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Evaluation of the effect of *Ficus thonningii* (blume) on soil physicochemical properties in Ahferom district of Tigray, Ethiopia

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A study to evaluate the effect of *Ficus thonningii* (Blume) on soil physicochemical properties was conducted in Ahferom district of Tigray, Ethiopia. For the soil physico-chemical property study, two factors (distance from the tree trunk and soil depth from the ground level) arranged in randomized complete block design (RCBD) with six replications was involved. The distance factor had three levels viz. at half of the canopy radius under the tree, canopy edge (radius of the canopy) and at three times canopy radius away from the trunk outside the canopy. The depth factor had two levels viz. surface (0 - 15 cm) and subsurface (15 - 30 cm) soil layers. Data were collected on soil physicochemical properties viz. soil texture, bulk density, moisture content, soil N, soil P and soil K, %OC, pH and electrical conductivity (EC). The collected data were subjected to ANOVA using the general linear model of SAS. Results of soil physicochemical properties revealed that except for soil texture, the studied soil physicochemical properties (soil bulk density, moisture content, soil N, soil P, soil K, %OC, pH, EC) were enhanced under *F. thonningii* canopy zone as compared to outside canopy zone. Hence, retention and planting of *F. thonningii* is recommended. The N and P stocks of soils under and away the canopy of *F. thonningii* are above the recommended range for optimum growth of most crops while K stock is rated low for optimal crop growth. Due to the deficient levels of soil K, sustainable crop production in the district requires supplementary application of K fertilizers.

Key words: Soil texture, Nitrogen, Phosphorus, Potassium, carbon stock, bulk density.

INTRODUCTION

Ethiopia faces high rates of deforestation (Kindeya, 2004). Vegetative cover has dwindled and soil fertility and productivity have declined. In some parts of northern Ethiopia, the land has been completely degraded and is no longer capable of supporting human population. Badege and Abdu (2003) reported that 94% of the Ethiopian population relies on wood based and biomass fuel for household energy. Scarcity of firewood has become acute in many parts of the country causing a continuous rise in prices, thus increasing the economic burden on the household budget. As a result, animal dung and crop residues are increasingly being used for household fuel rather than being added to the soil to improve soil fertility, thus further exacerbating the

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problems of environmental degradation. To tackle the multifaceted challenges of Ethiopian agriculture, there are different options in which agroforestry is one (Neufeldt et al., 2009). However, agroforestry should not be taken as universal remedy for all land use problems, but it may be considered as a potential alternative to some of the wasteful land use practices that exist in the country (Badege and Abdu, 2003).

Kindeya (2004) argued that proposed agroforestry options should start with the species to which farmers are most accustomed to. These would be the native multipurpose trees that have evolved under smallholder environmental and socioeconomic conditions. Hence, strategies to improve smallholder crop production should begin by investigating the merits and demerits of existing indigenous farming systems as knowledge of the contribution of trees to soil fertility is vital to encouraging tree planting by individual farmers (Jiregna et al., 2005). Studies by Kindeya (2004) and Teklay and Malmer (2004) have also revealed that the existence of indigenous tree species with great untapped potential for growing with agricultural crops.

Against this background, to gain immense benefits like fuel wood, food, shade, fodder, medicine, ecological services including soil fertility and microclimate amelioration from trees, farmers in Ahferom district of Tigray Region plant different indigenous and exotic trees. Among the indigenous species grown and managed by farmers in the district is the drought tolerant tree, *Ficus tonningii*; a multipurpose indigenous tree that easily propagates and provides medicine, wood, cash and year round fodder for animals.

Though *F. thonninigii is* widely grown in Ahferom and used as fodder in times of feed shortage in the district, it is still among the indigenous tree species least considered in agroforestry development practices in most parts of the country. Its fodder potential and nutritive value, its interaction with other crops in the farmland and its effects on soil physicochemical properties have not been scientifically quantified and documented.

Therefore, based on the foregoing information, this initiative was taken to investigate the effects of *F. thonningii* on some physicochemical properties of the soil under and away from its canopy at different soil layers in Ahferom district of Tigray, Ethiopia.

MATERIALS AND METHODS

Description of the study site

The study was conducted in central zone of Tigray Regional State, Ethiopia, in *Ahferom* district. The district has a geographical location of 14° 07' to 14°39' N and 38°57' to 39° 18' E. It is situated at 960 km north of the capital Addis Ababa and 181 km North West of *Mekelle* town, the regional capital. The district is characterized by rugged topography with altitude ranging from 1400 to 3200 m (BoARD, 2010). The rainfall distribution of the study area is unimodal, mostly falling within the months of June to September, exhibiting high temporal and spatial variability. The annual rainfall ranges from 450 to 650 mm, and with average annual temperature range of 25 to 34°C. The dominant soil types in the district vary in ranges of clay, loam, sandy loam and silty loam (BoARD, 2010).

Experimental details

There were two factors involved in the experiment, viz. distance from the tree trunk and depth from the ground level. The distance factor had three different treatment levels; at half of the canopy radius under the tree, canopy edge (radius of the canopy) and at three times canopy radius away from the trunk outside the canopy as control following the procedure by Jiregna et al. (2005) and Pandey et al. (2000). And the depth factor had two levels: Surface soil layer (at 0 to 15 cm) depth representing the top soil and the other lower layer (at 15 to 30 cm) depth to represent the subsurface soil layer. The design employed had a 3 * 2 factorial arrangement of treatments in randomized complete block design (RCBD) replicated six times, totalling 3 * 2 * 6 = 36 experimental units or samples.

Description of the studied trees for soil physicochemical property

Six isolated individual *F. thonningii* trees, outside the influence of other trees, were randomly selected for physicochemical attribute study. The trees were sampled from a locality within the same agroecology. Each individual tree was considered as a replicate. Each tree's canopy area was determined and divided into radial transects. Besides, tree height, canopy cover as area of tree influence and trunk diameter measurements were done on the six mature *F. thonningii* trees that were used for soil physicochemical property attribute study. The studied *F. thonningii* trees had mean trunk diameter of 42.67 cm and mean height of 11.25 m. The canopy diameter cover ranged from 8.00 to 10.75 m with mean canopy diameter cover of 9.28 m. The potential area of influence of each *F. thonningii* tree ranged from 50.24 to 90.72 m^2 with mean area of influence of 68.41 m^2.

Soil sampling

Four transects extending from the base of the tree trunk were laid out in East, West, North and South directions. From the four transects, soil samples were taken at three distances (at half of the canopy radius under the tree, canopy edge and at three times canopy radius away from the trunk outside the canopy) from the tree base and from two different depths (0 to 15 and 15 to 30 cm) of each respective distances with six replications. Overall there were 3 × 2 × 6 × 4 = 144 soil sub samples; 72 for the surface soil and 72 for the subsurface.

Samples within the same radial distances and same depths which represents sub samples, were pooled or bulked to achieve a composite sample; in total 18 composite sample out of the 72 sub samples from the upper 0 to 15 cm and 18 composite samples out of 72 sub samples from the lower 15 to 30 cm subsoil layer were collected, that is, four samples within same radial distance and same depth were pooled to form a single composite sample. And to avoid contamination between the layers while taking the soil samples, a 40 cm × 40 cm pit was dug and then the soil samples were taken by scratching the wall of the soil profile for the respective depth. First, a soil sub sample was taken for the 15 to 30 cm then for the 0 to 15 cm layer. By bulking the four sub samples and quartering a composite sample of 1 kg was prepared for the chemical and physical analysis purpose of soil properties: But for bulk density and moisture measurement a separate soil sample with core sampler was collected.

Table 1. Soil physical fertility parameters as influenced by radial distance and depth in Ahferom district.

Soil fertility parameter	Soil depth (cm)	Radial distance			Overall
		Mid canopy	Canopy edge	Canopy gap	
% Sand	0 - 15	19.00±2.48	21.83±3.02	24.00±2.29	21.61±1.50[a]
	15 - 30	21.67±1.76	22.67±2.28	24.33±2.11	22.89±1.15[a]
	Overall	20.33±1.50[A]	22.25±1.81[A]	24.17±1.47[A]	
% Silt	0 - 15	36.33±4.34	36.00±50	34.17±5.35	35.50±2.68[a]
	15 - 30	35.67±4.82	35.67±4.52	34.17±3.95	35.17±2.42[a]
	Overall	36.00±3.09[A]	35.83±3.21[A]	34.17±3.17[A]	
% Clay	0 - 15	44.67±5.19	42.17±5.76	41.83±6.62	42.89±3.20[a]
	15 - 30	42.67±5.53	41.67±5.70	41.5±5.25	41.94±2.98[a]
	Overall	43.67±3.62[A]	41.92±3.87[A]	41.67±4.03[A]	
BD ($g\ cm^{-3}$)	0 - 15	1.12±0.02	1.25±0.024	1.38±0.03	1.25±0.03[b]
	15 - 30	1.18±0.02	1.34±0.02	1.44±0.03	1.32±0.03[a]
	Overall	1.15±0.02[C]	1.29±0.02[B]	1.41±0.02[A]	
% MC	0 - 15	22.80±0.78	19.99±0.76	17.95±0.52	20.25±0.61[a]
	15 - 30	21.22±0.75	19.11±0.66	15.91±0.40	18.75±0.63[b]
	Overall	22.01±0.57[A]	19.55±0.50[B]	16.93±0.44[C]	

BD = Bulk density; MC = moisture content. Means along the same column (soil depth) and rows (radial distance) with different superscripts are significantly different (P<0.05); Values are Mean ± SEM.

Soil analysis and laboratory methods

Before chemical analysis, the collected samples were first air dried, then ground and sieved to separate the <2 mm fraction at Shire Soil Laboratory. Then the soil samples were delivered to National Soil Testing Laboratory Addis Ababa and were analyzed for organic carbon content by wet oxidation method of Walkley and Black (Schnitzer 1982); total nitrogen by the Kjeldahl method (Bremner and Mulvaney, 1982). Available P was determined by Olsen method (Olsen et al., 1954); Available K by neutral ammonium acetate extraction (Merwin and Peach, 1951); soil pH and EC was determined in a 1:2.5 soil to water suspension (Jackson, 1973); texture was determined by the Hydrometer (Bouyoucos); soil moisture content by oven drying at 105℃ and bulk density by weighing oven dried (105℃) soil samples with known volume (Brady and Weil, 2002).

After chemical analysis, soil BD, soil depths and concentration[1] of soil nutrients (Carbon, Phosphorus and Potassium) were used to calculate the soil nutrients from concentration basis to an amount or nutrient stock basis (soil C, soil P and soil K stocks) according to the procedure followed by Enideg (2008).

Statistical analysis

The data collected were subjected to two way analysis of variance (ANOVA) using the General Linear Model (GLM) procedures of SAS (SAS, 2002). Comparison of treatment means was performed using Fisher's Least Significant Difference test at P < 0.05 probability level. Unless otherwise stated, any mention of significance is based on the 5% level. Besides, Pearson correlation analyses were performed to reveal the relationships between organic carbon, soil depth and distance from the tree with other soil physicochemical properties.

RESULTS AND DISCUSSION

Soil physical properties

Soil texture

Soil texture, as factor that might affect soil physicochemical and to some extent soil biological properties, was not significantly affected (Table 1) both laterally as function of distance from tree trunk and vertically by the presence of *F. thonningii* trees. The non significant differences in the mean proportions of sand, silt and clay fractions between the soils under the canopies of *F. thonninigii* and in the open farmland suggests that the soils, are texturally similar, being clay for the surface and clay loam for the subsurface and having been derived from the same parent material, under the same climate, and similar topography and vegetation cover. Hence, any observed difference between the soil under the tree canopies and in the open farmland is most likely due to the effects of the trees on the soil, rather than to mineralogical or textural differences between the soils. And it is discussed as it is induced by the presence of *F. thonningii* trees in the landscape.

[1] Nutrient concentration in this study refers to the amount of nutrients in %, ppm, mg per g, mg per kg etc.

Soil bulk density (BD)

Comparisons of soil BD showed that there was a highly significant ($P<0.0001$) variation of BD with increasing distance from tree and a significant ($P=0.0002$) difference with soil depth (Table 1). However, the interaction effect of distance from tree trunk and soil depth was not significant ($P>0.05$). The surface and subsurface soil under canopy were 14.31 and 12.37% lower in density than the respective depth of soil outside the canopy. The surface soils under canopy were 5.7% lower than the subsurface soil under canopy and the surface soil outside canopy were 3.83% lower than the subsurface soil outside the canopy.

BD findings for this study are in concert with the findings of other scholars (Aweto and Dikinya, 2003; Tadesse et al., 2000; Pandey et al., 2000). For instance, results of Tadesse et al. (2000) on BD under and outside *Millettia* trees revealed that both the BD of the surface soils (0.61 g cm^{-3}) and the subsurface soils (0.76 g cm^{-3}) under the trees were lower than the bulk density of the surface soils (0.69 g cm^{-3}) and the subsurface soils (0.80 g cm^{-3}) in the open areas. Pandey et al. (2000) also reported lower BD under the canopy of *A. nilotica* in a traditional agroforestry system in central India, while Aweto and Dikinya (2003) reported lower BD under the canopies of *P. africanum* and *C. apiculatum* as compared to open rangeland from Botswana. Moreover, Jiregna et al. (2005) also reported lower BD levels under *Cordia africana* and *Croton macrostachyus* canopies as compared to open farm while Enideg (2008) reported though not significantly higher bulk density outside the canopy of *F. thonningii* as compared to the canopy zone in Ethiopia.

Lower soil BD under the tree species' canopies is presumably due to the effect of litter addition to the soil. This has resulted from organic matter build up in the soil under the canopies relative to levels in soil outside the canopies. Also, the higher concentration of tree roots near the base of the trees may have had the effect of loosening the soil, thereby reducing soil BD. Furthermore, the soil outside the tree canopies dries out more, being exposed to direct solar radiation. This not only accelerates thermally induced soil organic matter decomposition, but results in the shrinking of organic matter and clay colloids, thereby making the soil more compact.

Soil moisture content (MC)

The analysis of variance for soil MC revealed that soil MC was highly significantly ($P<0.0001$) affected by distance from the tree trunk and significantly ($P=0.0002$) affected by soil depth (Table 1). However, the interaction effects of soil depth and distance from the tree trunk was not statistically significant ($P>0.05$). The surface and subsurface soils under canopy were 19.19 and 26.00% higher than the surface and subsurface soils outside the canopy zone. Besides, the surface soil under canopy zone were 6.12% higher than the subsurface soil under canopy zone while the surface soil outside the canopy zone were 12.87% higher than the subsurface soil outside the canopy zone.

Results of the present study on percent soil MC corroborate with the findings of Tadesse (2000). Results of percent soil MC under and outside *Millettia* trees found by the authors revealed that both the MC of the surface soils (19.60%) and the subsurface soils (10.00%) under the trees were higher than the MC of the surface soils (15.90%) and the subsurface soils (8.90%) in the open areas. Besides, Abebe (2006) reported a significant variation in MC that varies with tree species and with geographical location of tree species from the Highland of Harargie in Ethiopia.

The relatively higher soil MC under *F. thonningii* canopy as compared to soil MC beyond canopy and higher surface soil as compared to subsurface soils might be due to variation in Soil organic matter (SOM). SOM makes the soil to retain water by increasing its surface area and improving the soil structure. It might be also due to the shading effect of the tree. Generally, the soil outside the tree canopies might dry out more, being exposed to direct solar radiation whereas the shade provided by the trees of *F. thonningii* would have enhanced the MC under their canopy.

Soil chemical properties

Soil pH

The analysis of variance revealed a statistically significant difference in soil pH with distance ($P<0.0001$) from tree trunk and soil depth ($P=0.0063$) (Table 2). However, the interaction effect of soil depth and distance from tree trunk interaction for soil pH was not significant ($P=0.8318$). Soil pH showed an increasing trend with increasing distance from tree trunk and increasing soil depth. The mean soil pH values of the surface and subsurface soil beyond the canopy zone were 4.92 and 4.79% higher than the respective soil depths under canopy zone. Moreover, the mean soil pH of the subsurface soil of the under canopy and beyond canopy were 1.52 and 1.40% higher than the surface soil of their immediate soil depths. Generally, lower mean soil pH values were reported for soils under the tree canopy as compared to soils outside canopy and for the surface soil as compared to their immediate subsurface soils. The generally lower soil pH values under canopy of *F. thonningii* as compared to canopy gap might be due to several mechanisms that release H^+ ions, such as soil base cation uptake (or depletion) by the tree, decomposition of organic matter to organic acids and

Table 2. Soil chemical fertility parameters as influenced by radial distance and depth in Ahferom district.

Soil fertility parameter	Depth (cm)	Radial Distance			Overall
		Mid canopy	Canopy edge	Canopy gap	
pH	0 - 15	6.6±0.04	6.80±0.07	7.05±0.07	6.82±0.06^{b}
	15 - 30	6.7±0.04	6.93±0.06	7.12±0.05	6.92±0.05^{a}
	Overall	6.65±0.03^{C}	6.87±0.05^{B}	7.08±0.04^{A}	
EC (dSm^{-1})	0 - 15	0.03±0.00	0.05±0.00	0.07±0.01	0.05±0.01^{b}
	15 - 30	0.04±0.00	0.06±0.00	0.10±0.01	0.06±0.01^{a}
	Overall	0.04±0.00^{C}	0.05±0.00^{B}	0.08±.01^{A}	
%N	0 - 15	0.22±0.02	0.17±0.01	0.14±0.01	0.17±0.01^{a}
	15 - 30	0.18±0.01	0.15±0.01	0.13±0.01	0.15±0.01^{b}
	Overall	0.20±0.01^{A}	0.16±0.01^{B}	0.13±0.01^{C}	
%OC	0 - 15	1.84±0.09	1.29±0.04	1.02±0.05	1.38±0.09^{a}
	15 - 30	1.41±0.03	1.10±0.05	0.93±0.06	1.15±0.05^{b}
	Overall	1.62±0.08^{A}	1.20±0.04^{B}	0.97±0.04^{C}	
C/N	0 - 15	8.85±0.47	7.73±0.20	7.30±0.17	7.96±0.23^{a}
	15 - 30	7.92±0.29	7.33±0.10	7.43±0.19	7.56±0.13^{b}
	Overall	8.38±0.30^{A}	7.53±0.12^{B}	7.37±0.12^{B}	
P (ppm)	0 - 15	21.10±0.91	20.17±0.79	15.34±0.70	18.87±0.75^{a}
	15 - 30	20.39±0.73	15.55±0.67	14.23±0.70	16.72±0.75^{b}
	Overall	20.75±0.57^{A}	17.86±0.85^{B}	14.79±0.50^{C}	
K (ppm)	0 - 15	51.5±1.71	49.83±1.51	33±2.71	44.78±2.31^{a}
	15 - 30	50.67±1.67	34±2.67	31.5±2.74	38.72±2.45^{b}
	Overall	51.08±1.16^{A}	41.91±2.80^{B}	32.25±1.85^{C}	

Means along the same column (soil depth) and rows (radial distance) with different superscripts are significantly different ($P<0.05$); Values are Mean ± SEM.

CO_2, root respiration and nitrification. Rhodes (1997) suggested that increased accumulation of aboveground biomass and associated cation uptake by the tree component of agroforestry systems as possibly one of the causes for decreased pH in soils.

According to FAI (1977), soils having pH value in the range 6.50 to 8.70 are considered normal, that do not require treatment, and are optimum for most crops. The mean soil pH of the soil under canopy of *F. thonningii* ranged from 6.6 to 6.93 while the soil pH of the soil beyond canopy ranged from 7.05 to 7.12. As the soil pH under canopy and outside canopy of *F. thonningii* are within the normal recommended range, the soils can support most agricultural crops.

Findings of this research are in agreement with Pandey et al. (2000) and Hailemariam et al. (2010). Pandey et al. (2000) observed soil pH value that differed among canopy positions ($P<0.0001$) and soil depths ($P<0.0001$), and soil pH, averaged across all the depths, under mid canopy was 7.71% lower compared to that under canopy gap, while Hailemariam et al. (2010) found, lower pH value under canopy (7.96) than beyond canopy (8.22) showing a decrease of 3.10% under *Balanites aegyptiaca* at Goblel and Korbebite sites from Northern Ethiopia. From a study of single tree influence on soil properties in forest ecosystem, Rhodes (1997) noticed a lower pH that ranges from 4.90 to 6.10 and 5.10 to 6.80 under mid canopy and canopy edge respectively to 5.50 to 6.90 beyond canopy under *Pseudotsuga menziesii*, *Pinus ponderosa, Libocedrus decurrens* which is also in line with the present study findings.

Contrary to the present study, other researchers (Tadesse et al., 2000; Jiregna et al., 2005) reported higher pH values for both surface and subsurface soils under tree canopy as compared to outside canopy zone. Tadesse et al. (2000) reported, though not significant, higher pH value under canopy of *Millettia* as compared to open fields. Moreover, Jiregna et al. (2005) from their study on trees on farms and their contribution to soil fertility parameters in Badessa, Eastern Ethiopia reported that the presence of isolated *C. africana* and *C. macrostachyus* trees on farms in Badessa area had no significant influence on pH.

Soil electrical conductivity (EC)

The analysis of variance for soil EC revealed that soil EC were significantly affected by distance (P<0.0001) from tree trunk and soil depth (P=0.0010) (Table 2). Whereas EC were not significantly (P=0.1144) affected by the interaction of distance from tree trunk and soil depth. The surface soil at canopy gap were 1.78 times higher than the surface soil at canopy zone while the subsurface soil at canopy gap were 1.88 times higher than the subsurface soil under canopy zone. The subsurface soil under canopy was 1.20 times higher than immediate surface soil whereas the subsurface soil under canopy gap was 1.27 times higher than the immediate surface soil. The generally lower soil EC under tree canopies as compared to soils outside canopy might be due to the increased accumulation of aboveground biomass and associated cation uptake by the *F. thonningii* tree.

FAI (1977) suggested that soils with EC value of below 0.80 dS m^{-1} are considered normal and suitable for all crop types. The EC soils under canopy of *F. thonningii* ranged from 0.03 to 0.06 dS m^{-1} while that of beyond canopy ranged from 0.07 to 0.10 dS m^{-1}. Hence, the soils under and outside the canopy of *F. thonningii* are suitable for most crops.

The findings of the current study seem to be in agreement with Bhojvaiw et al. (1996) that conducted a research on reclaiming sodic soils for wheat production by *Prosopis juliflora* and found increased soil EC under *P. juliflora* as compared to that of the non sodic farm soil in India.

Soil organic carbon (SOC) and total soil carbon stock (SCS)

SOC was significantly affected by both the main effects (P<0.0001) of distance from tree trunk and soil depth and their interactions (P=0.0006) (Table 2). SOC decreased with increasing distance from tree trunk and with increasing soil depth. The surface SOC of canopy zone was 1.54 times higher than the respective soil subsurface outside the canopy zone while the SOC of subsurface soil were 1.35 times higher than the subsurface soil of outside canopy zone. Similarly, SOC of the surface soil under canopy was 25% higher than the immediate subsurface soil. Besides, SOC of the subsurface soil under canopy was 9.14% more than the immediate subsurface soil. The high SOC and carbon stock under canopy as compared to soil beyond canopy might be due to the organic matter inputs from fine root degeneration and litter fall. The SOC of the soil under canopy of *F. thonningii* of the present study ranged from 1.10 to 1.84% under canopy zone and from 0.93 to 1.02% under canopy gap. Hence, the soils under canopy zone and the surface soil outside canopy zone can be categorized under high SOC range whereas the subsurface soil outside canopy is in the medium range of SOC value according to Bhandari and Tripathi (1979 cited in Agena, 2009).

For the same species, Enideg (2008) reported SOC of surface and subsurface soils under canopy zone higher by 46.69 and 23.01%, respectively as compared to the surface and subsurface soil beyond the canopy. Many authors also reported a higher level of SOC concentration under the canopy of trees as compared to beyond the canopy and a higher level of SOC concentration of surface soils compared to their immediate subsurface soil for other species which is in concert with the present investigation. For instance, Abebe (1998) from his evaluation of the contribution of scattered *C. africana* trees to soil properties in cropland and rangeland ecosystems in Western Oromia, Ethiopia found soil organic carbon concentration of the top soil under canopy of *C. africana* in both the rangeland and cropland ecosystems that were respectively 35 and 43% higher than their immediate subsurface soil. Besides, he also found greater by 16, 17 and 6% SOC under canopy at a distance of 0.5, 2 and 4 m as compared to 15 m distance in the open area beyond canopy. Similarly, from their study on *Millettia ferruginea* impacts on soil fertility Tadesse et al. (2000) observed significantly higher SOC in the surface and subsurface soil beneath canopy as compared to the open field outside canopy of *Millettia*.

Soil carbon stock[2] (SCS) of the surface soil at the mid canopy and canopy edge were 46.51 and 14.66% higher than the surface SCS beyond canopy while the subsurface SCS of the mid canopy and canopy edge were 29.00 and 10.46% higher than their respective subsurface SCS beyond canopy (Figure 1).

SCS of surface (0 to 15 cm) and subsurface (15 to 30 cm) soil layers were done separately and the data were later pooled to represent SCS (Mg ha^{-1}) of the 0 to 30 cm soil layer. The results thus obtained are given in Figure 2. The SCS of the present study ranged from 22063 to 30812 kg ha^{-1} for the soils under tree canopy and from 19974 to 21030 Kg ha^{-1} for the soils outside tree canopy. The results of the pooled SCS revealed that the SCS of the 0 to 30 cm under mid canopy and canopy edge respectively were 38 and 12.63% higher than the SCS of the 0 to 30 cm under canopy gap. Comparing the SCS of the present study (19974 to 30812 kg ha^{-1}) with those reported by Enideg (2008) for the same species, the SCS of the present study was higher. Enideg (2008) reported a SCS that ranged from around 13000 to 26000 kg ha^{-1}, this variation in SCS might be the soil depth (15 cm of this against 10 cm of Enideg) considered.

Soil nitrogen (N)

Soil N concentration also showed significant variation

[2] Nutrient stock refers to the amount of nutrients on hectare basis

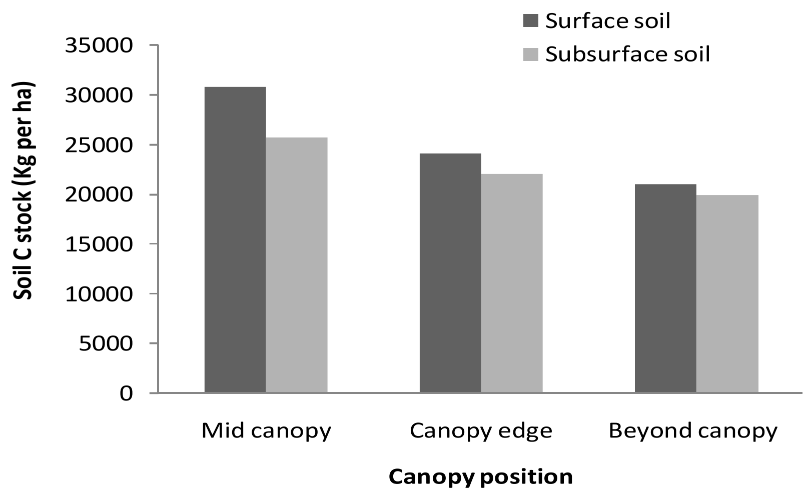

Figure 1. Soil carbon stock as influenced by canopy positions and soil depths.

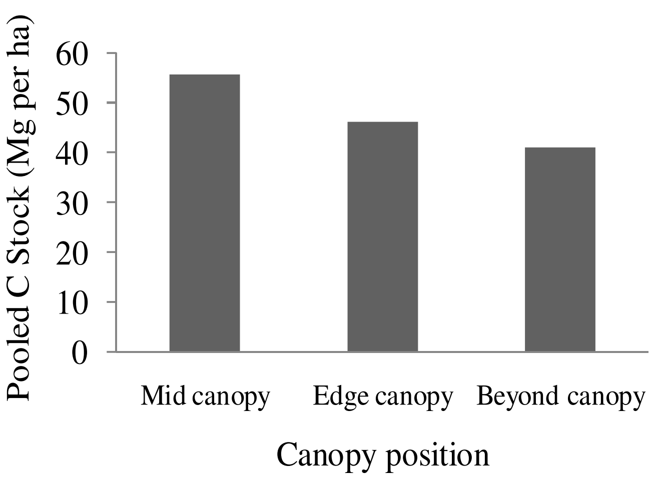

Figure 2. Pooled soil C stock at the 0 to 30 cm layer as influenced by canopy positions.

between soil depths and among the different distances from tree trunk (P<0.0001 and P<0.0001, respectively) (Table 2). However, soil N was not significantly (P=0.2336) affected by the interaction of soil depth and distance from tree trunk. Soil N concentration showed decreasing trend with increasing distance from tree and with increasing soil depth. The surface soil under canopy was 36.91% more in soil N concentration than the respective soil outside tree canopy. Likewise, the subsurface soil N concentration under tree canopy was 32% higher than the soil outside canopy zone. Moreover, the surface soil under canopy was 16.16% higher than the immediate subsurface soil under canopy while the surface soil outside canopy zone was 12% higher than its immediate subsurface soil. The higher total soil N accumulation under canopy zone as compared to outside canopy zone of the present study might be attributed to high accumulation of organic matter under tree canopies. Reports of the present study agree with the findings of Enideg (2008) and Jiregna et al. (2005) who found higher level of soil total N under canopy as compared to the open field. The former author reported an increase of in average total nitrogen under *F. thonningii* canopy by 85% in the surface soil and by 63% in the subsurface soil depths as compared to soils in the open pasture. Yet, the latter authors reported total soil N of surface and subsurface soils higher under tree canopies by 22 to 26% for *C. africana* and 12 to 17% *C. macrostachyus* than the corresponding soils away from the tree canopies. Besides, Tadesse et al. (2000) found significantly higher total soil N of both surface and subsurface soil under the canopy of *Millettia* as compared to open area outside the canopy zone of *Millettia*.

Carbon to nitrogen ratio (C/N)

The concentration of soil organic carbon to soil nitrogen (C/N) ratio differed significantly for all the distances (P=0.0002) from tree trunk and soil depths (P=0.0375) but it did not differ for the interaction (P=0.0761) of distance from tree trunk and soil depths (Table 2). The soil C/N ratio decreased with increasing distance from tree trunk and increasing soil depth. The surface and subsurface soil C/N under canopy were 13.58 and 2.58% higher than the surface and subsurface soil C/N outside canopy, respectively. Besides, the surface soil C/N under canopy and outside canopy were 8.74% higher and 1.83% lower than their immediate subsurface soils. The higher C/N ratio under canopy zone as compared to outside canopy zone of the present study might be attributed to high accumulations of organic matter (OM) under tree canopies through litter fall and root degeneration.

Table 3. Correlation of selected soil physical and chemical properties with organic carbon, distance from the trees and soil depth in Ahferom district.

Property	R		
	Organic carbon	**Distance**	**Depth**
Moisture content	0.82**	- 0.78**	- 0.28^{ns}
Bulk density	- 0.85**	0.86**	0.27^{ns}
pH	- 0.65**	0.80**	0.22^{ns}
Electrical conductivity	- 0.89**	0.79**	0.27^{ns}
Nitrogen	0.91**	- 0.70**	- 0.30^{ns}
Organic carbon	-	- 0.81**	- 0.36*
C:N ratio	0.56**	- 0.52**	- 0.25^{ns}
Phosphorus	0.60**	- 0.74**	- 0.33^{ns}
Potassium	0.62**	- 0.75**	- 0.30^{ns}

*, ** and ^{ns}=significant at P<0.05, P<0.01 and non-significant at P<0.05, respectively. R=correlation coefficient.

Results of the present study are not in agreement with findings of different authors (Enideg, 2008; Tadesse et al., 2000). For instance, Enideg (2008) reported a C/N ratio that increases with increasing distance from *F. thonninigii* and with increasing soil depth. Yet, Tadesse et al. (2000) observed lower C/N ratio under *Millettia* tree than in the open areas for both the surface and the subsurface soils, despite irregularities at the canopy edges.

Soil phosphorus (P)

Soil P concentration was affected by the main effects of distance (P<0.0001) from tree trunk and soil depth (P<0.0001) and their interaction (P<0.0001) effect (Table 2). Soil P concentration decreased with increasing distance from tree trunk and increasing soil depth. The mean soil P concentration of the surface and subsurface soil under canopy were 34.56 and 26.24% higher than the respective surface and subsurface soil outside the canopy zone. Besides, the soil P concentration of surface soil under and outside tree canopy were 14.85 and 7.75% higher than their immediate subsurface soils. The higher soil P accumulation under canopy zone as compared to outside canopy zone of the present study could be due to high accumulation of OM under tree canopies.

In support to the present study, Tadesse et al. (2000) observed available soil P concentration in the surface soils that were significantly higher under the trees than in the open fields; and the surface soil values were higher than the subsurface. Whereas Enideg (2008) reported even though the average P content under canopy was 12 and 5% higher than the open pasture in the surface and subsurface soil depths respectively for the same species; there was no significant difference in P content between the soils under canopy and open pasture, contradicting the present investigation.

Soil potassium (K)

Mean soil K concentration showed a highly significant variation with increasing distance (P<0.0001) from the base of the tree trunk and soil depth (P<0.0001) and their interaction (P<0.0001) effects (Table 2). The surface soil K concentration under canopy zone was 60.00% higher than the surface soil K concentration outside canopy zone while the subsurface soil K concentration under canopy was 38.80% the subsurface soil outside canopy zone. The soil surface K concentration under canopy zone and outside canopy zone were 19.69 and 3.83% higher than the respective soil K concentration outside canopy zone. The higher soil K accumulation under canopy zone as compared to outside canopy zone of the present study could be due to high accumulation of OM under tree canopies. In support of this study Tadesse et al. (2000) reported surface soils that were all significantly higher in soil K concentration under the *Millettia* trees than in the open fields; and the surface soil K concentration values that were higher than the subsurface ones. Besides, Abebe (2006) reported that soil K that were highly significantly (P<0.01) affected by all forms of the main effects (tree species, distance from the tree, soil depth and location) and all forms of their interaction effects from Harrargie of Ethiopia for *Acacia albida, C. africana* and *C. macrostachyus* while Enideg (2008) reported similar results under canopy of *F. thonningii* from Gondar, Ethiopia.

Pearson correlation analysis of soil physicochemical properties

Simple correlation analyses were carried out for selected soil physicochemical properties with soil organic carbon, soil depth and distance away from the tree trunk (Table 3). The correlation coefficients revealed that percent SOC was positively and highly significantly correlated with

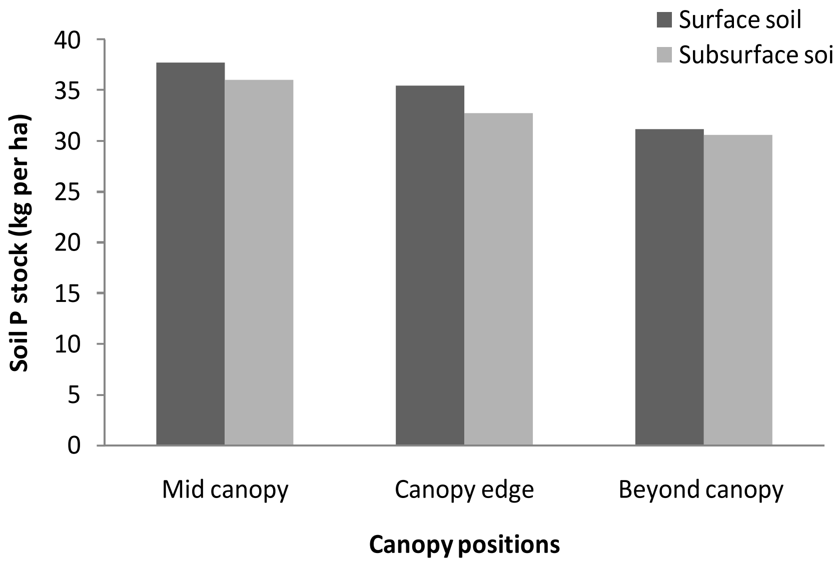

Figure 3. Soil P stock as influenced by canopy position and soil depth.

most (percent MC, C/N and soil P and soil K concentration) of the selected soil physicochemical properties except with soil BD, soil pH and EC which it correlated negatively, yet highly significantly.

The analysis of simple linear correlation coefficients revealed that there was a positive and highly significant correlation between distance from tree trunk and soil BD, soil pH and soil EC while there was a negative but highly significant correlation between distance from tree and most of the selected soil physicochemical properties viz. percent soil MC, soil N, soil OC, C to N ratio, soil P and soil K concentrations. This highly significant correlation revealed that the SOC greatly influenced important soil chemical properties. Hence, maintaining SOC of the soil may improve the important soil physicochemical properties.

Except for percent SOC, that significantly and negatively correlated with depth, the simple linear correlation coefficients revealed that all the selected soil physicochemical properties had a non-significant correlation with soil depth. Soil BD, soil pH and soil EC correlated positively with depth. Nevertheless, the rest of soil physicochemical properties, viz. MC, SOC, C/N, soil N, soil P and K soil concentration, correlated negatively with soil depth.

From his study on the importance of *F. thonningii* in soil fertility improvement in Gondar Zuria of Ethiopia, Enideg (2008) observed that soil N that had strong positive correlation ($P<0.01$) with SOC while P showed significant correlation with SOC ($P=0.01$) and soil N ($P=0.05$). From his correlation results the author revealed that P in these soils is predominantly found in organic forms not an inorganic chemical binding. Similar results were also reported by Abebe (2006) from Harargie of Ethiopia under *A. albida, C. africana* and *C. macrostachyus.*

Soil stock of macronutrients (kg/ha)

Soil phosphorus stock (Kg/ha)

Soil P stock of the soils varied from 31.19 to 37.78 Kg/ha for the surface soil while it ranged from 30.58 to 36.05 kg/ha for the subsurface (Figure 3). Soil P stock of soils under canopy ranged from 32.76 to 37.78 kg/ha while it ranged from 30.58 to 31.19 kg/ha for soils beyond canopy. The P stock of the surface soil under mid canopy and canopy edge were 21.13 and 13.63% higher than the surface soil beyond canopy. Besides, the subsurface soil under mid canopy and edge of canopy were 17.89 and 7.13%, respectively higher than the subsurface soil under canopy gap. The generally higher soil P stock under canopy as compared to way canopy could be due to higher OM accumulation under canopy.

FAI (1977) regarded soils having P stock of higher than 22.40 kg per ha to be high in P to support crop growth. Hence, the soils under study have soil P level which is above the high level required for normal crop growth.

Soil potassium stock (kg/ha)

Soil K stock of the surface soil differed from 31.19 to 37.78 kg/ha, while the soil K stock of the subsurface varied from 30.58 to 36.05 kg/ha (Figure 4). K stocks of the soils under canopy zone of the tree ranged from 73.07 to 93.20 kg/ha while it ranged from 67.86 to 70.86 kg/ha for soils outside canopy. The K stock of the surface soil under mid canopy and canopy edge were respectively 31.53 and 22.38% higher than the surface soil beyond canopy. Similarly, the subsurface soil under mid canopy and edge of canopy were 32.90 and 8.54% higher than the subsurface soil under canopy gap. Soils

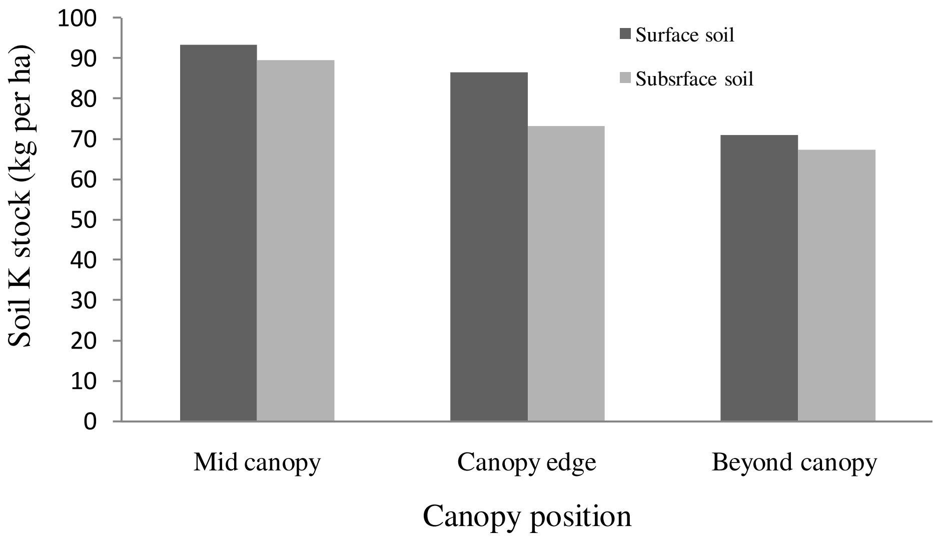

Figure 4. Soil K stock as influenced by canopy position and soil depth.

under canopy had higher level of soil K stock as compared to those outside canopy and surface soils had as well, higher level of soil K stock as compared to subsurface soils of their immediate layer. This higher level of soil K stock under canopy as compared to outside canopy could be due to the high accumulation of OM under canopy.

However, higher levels of soil K stock were reported under canopy as compared to outside canopy; all soils under study (both under and outside canopy and surface and subsurface soils) were rated as low (less than 137 kg per ha) in soil K according to FAI (1977). This trend was also evident from soils under *Tithonia diversifolia;* a plant which is rich in foliar N, P and K (Jama et al., 2000).

The soil P of the present study, however, is lower than those reported by Enideg (2008) for the same species from Gondar Zuria of Ethiopia. The author recorded soil P that ranged 864.19 to 1017.16 kg/ha for soil under canopy and from 792.85 to 847.44 kg/ha. This high variation in soil P stock could be due to the fact that he considered total P, while available P was considered in this study.

CONCLUSION AND RECOMMENDATION

F. thonningii, selected as useful multipurpose tree by farmers in the landscape, positively and significantly influenced soil nutrients to be higher via protection against leaching, translocation of nutrients from deeper to the surface layer and accumulation of litter which created a temporary nutrient pool in the surface soils under the canopies. The current study revealed that presence of *F. thonningii* trees in the land use have enhanced soil physico-chemical properties by increasing soil moisture content, %N, P, K, %OC and C/N ratio both vertically and horizontally while by lowering soil bulk density, pH and EC. However, its presence had no effect on soil texture (sand, silt and clay fractions) as texture is more related to parent material than tree influence. Hence, retention of *F. thonningii* in the farmland and grazing fields as well as its planting in degraded areas within its agro-ecological zone should be widely considered. Since N and P stock of soil under and away *F. thonningii* showed sufficient level and even above the recommended range for optimum growth of most agricultural crops, its inclusion into agricultural system can save fertilizer input cost for applying the respective nutrients. On the other hand, since K stock is rated low for optimal crop growth, sustainable crop production in the district with integration of *F. thonningii* requires application of supplementary K fertilizers.

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