Vol. 10(6), pp. 124-129, October-December 2019
DOI: 10.5897/JSSEM2019.0738
Articles Number: 4B982AC62072
ISSN: 2141-2391
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Journal of Soil Science and Environmental Management

Full Length Research Paper

Soil bulk density, soil moisture content and yield of Tef (*Eragrostis tef*) influenced by *Acacia seyal* Del canopy in Parkland agro-forestry system

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Received 18 February, 2019; Accepted 21 March 2019

The effect of *Acacia seyal* tree on soil bulk density, soil moisture content, grain and biomass yield of tef (*Eragrostis tef*) were examined on six selected comparable *A. seyal* trees on croplands. Composite soil samples (6 trees × 3 distances × 2 soil depths) were collected at three distances from the tree base (1, 2.5 and 9 m) and two soil depths (0-15 and 15-30 cm) in four radial directions. Grain and biomass yield of tef were also sampled from 1 m^2 plot at the three distances from where the soils were sampled. The result indicated that soil bulk density (BD) and soil moisture content (SMC) were significantly affected both by distance from the tree base and soil depths. Grain yield of tef and SMC was higher whereas BD was lower under the canopy of *A. seyal* than that of beyond the canopy. The reduction of grain and biomass yield at the nearest distance may be attributed by competition for light and water between tree and crop. However, biomass yield of associated tef were the same under the canopy and away from the canopy of *A. seyal*. Therefore, the result indicates that retaining of *A. seyal* tree on croplands with the integration of food crops, could be an additional benefit for the farmers without competing their crop production.

Key words: *Acacia seyal*, soil physical property, biomass, grain yield of tef.

INTRODUCTION

Smallholder agriculture is the dominant sector of the Ethiopian economy that provide over 85% of the total employment and foreign exchange earnings and approximately 55% of gross domestic product (GDP) with 85% of the population living in rural area (Abera, 2010). Tef (*Eragrostis tef)* is an indigenous and one of the major cereal crops in Ethiopia and covered an area about 2.8 million ha (22.95%) followed by maize (16.91%), sorghum (14.85%) and wheat (13.33%) during the main season of 2015/2016 (CSA, 2016). It has 16.76% of share from total production of cereal (88.68%) in the country. However, in semiarid area of Ethiopia, crop productivity in general and tef productivity in particular have been affected by recurrent drought and low soil fertility (Kidane and Tesfaye 2016). Water and soil fertility are the most limiting and determining factors for low crop productivity and instability.

Nevertheless, agroforestry system which is the integration of trees on farmlands with annual crops has provided low cost (Yengwe et al., 2018), sustainable

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opportunity for soil fertility enhancement (Tanga et al., 2014) and has increased agricultural productivity (Nair, 1989). Trees as the main components of agroforestry can play a substantial role to modify the microclimate, enhance soil fertility and crop productivity of the area of its canopy influence by adding nitrogen through nitrogen-fixation and recycling nutrients through litter-fall or biomass-transfer (Umar et al., 2013; Bishaw and Abdu, 2003; Kohili et al., 2008; Young, 1997; Berhane and Agajie, 2006). Despite its importance, the integration of tree with annual crops can have both positive and negative effect on the function of the agro-ecosystem. For instance, both the negative and positive effects of tree on soil moisture content have been reported by various scholars in the country (Hailu et al., 2000; Hailemariam et al., 2010) as well as elsewhere outside the country (Akpo et al., 2005; Raddad and Luukanen, 2007).

Acacia species are the commonest tree species that has been grown in agricultural land (Birhane et al., 2018). *Acacia seyal*, is one of the tree species widely used in agroforestry practices in Ethiopia in general and in the study area in particular (Endale et al., 2017; Hailemariam et al., 2018). The farmers had left the tree on their farm boundaries, marginal areas, and inside farmlands in order to fulfill their wood requirement and to generate extra income.

A. seyal Del belongs to the family Fabaceae and subfamily Mimosoideae and it has the common name such as Wachu in Amharic, and white galled acacia and white whistling torn in English (Tesemma, 2007). *A. seyal* is common in many parts of Africa, especially north of the equator, from 10 to 12 degrees. It also occurs in Eastern and Southern Africa (Orwa et al., 2009). In Ethiopia, it is also found on seasonally flooded black-cotton soil, in river valleys and wooded grassland of dry and moist Weyna Dega agro-climatic zones (Bekele and Tengnäs, 2007).

A. seyal used for firewood, charcoal, poles, posts, medicine (bark, gum), fodder (leaves, twinges, bark, flowers and pods), bee forage, nitrogen fixation, soil conservation, shade, windbreak, gum, tannin, dye (McAllan, 1993). *A. seyal* forms either pure stands of different densities or mixed stands associated with other species (Mohammed, 2011).

In the study area, there are no scientific evidences on the effect of scattered trees on the microclimate, soil fertility and crop productivity. Yigardu (2002) has been studied on the biomass and composition of tree species on-farm lands. Therefore, the objective of the study is to investigate the effect of *A. seyal* (Del) on soil bulk density, soil moisture content and yield of *tef* in parkland agroforestry system of semiarid area of Amhara.

MATERIALS AND METHODS

Description of the study area

The study was conducted in Sirinka catchment which is found in Habru district (Wereda), North Wollo zone, Amhara region. It is geographically located in between 11°41.2' - 11°47.7' N and 39°31.4' - 39°37.6' E. The catchment comprises three adjacent kebeles (the smallest administrative unit of Ethiopia), namely: Gerado, Sirinka and Goshuweha. The research was conducted at Sirinka and Goshuweha kebeles based on the presence of good distribution of the tree. The district is intermediate lowland agro ecologies that range from 1000 to 2400 m above sea level. The climate of the study area is generally characterized by arid and semiarid climate. The mean minimum and maximum daily temperature falls between 13 and 26°C and the mean annual rain fall varies from 750 to 1000 mm with bimodal distribution, the main rainy season lies between June and September and the short rainy season occurring from March to April but the amount and distribution of the rain is fluctuated (Figure 1). The district characterized by rugged and undulated topography. The western part makes a chain of hill that border the high land escarpment of the country from rift valley low lands. According to the soil study conducted by Sirinka Agricultural Research Center (SARC), the two dominant soil types found in the study area are utric vertisol and vertic cambisol.

Tree selection and soil sampling

By adopting Yeshanew (1997)'s method, single/isolated *A. seyal* trees were systematically selected from farmers' fields which have similar topography, cropping history, management practice and distribution of trees. And also, trees with approximately the same size and age were used for the study purpose.

There are two factors in this study. The first one is distance from the tree base, and the second one is soil depth from the ground level. Factor one encompasses three levels: 1, 2.5, and 9 m (considered as control) and factor two also include two levels: 0-15 cm (surface soil) and 15-30 cm (subsurface soil) depth. Representative soil samples were taken at three different distances from the tree base and at each distance from two different depths in four different directions, from each of the six trees. Soil samples for the same distance and depth were bulked to form a composite soil sample. So, totally 36 composite soil samples (36=3 horizontal distances × 2 soil depths × 6 trees as replications) were collected.

Crop sampling and data collections

To measure sample biomass and grain yield of associated tef (local variety, Magna) a total of four 1 m × 1 m (1 m^2) area sample quadrants were used and laid at 1, 2.5 and 9 m (control) distances from the tree base. At each quadrant, sample weight of biomass and grain yield of tef was taken. The fresh biomass was taken and dried by oven with 65°C for 48 h. The harvested grain as well as biomass of tef from a quadrant (1 m^2) in grams was converted to kilogram per hectare.

Soil analysis and laboratory methods

Soil particle size (clay, silt, sand) distribution was determined by hygrometer method (Bouyoucos, 1951). The soil moisture content was measured by gravimetric method (Black, 1965b). In this method, moisture content was calculated using the following formula:

$$\theta_d = \frac{\text{weight of wet soil-weight of oven dry soil}}{\text{weight of oven dry soil}} \times 100 \quad (1)$$

where θ_d = soil moisture content in dry weight basis.

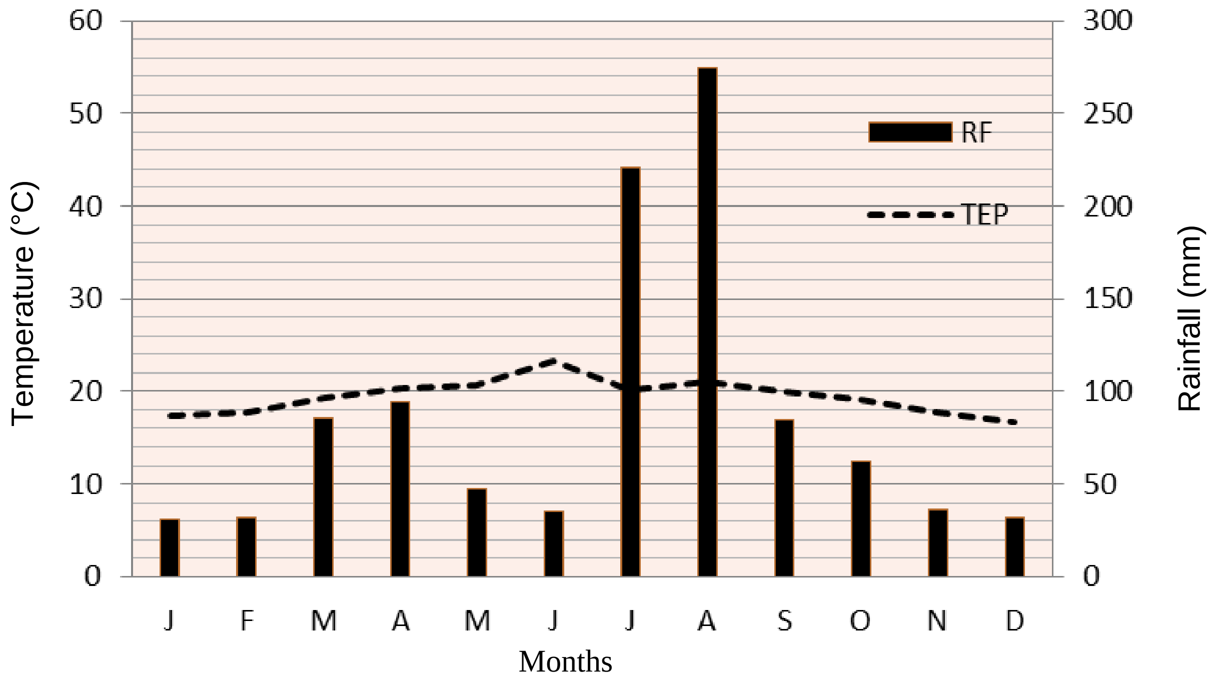

Figure 1. The mean monthly temperature and rain fall data of the study area (1992-2012, Sirinka station).

Soil bulk density (g/cm^3) was determined by measuring the dry mass of soil per unit of volume of the core (98.13 cm^3). The following formula was used to calculate the bulk density of the soil:

$$\text{Bulk Density} = \frac{\text{dry mass of sampled soil(g)}}{\text{Volume of the core } (\text{cm}^3)} \quad (2)$$

Data analysis and interpretation

All statistical comparison used SAS software window version 9 (SAS Institute, 1999). The quantitative data that were obtained from laboratory were analyzed by two way analysis of variance (ANOVA) to test variations between distances, depths and their interaction. Least significant different test (LSD) was used for mean comparison when differences were significant at 5% of probability level. Simple correlation analysis was also carried out by SAS to examine magnitudes and direction of relationships between selected soil physical properties and biomass and grain yield of tef.

RESULTS AND DISCUSSION

Soil texture

The result indicated that clay, silt and sand fractions were similar both for distance from the tree base and soil depths (Table 1). The textural classes of soil both under and outside the tree canopy and surface and subsurface soil have had clay texture. This result indicated that scattered *A. seyal* tree do not influence soil texture and since the soil depth was only 30 cm deep, it may be too shallow to show textural differences. In addition, similarity in %clay, %silt and %sand fraction of the soil under different canopy position of the tree and soil depths might indicate the similarity of the parent material in the studied field. Because, size of soil particles is not influenced by soil management practices, rather it is predominantly by the parent material form which the soil formed. These findings are supported by other studies that observed no variation of soil texture both laterally and vertically under and outside the canopy of tree in Ethiopia (Hailu et al., 2000; Abebe et al., 2009) and in Kenya (Githae et al., 2011).

Soil bulk density (BD)

Soil bulk density was significantly influenced by both horizontal distances from the tree base and by soil depths (Table 1). Generally, in the present study the value of bulk density shows increasing trend from the tree base towards outside the canopy and from surface soil to subsurface soil (Table 2). It indicated that the soil under *A. seyal* canopy had lower bulk density as compared to that of outside the canopy, this may be due to organic matter build up under the canopy from litter fall and higher turnover of fine roots closest to the tree. Thus the accumulation of litter fall under the canopy buffered the soil against rain drop impact, wind erosion and associated compaction as evidenced by the lower bulk density (Shukla et al., 2006). The present study agrees

Table 1. Summary of two -way analysis of variance (ANOVA) of soil textural classes, soil bulk density and soil moisture content in relation to distances from the tree base and soil depths.

Variable	Distances (Factor A)			Soil depth (Factor B)			Factor(AXB)		
	MS	F value	P value	MS	F value	P value	MS	F value	P value
%Clay	29.68	0.69	0.5113	100.00	2.32	0.1402	0.52	0.01	0.9880
%Silt	58.33	1.42	0.2599	11.11	0.27	0.6072	19.44	0.47	0.6278
%Sand	81.77	3.33	0.0524	44.44	1.81	0.1908	22.05	0.9	0.4206
BD(g/cm^3)	0.16	6.86	0.0042	3.81	160.42	0.0001	0.008	0.034	0.7172
SMC (%)	17.59	5.31	0,0120	153.06	46.2	0.001	8.97	2.71	0.0861

MS= Mean squire, BD g/cm^3= soil bulk density, SMC%= soil moisture content.

Table 2. Soil %clay, %silt, %sand, BD and SMC in relation to distances from the tree base and soil depths.

Treatment	Soil parameter				
	%Clay	%Silt	%Sand	BD (g/cm^3)	%SMC
Distances (m)					
1	51.66±3.15^a	29.58±7.74^a	19.65±2.77^a	1.56±0.11^b	20.20±1.38^b
2.5	48.54±4.13^a	30.41±5.82^a	21.04±3.48^a	1.56±0.10^b	21.90±1.38^a
9	49.79±4.57^a	26.25±5.27^a	23.95±4.75^a	1.76±0.10^a	19.65±1.53^b
Soil depths (cm)					
0-15	48.33±3.22^a	29.30±1.53^a	22.36±3.04^a	1.30±0.04^b	18.49±0.88^b
15-30	51.66±3.19^a	28.19±1.53^a	20.14±3.06^a	1.96±0.04^a	23.76±1.06^a

The mean value under each columns with the same superscript letter are not significant different at P<0.05. BD g/cm^3= Bulk Density, SMC%= Soil Moisture Content, values are mean ±SE. SE= Standard error.

with the observations of Hailu et al. (2000), who found that lower soil bulk density under *Millettia ferruginea* tree canopy than that of open area in Southern Ethiopia. Similarly, Jiregna et al. (2005) also found that the soil bulk density under the canopy of *Commiphora africana* is lower than that in the open area. Nevertheless, Hailemariam et al. (2010) have shown in his report that there was no significant difference between bulk density of the soil under and outside the canopy because of lack of differences in soil organic matter level.

Soil moisture content (SMC)

The moisture content of the soil influenced by distance from the tree base and soil depths showed declining trend as a function of distance from the tree base toward open lands and increasing trend from surface soil to the corresponding subsurface soil (Table 2). The results of the present study are in line with that of Hailu et al. (2000). In his findings, the moisture content of surface and subsurface soil under the canopy was also found to be higher than that of the corresponding surface and subsurface soil outside the canopy. Akpo et al. (2005) also found higher moisture content in surface soil under tree canopy than the corresponding surface soil outside the canopy in Senegal. The higher moisture content under the tree canopy might be due to the mulching effect from litter layer and shade that reduce evaporation (Moody and Jones, 2000). Moreover, the higher soil organic matter under the canopy may be responsible for higher moisture content. In agreement to the present study the higher soil moisture content (SMC) was observed at subsurface soil than that of the surface soil under *Acacia senegal* agroforestry in clay soil of Blue Nile, Sudan, due to top soil dried much faster than subsoil during dry season (evaporation) and water extracted by crops (Raddad and Luukanen, 2007). In contrast, Hailemariam et al. (2010) observed that moisture content of the soil decreased towards tree trunk.

Grain yield of tef

As shown in Table 3, the grain yield of tef did show significant difference among distances from the tree base. The higher grain yield of tef was observed at 2.5 m from the tree base, which is the place where the interface of tree canopy and the open land. Therefore, the grain yield increment may be due to the improvements of soil environment and minimum competition between the roots of tree and associated crop. In line with the present

Table 3. The mean value of grain, fresh biomass and oven dry biomass yield in relation to distance from the tree base under the canopy of *A. seyal* on croplands of Sirinka catchment.

Distance (m)	Grain yield (kg/ha)	FBM (kg/ha)	ODBM (kg/ha)
1	1159^{b}±1.26	3784^{a}±3.6	3398^{a}±3.4
2.5	1924^{a}±2.40	4877^{a}±4.6	4397^{a}±3.9
9	1582^{ab}±2.43	4906^{a}±7.9	4228^{a}±7.2
LSD	*	ns	ns

Mean value (±SE) with under each columns with the same superscript letters are not significantly difference at P<0.05 significant level. FBM= Fresh biomass, ODBM= oven dry biomass at 105°C for 24 h, Mean=overall mean of yield, CV= coefficient of variation%, LSD=least significant difference, * = significant at P<0.05, ns=not significant difference at 5%, SE=standard error.

study, Mubarak et al. (2012) in semi-arid tropics of Sudan reported that millet yield under *Azadirachta indica* and *Balanites aegyptiaca* were higher than the control by about 43%. Under *Faidherbia albida* in the highland of Tigray, Northern Ethiopia, Hadgu et al. (2009) found that barley yield was significantly higher at 1 m distance from the tree trunk compared to yields at 25 and 50 m, due to nitrogen fixation by *F. albida* and nitrogen supply by shedding its leaves during cropping season. However, in contrast with the present study, research conducted in Northern Ethiopia by Hailemariam et al. (2010) reported that grain yield of sorghum was not different among distances from the tree base, Osman et al. (2011) observed that the performance of cowpea and pearl millet intercropped under *Parkia biglobosa* did not differ among the four zones which was laid at different distance from the tree trunk. Bazie et al. (2012) observed that the grain yield of sorghum under pruned *Phyllocrania paradoxa* and *P. biglobosa* tree were five times higher than that of unpruned trees. These yield reduction are mainly attributed by the shade of the tree (Kohili et al., 2008) that reduce sunlight reaching soil and crops.

Biomass yield of tef

Fresh as well as oven dry biomass of tef in the present study were not affected by distance from the tree base or by different canopy positions of *A. seyal* tree. However, as shown in Table 3, the fresh biomass of tef shows increasing trend as a function of distance from the tree base towards open canopy but dry biomass of tef had not shown clear trends. In line with the present investigation Hailemariam et al. (2010) observed that biomass yield did not differ among three zones away from the tree. Bazie et al. (2012) found that straw dry matter of sorghum was higher under pruned *P. paradoxa* and *P. biglobosa* as compared to unpruned trees. This may indicate shading effects on dry matter production.

Conclusion

This study evaluated the possible impact of *A. seyal* trees on available soil water, soil bulk density and yield of tef (*Eragrostis tef*) grown under the tree canopy. From the result of this study, we can conclude that the presence of *A. seyal* tree on croplands had no effect on soil texture, but it improves soil moisture content and soil bulk density. In addition, the grain yield of associated tef crop is better at the interface of the tree canopy. Therefore, the incorporation of *A. seyal* tree on cultivated land could be an additional source of benefit for small holder farmers. However, the impact of crown management on yield and growth performance of associated crop and fine root distribution and dynamics along soil depths and horizontal distances should be further investigated.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interest.

ACKNOWLEDGEMENTS

The authors would like to express their deepest gratitude to Amhara Region Agricultural Research Institute (ARARI) for giving them the chance to pursue this study and financially supporting the expenses and field research of the study. They are also grateful to Sirinka Agricultural Research Center (SARC) for the study leave, laboratory facilities and transportation during the field work.

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