels (Tables 2). Contrary to this finding, Manjiru et al. (2014) reported non-significant variation of moisture content between open field and under canopy of *F. albida* and *Croton macrostachyus* trees in southern Ethiopia. It is well known that incorporation of organic matter in soil improves physical (aggregate stability, bulk density and water retention) and biological properties (nutrients availability and cation exchange capacity) of soils. This observation agrees with that of Manjiru et al. (2014) which show a significant difference in bulk density along radial distance from *F. albida* and *C. macrostachyus* trees in southern Ethiopia.

Soil pH and electrical conductivity

The analysis of variance for soil pH revealed that under both selected tree species, soil pH was lower than in the open field. The lower pH value under the canopy could be attributed to accumulation of organic matter under the trees through litter fall and root decay. In line with this

Table 4. Organic carbon total, nitrogen and available phosphorus as influenced by the trees.

Tree species	Radius	Tuka			Langano		
		OC	TN	Av. P	OC	TN	Av. P
Faidherbia	1.35	5.49	0.43 [a]	14.85 [a]	5.33 [a]	0.39 [a]	14.54
	3.35	4.95	0.39 [a]	14.21 [a]	3.76 [b]	0.44 [a]	12.89
	26.35	4.58	0.28 [b]	12.01 [b]	3.98 [b]	0.23 [b]	12.47
	CV %	14.75	17.75	8.86	17.43	24.14	9.60
	LSD %	1.18	0.10	1.94	1.21	0.14	2.04
Tortilis	1.35	4.99 [a]	0.42 [a]	14.70 [a]	5.43 [a]	0.54 [a]	15.34 [a]
	3.35	5.10 [a]	0.40 [a]	13.61 [a]	4.69 [ab]	0.38 [b]	14.15 [a]
	26.35	3.41 [b]	0.26 [b]	11.91 [b]	3.78 [b]	0.28 [c]	12.72 [b]
	CV %	21.07	21.36	6.38	18.44	13.85	5.44
	LSD %	1.52	0.12	1.37	1.37	0.09	1.23

Table 5. Effect of *F. albida* and *A. tortilis* on CEC and exchangeable bases along radius of trees.

Tree species	Radius	Tuka					Langano				
		CEC	Ca	Mg	Na	K	CEC	Ca	Mg	Na	K
Faidherbia	1.35	30.15 [a]	17.124 [a]	6.93 [a]	1.39	1.93	29.68 [a]	13.48 [a]	7.42 [a]	1.19	1.50
	3.35	29.47 [a]	16.679 [a]	6.17 [a]	1.33	1.71	29.82 [a]	11.93 [a]	5.95 [b]	1.13	1.20
	26.35	23.99 [b]	12.56 [b]	3.72 [b]	1.25	1.46	25.08 [b]	8.52 [b]	4.88 [c]	1.11	1.14
	CV %	10.81	9.35	15.58	25.32	37.90	8.83	16.18	7.78	7.73	18.02
	LSD %	4.82	2.31	1.40	0.53	1.03	3.98	2.93	0.76	0.14	0.37
Tortilis	1.35	32.05 [a]	19.37 [a]	5.86	1.48	1.51	26.79	11.18 [a]	6.38	1.41	1.51
	3.35	28.19 [b]	19.06 [a]	4.76	1.31	1.94	27.00	11.03 [a]	5.80	1.21	1.65
	26.35	23.56 [c]	12.31 [b]	4.65	1.33	1.90	25.95	8.26 [b]	4.94	1.39	1.54
	CV %	7.23	16.22	15.78	15.12	19.83	7.24	13.27	13.03	23.82	20.59
	LSD %	3.2295	4.3894	1.28	0.33	0.57	3.0783	2.1556	1.1896	0.5092	0.5171

finding, Kahi et al. (2009) reported significant difference ($P<0.05$) in pH between the soils within and outside the canopies of both trees, with a higher pH in the open cultivated land than under the canopy areas. Electrical conductivity was not affected by tree species at both locations. Contrary to this finding, Hailemariam et al. (2010) reported higher EC value under the canopy than the open field of *B. aegyptica* at Limat site in northern Ethiopia.

Soil organic carbon, total nitrogen and available phosphorus

The three nutrients were higher under the canopies of the scattered *F. albida* and *A.tortilis* tree species and all showed a decreasing trend with increasing distances from the base of the tree towards the open field (Table 4). It is due to the fact that, the higher organic carbon, total nitrogen and available phosphorus under the canopies as compared to open field can be attributed to the decomposition of accumulated organic matter from litter fall or due to the higher organic input from fine root degradation. Higher concentration of available phosphorus under the canopy of *F. albida* and *A. tortilis* might be due to the release of available organic phosphorus during the decomposition of organic matter and higher microbial population stimulated by organic matter input which supported phosphorus solubilisation from fixation. This result confirms the finding of Manjiru et al. (2014) who reported significant difference in available soil phosphorus with radial distance from tree base under *F. albida* and *A. tortilis* in southern Ethiopia.

Cation exchange capacity and exchangeable bases (Ca, Mg, Na and K)

The means of CEC, Ca and Mg were reduced from 30.15 to 23.99, 17.12 to 12.56 and 6.93 to 3.72 under the canopy of *F. albida* for open land, respectively at Tuka location and the same is true under *A. tortilis*. The cation exchange capacity was higher under tree canopies as compared to open grassland sites, as studies elsewhere showed (Abdallah et al., 2012). The result depicts the trees influence with added organic matter to attain higher CEC values at their inner crown radii. The amount of cations in the soils decreased gradually and significantly (P<0.05) as the distance from the tree trunk increased. This could be due to the high accumulation of litter under the tree canopies as the cations are released when the accumulated litters from the canopies of the trees undergo microbial decomposition followed by mineralization. As a result, the amount of exchangeable cations would be higher under tree canopies than the open field. Kindu et al. (2009) also reported that the content of K, Ca and Mg varied in distant horizontal positions, that is, it decreased from the closest to the middle and distant positions of the soil under *Hagenia abyssinica, Senecio gigas and Chamaecytisus palmensis* trees.

CONCLUSION AND RECOMMENDATIONS

This study was conducted to evaluate the effect of *F. albida* and *A. tortilis* on soil physico-chemical properties in Bora district Central Rift Valley, at Tuka and Langano kebeles. Understanding species-specific difference in tree soil interactions has important and immediate interest to farmers and agro-foresters concerned with maintaining or increasing the productivity of the soil. The study revealed that, the indigenous parkland agroforestry practices using *F. albida* and *A. tortilis* trees improve soil fertility in Dugda woreda, Central Rift Valley of Ethiopia. The findings suggest that both tree species can be incorporated into annual cropping systems to improve soil fertility which in turn improves crop productivities. Trees improve soil nutrient content and water holding capacity of the soil with addition of organic material through litter fall. Therefore, due to mineralization of the organic matter added, the soil nutrient (OC, TN, available P, cation exchange capacity and exchangeable bases) was higher under the canopy of the two trees, so it is very important to incorporate both *F. albida* and *A. tortilis* in the farmland. In general, park land agroforestry system is very important in soil fertility management, especially for poor farmers, in order to boost their productivity and enhance green agriculture approach of the country.

The following are recommended: (1) Farmers knowledge improvement on importance of *F. albida* and *A. tortilis* for soil fertility management and improvement of crop productivity because, most farmers clear the trees from their farm completely rather than using another technology like appropriate pruning. (2) Further research on *F. albida* and *A. tortilis* regarding their age class, should be done because, very old and large canopy of these trees increases only biomass but reduce yields of wheat grown under it as reported by district expert and field visit. (3) Another study on confirmation and validation is important to substantiate the findings of the current study and offer the findings to the policymakers in order to enhance parkland agroforestry system

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Abbreviations: ANOVA, Analysis of variance; **Av. PA,** available phosphorus; **BD,** bulk density; **CEC,** cation exchange capacity; **CV,** coefficient of variation; **Exa,** exchangeable; **EC,** electrical conductivity; **GLM,** general linear model; **ICRAF,** International Center for Research in Agroforestry; **LSD,** list significance difference; **MC,** moisture content; **SAS,** statistical analysis software; **RCBD,** randomized complete block design; **OC,** organic carbon; **TN,** total nitrogen.

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