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Effects of scattered Faidherbia albida (Del. A. Chev) tree on yield and yield components of three Cereal crops in Central Ethiopia

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Abstract

Understanding tree-crop interaction is a key aspect in determining approprate tree-crop combination and managements. However, little is known about the influence of tree crop interaction and tree management on crop productivity. The study was conducted with the aim of investigating the effects of Faidherbia albida on yield and yield components of three cereal crops: wheat (Triticum aestivum L.), maize (Zea mays L.) and teff (Eragrostis tef (Zucc.) Trotter) in Central Ethiopian farmers field at Silti District.Three independent experiments were conducted using randomized complete block design with five replications for each experiment. The treatments consist of five radial distances at: 1.5m, 3.5m, 5.5m and 12.5m and contorl (25 m far from tree trunk). The yield and yield components data were collected from four directions and then the average was taken for analysis using one way ANOVA and mean separation was done using LSD at 5% significance level. Results showed that yield and yield component of wheat and maize were higher under and near the tree canopies than far from canopies. In contrast teff yield and yield component increased with increasing distance from tree trunk. Plant height, number of tiller per plant, spike length, total aboveground biomass and grain yield were all significantly higher (P < 0.05) for maize and wheat associated with F. albida compared to outside the canopy. Whereas, results from teff showed lower yield and above ground biomass close to the tree trunk compared to outside the canopy. The tree also used for fencing, fuelwood, fodder, construction and income generation. Therefore, the present study clearly showed that compatibility of maize and wheat under F. albida land use system are better tree crop combination design not only to enhance cereal productivity but also other tree benefits to farmers, while teff is incompatible to grow under F. albida land use system. Further study is required for the detailed species physiological response of the studied crops to shade.

Keywords: *Agroforestry, F. albida, cereal crops, crop productivity, Ethiopia*

1. Introduction

The smallholder agricultural sector in East Africa, including Ethiopia is the dominant economic and social activity for millions of households who are often resource-poor, food-insecure and most vulnerable to climate change (Affholder et al. 2013). However, agriculture is predominantly subsistence and rain-fed based with low input farming and hence characterized by low yield. Consequently, poor agricultural productivity has led to food shortages and these problems are likely intensified, as the human population is growing faster in these regions (Alain, 2018). Soil degradation and soil nutrients depletion is the most serious environmental constraint to crop production in Sub-Saharan Africa (Lal, 1988). The wide spread loss of soil carbon, Nitrogen and other nutrients from agricultural landscapes are severely reduce agricultural production in the region (Syers, 1997; Lal, 2001; Tadesse, 2001).In Ethiopia, the qualities of most agricultural soils have dramatically declined due to successive high rate of soil erosion and associated loss of soil organic carbon and nutrient contents (Hurni, 1993; Lemenih, 2004). Soil degradation is further worsened due to nutrient depletion arising from long years of land cultivation, and inadequate nutrient inputs, absence of appropriate cropping practices, lack of nutrient saving and recycling technologies (Stoorvogel & Smaling, 1993).

High population pressure and corresponding shortage of agricultural land led to shorter fallow periods, use of crop residues for forage and fuel wood instead of soil fertility maintenance, and expansion of farming system to marginal land causing severe decline in soil productivity (Haileslassie et al. 2006). Ethiopia has made extensive efforts to boost the production and productivity of major cereal crops like maize, wheat, teff, and sorghum through wider adoption and dissemination of inorganic fertilizers, improved seed variety, soil conservation practices and technologies (Gebresilassie, 2015). However, the downward spiral of soil fertility and the corresponding declining of crop productivity and production are still unabated (Getahun et al. 2014). Consequently, the gap between demand and supply of food is still large (Getahun et al. 2014 &Tesfaye, 2018). Agroforestry has a considerable potential for improving biodiversity, soil fertility and crop yield and provide other multi-purpose benefits for farmers (Nair, 1993; Young, 1997). Hence, promoting green agricultural growth through integrating agroforestry tree with cereal crops in smallholder farmers would be one possible strategy for boosting cereal productivity while protecting the environment. Additionally, it can improve the microclimate beneath the canopies and mitigate climate changes through sequestering carbon (Shiferaw et al. 2014). Traditional *F. albida*-crop integration is one of such a strategy (ICRAF, 2000; Garrity et al. 2010; ECRGE, 2011) and has been widely practiced for many generations by smallholder farmers in central rift valley of Ethiopia (e.g. Poschen, 1986; Kamara & Haque, 1992; ICRAF, 2000).

F. albida is an indigenous nitrogen fixing tree with a unique 'reverse phenology' − i.e., shedding leaves during the crop growing season, which permits penetration of enough radiation for the understory crops, has been understood to be one of the main reasons for its positive interaction with crops and it is well adapted and growing in different habitats, soil types and agro-ecologies with various cereals (Rao et al. 1998). Due to its nitrogen fixation ability and deep rooted nature, the tree can enhance soil fertility by adding nutrient and organic carbon into soil system through litter fall decomposition and nutrient pumping (Kamara & Haque, 1992; Roupsard, 1999; Kho et al. 2001; Payne et al. 1998). Beside these, internal nutrient inputs, soil under the canopies of the tree could also receive external nutrient through manuring from livestock and bird and other animal dropping (IIRR & NAPC, 2016).

Studies in Ethiopia have shown that *F. albida* improves soil fertility mainly nitrogen and organic carbon, which is assumed to be convert into higher crop yield under its canopy than away from it (Poschen, 1986; Manjur et al. 2014). Similarly, studies conducted in Malawi (Saka et al. 1994) and Niger (Kho et al. 2001) showed high soil fertility and crop yield beneath the canopies of *F. albida* tree compared to open area. However, in some cases such positive synergies were not observed (Poschen, 1986).

Therefore, the effects of on farm scattered trees including that of *F. albida* on cereal crop yield is inconsistent and depends on several factors such as crop type, tree management applied, difference in tree morphology and age, tree density, and climatic and soil conditions (Poschen, 1986; Bayala et al. 2015). For examples, Jiru (1997) reported increased grain yield for sorghum, wheat and maize when they grow under lopped *F. albida* than far from canopies while the same authors found yield loss for teff when it was intercropped with lopped *F. albida* trees close to tree trunk than open area in central Ethiopia. The existence of such deferential tree crop interactions among different crop species signal the need for more site and crop specific studies in order to design best tree crop combination and this study was designed to fill this research gap. Moreover, improperly selected and managed trees in agroforestry strongly compete with crops for light, resources, shade, and water and thus can have a devastating effect on crop yields. Therefore, understanding *F. albida* crop interaction is essential for formulating appropriate tree crop combination and tree management strategies. Thus, there is a need to know what difference exist in tree crop interaction with increasing distance from *F. albida* tree trunk in order to design the best tree crop combination. Therefore, this article aims to: (1) investigate the effect of scattered *F. albida* tree on cereal production and productivity by measuring yield and yield components with increasing distance from tree trunk, and (2) identify compatible and incompatible cereal crops to integrate with *F. albida* tree in Silte Zone, SNNPRS of Ethiopia.

2. Materials and Methods

2.1 Study site description

The study was carried out in Silti district located approximately between 7°38' to 8°07' N latitude and from 38°12' to 38°30' E longitude in Siltie Zone of Southern Nations, Nationalities and Peoples Regional State (SNNPRS) of Ethiopia (Fig. 1). According to Silti wereda agriculture and natural resource office the district has an altitude ranging from 1650 to 3100 masl and the dominant soil types included eutric Cambisols, chromic Luvisols, chromic Vertisols, eutric Fluvisols, Leptosols and pellic Vertisols. The district is dominantly Weyna Dega (mid altitude) in agroclimatic condition in which *F. albida* growth lies between 1700 to 2000 masl.The climate is also characterized by bimodal rainfall distribution with a total of 875 – 1,213 mm, and the mean annual temperature of 12°C - 25°C (average data from nearest meteorological stations). The dominant and important scattered trees on farm land in the district are *Acacia* species particularly *F. albida*, *Eucalyptus spp., Cordia africana*, and *Corotonmacrostachy*.The dominant annual crops intercropped with *F. albida* trees are Zea mays (maize), Triticum aestivum L(wheat), Eragrostis tef (teff), Sorghum bicolor L (sorghum), Hordeum vulgare L(barely) and vegetables such as green paper.

A typical cereal crop (Wheat, Maize, and Teff) production practices in the study area commenced for maize in March and for teff in April to June. However, production practice for wheat is commenced after rain softens the soil, and fields can be ploughed multiple times (average of three times). Sowing was occurred around the end of March for maize and between late June and early July for teff and wheat. Manual row seeding was used for maize, wheat, and teff. Pollarding, lopping, pruning, tinning and total removal of trees in their farming plots of tree management practice were applied in the study area.

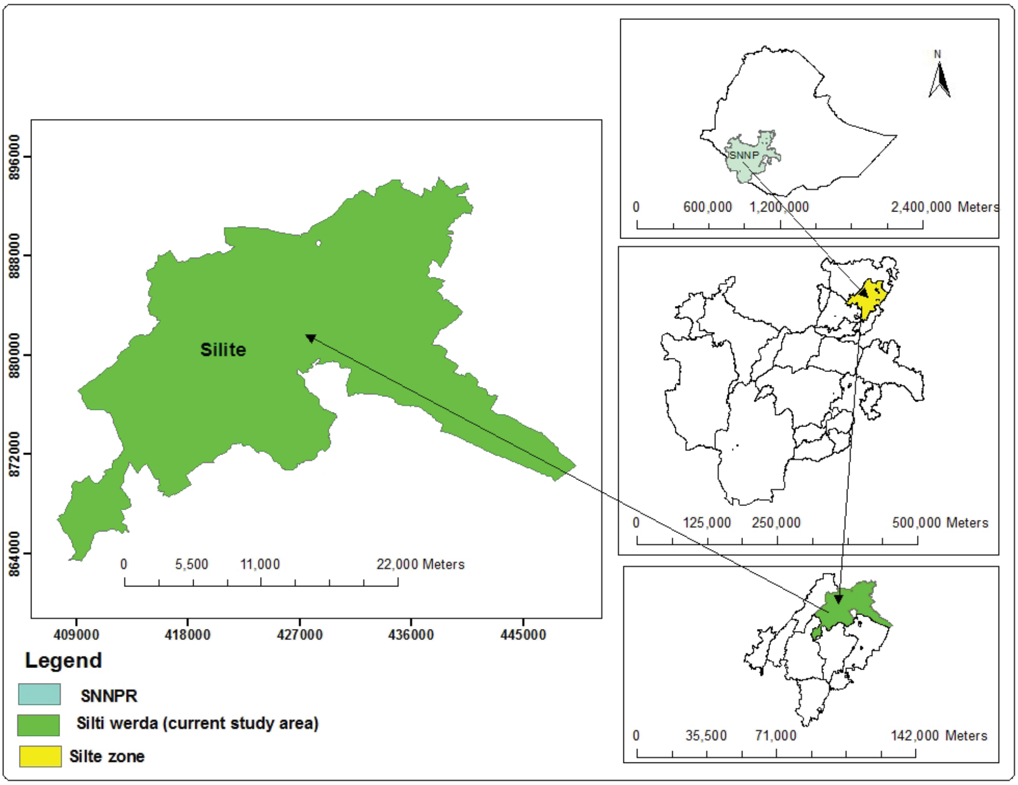

Figure1 *Location map of the study area*

2.1 Experimental design

Three independent experiments were conducted using randomized complete block design (RCBD) to evaluate performance of three cereal crops (wheat, maize and teff) grown beneath the pollarded *F. albida* tree. For each experiment, 5 mature isolated and a total of 15 on farm *F. albida* trees which have about similar size, shape and age and uniform soil, topography and crop husbandry were selected. To investigate each experiment, a total of 15 farmers were selected (5 farmers per experiment who owned and managed the tree on maize, wheat and teff fields). Farm fields used for experimental data collection were selected mainly using the following criterion: (1) the tree species of interest was grown within the selected crop fields, (2) the selected tree was located in the selected crop fields isolated from other on-farm trees at least by 50 m, and (3) open field and under canopy plots had similar characteristics, except for the presence of the tree. Each of these three independent experiments were replicated up to five times under five experimental units totaling to 75 experimental units, and five radial distance from tree trunk 1.5m, 3.5m, 5.5m, 12.5m and 25 m (control) were considered as treatments. Each quadrant (1m*1m) dimension was used for experimental unit and data were collected under the units. Manjur et al. (2014) experimental design was modified for this research work by using two additional experimental units (Fig. 2).

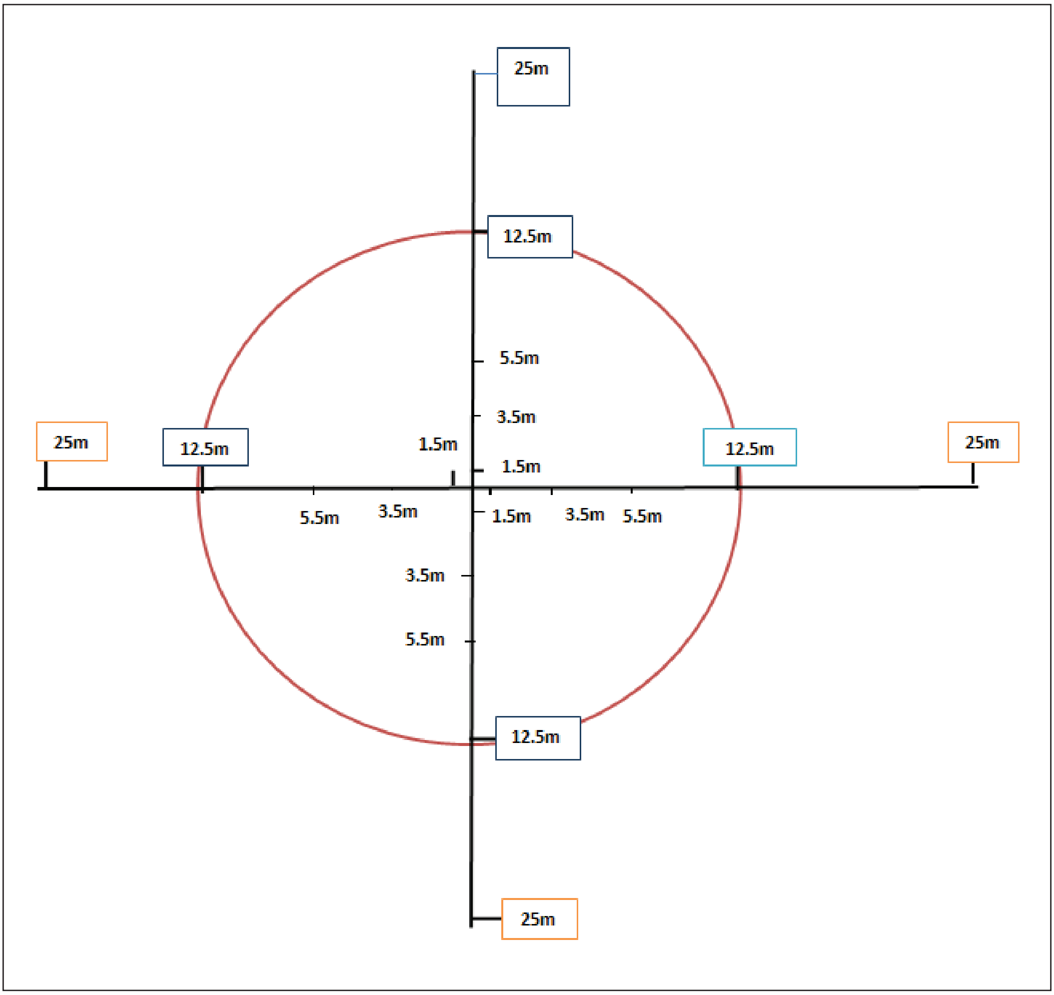

Figure 2 *Experimental design modified (adapted from:Manjur et al., 2014)*

Where:

1) The center of the circle represents a single F. albida tree;

2) The circle represents the area covered by the canopy of the tree;

3) The area covered by the canopy is divided into four radial transects (fully labeled here);

4) Five plots (1m * 1m each) were established on each radial transect at distances of 1.5 m, 3.5 m, 5.5 m

12.5 m, and at 25 m away from the tree trunk all directions and a total of twenty fiveplots were considered in single experiment.

5) The five plots for a similar distance on each of the four radial transects were considered as a single treatment, e.g. the plots at a distance of 1.5 m on each of the four radial transects.

Note that the figure is not drawn to scale and, of course, the area covered by the canopy is not a perfect circle.

2.1 Methods

Prior to crop planting, the canopy of each tree was properly managed through pollarding to minimize the competition of tree for growth mainly for light against crops. The study was carried out under on farm condition where the experiments for the three crops were set up on nearby farmlands on similar soil types, climate, tree management, cropping history and landscape conditions. Average canopy radius of 12.5 m was used as a bench mark of maximum of radius from the base of the tree trunk which was measured data using GPS in the area (Table 1). In order to minimize residual effects from prior land management, cropping history of the farm plots was checked with the owners. Hence, plots that were consistently cropped with cereals for five years were considered. Trees with relatively similar age, diameter, height and canopy cover were selected (Fig. 3).

Figure 3 *GPS coordinate data collection and tree management practice*

Tree height was estimated using graduated poles and diameter at breast height was measured with a Caliper. Canopy width and length was measured with measuring tape by stretching it from point judged to be directly below the edge of the canopy to tree trunk. Compass and meter tape used to determine sampling direction and radial distance (1.5m, 3.5m, 5.5m and 12.5m and 25 m) along the sample transects. GPS was used to identify the exact location of the trees. Data were collected from four directions (east, west, north and south), and the average of the four directions per radial distance was used in data analysis.

Planting date was 16 April and harvested on October 11 for maize (Shone variety) and it was 08 July for wheat (Shorima variety) and harvested on October 31 and planting date was 28 July for teff (quncho variety), and harvested on November 11 all in 2018. Maize plots were fertilized with 73 kg ha^{-1} Dap, 56 kg ha^{-1} Urea (split applied 50% at sowing and the remaining side dressed at the age of 3-4 leaf). Wheat plots were fertilized with 80 kg ha^{-1} Dap, 60 kg ha^{-1} Urea (split applied 50% at sowing and the remaining side dressed at the age of 25-30 days), and teff plots were fertilized with 66 kg ha^{-1} Dap, 52 kg ha^{-1} Urea (split applied 50% at sowing and the remaining side dressed at the age of 30-34 days). Seed was drilled at a spacing of 30 cm between rows and plants, 25 kg ha^{-1} for maize and drilled at a spacing of 25 cm between rows at the rate of 110 kg ha^{-1} for wheat. Teff was drilled at a spacing of 20 cm between rows at the rate of 16 kg ha^{-1} (Fig 4). Field cultivation and site preparation involved the traditional "Maresha" plowing with a pair of oxen. Weeding was carried out using hoeing for maize, and combination of herbicide (2,4D) and hand weeding were used for wheat and teff.

Figure 4 *shows site preparation, sowing, and seedling crops.*

2.1 Experimental data collection

Measured variables for maize includes: average plant height, number of plant per m^2, number of ear per plant, Length of ear, grain yield and above ground biomass, and for that of wheat and teff: average plant height, tillers/m^2, tillers/plant, spike length, grain yield and above ground biomass. Grain was separated from the straw by threshing manually. Grain yield was quantified in quintals ha^{-1} and above ground biomass was in ton ha^{-1}.

Yield gain/loss of wheat, maize and teff, under the influence of tree were computed using the following equation.

$$\text{Yield } gain/loss = \frac{YUIT-YOIT}{YUIT} * 100 \text{-----------} 1$$

Where YUIT is yield under the influence of tree, YOIT is yield outside the influence of tree.

Table 1 *F. albida tree characteristics data, mean of their height, DbH, canopy size and (GPS) coordinates*

No	Sample Acacia *albida* tree for	Average height in meter	DbH in centimeter	Canopy size in meter	X,Y (GPS) coordinate (in meter)	
					X coordinate	Y coordinate
1	Maize	13	95.5	15	887474	429966
2	Maize	14	89.2	16	887663	429972
3	Maize	16	79.9	16	887570	429846
4	Maize	12	79.6	16	887454	429902
5	Maize	15	89.2	14	887103	430790
6	Wheat	10	90.7	14	868922	432592
7	Wheat	8	63.7	12	868902	432528
8	Wheat	11	70	10	868505	433583
9	Wheat	12	66.9	12	868506	433925
10	Wheat	14	73.9	13	868560	433978
11	Teff	17	64	10	887886	430023
12	Teff	15	76.4	12	887383	430232
13	Teff	14	73.2	13	887347	430287
14	Teff	12	82.8	11.5	887475	430394
15	Teff	13	70	12	887121	430861

2.1 Data analysis

The data of crop yields and yield component in response to distance from tree trunk were tested with one-way-ANOVA. Then, the mean for treatments that showed significant differences by F-test were separated by least significant difference (LSD) test and significance was declared at 0.05 significant levels, which is the most widely used multiple comparison procedure (Zar,1996). All statistical analyses were conducted in R Core Team (2015) software.

3. Results and Discussion

3.1 Effects of F. albida on Maize yield and yield component

The analysis of variance of the study revealed that the grain yield and yield components of maize were significantly (P≤0.05) affected due to the presence of *F. albida* tree. The grain yield of maize decreased significantly with increasing distance from the tree trunk. Considerably higher maize yield (P≤0.05) was found close to tree trunk (i.e., at 1.5 m) than far from the tree trunk at 25m. As compared to the control (25m), there were a significant maize grain gain of 30.1% and 26.1% close to tree trunk and at the edge of the canopies (3.5m), respectively. Similarly, above ground biomass of maize showed statistically significant (p=0.05) difference among radial distance from *F. albida* tree trunk (Table 2).

Table 2 *The effects of F. albida on maize yield and yield components*

parameters	Radial distance (m)									
	1.5	3.5	5.5	12.5	25	Cv	LSD	F value	(Pr > F)	LS
Height in m	2.692^{a}	2.664^{a}	2.548^{b}	2.534^{b}	2.428^{c}	1.80	0.062	26.4	7.1e-07	***
Number of stem per m^2	6^{a}	5.8^{ab}	5.4^{bc}	5.0^{c}	4.0^{d}	7.75	0.544	19.1	6.3e-06	***
Number of ears per stem	1.2	1.2	1.0	1.0	1.0	22.7	NS	1.0	0.436	.
Ear length	27.4^{a}	28.0^{a}	28.4^{a}	26.0^{b}	21.4^{c}	3.75	1.282	44.5	1.8e-08	***
yield in quintal per ha	60.88^{a}	57.64^{ab}	54.06^{b}	49.38^{c}	42.58^{d}	6.41	4.549	22.4	2.2e-06	***
Agb in ton ha^{-1}	23.4^{a}	21.52^{a}	18.66^{b}	17.78^{b}	15.56^{c}	7.97	2.073	20.7	4.5e-06	***
Yield gain	**30.1%**	**26.1%**	**21.2%**	**13.8%**						

***= (*P<0.001*), ‘ . ’= (*P<0.1*), CV= coefficient of variation, LS= Level of significance, LSD= List Significant Difference, Agb = Above ground biomass

3.1 Effects of F. albida on Wheat yield and yield components

Wheat yield was significantly affected by distance from the center of *F. albida* tree trunk. Likewise, above ground biomass was strongly affected by distance from the tree trunk. Significantly higher above ground biomass ($p<0.05$) was recorded at 1.5 m and it was lower as it gets far from the tree trunk (Table 3).

Table 3 *The effects of F. albida on wheat yield and yield component*

Parameters	Radial distance (m)									
	1.5	3.5	5.5	12.5	25	Cv	LSD	F value	(Pr > F)	LS
Height in cm	85.6[a]	81.7[b]	80.1[b]	74.9[c]	69.3[d]	2.9	0.3	31.8	2.4e-09	***
Number of tillers per plant	5.6[a]	5.4[a]	4.4[b]	3.8[b]	3.8[b]	10.9	0.7	14.8	3.1e-05	***
Number of tillers per m^2	639.2[a]	634.4[a]	577.4[a]	471.4[b]	455.6[b]	12.2	91	8.4	0.00077	***
Spike length in cm	8.5[a]	7.8[b]	7.6[b]	6.98[c]	6.6[d]	2.9	0.3	58.5	2.4e-09	***
yield in quintal per ha	49.2[a]	48.5[a]	43.5[b]	38.5[c]	37.2[c]	6.5	3.8	19.2	5.9e-06	***
agb in ton ha^{-1}	18.3[a]	18.1[a]	15.6[b]	15.4[b]	13.9[c]	5.1	1.1	25.1	1.0e-06	***
Yield gain	**24.3%**	**23.2%**	**14.5%**	**3.4%**						

***= (*P<0.001*), CV= coefficient of variation, LS= Level of significance, LSD= list significant difference, Agb = above ground biomass

3.1 Effects of F. albida on Teff yield and yield components

Teff yield and yield components were significantly affected by distance from the center of *F. albida* tree trunk. In contrast to maize and wheat, teff yield and yield components showed an increasing trend with increasing distance from tree trunk. Statistically higher teff yields ($p<0.05$) of 25.46 quintal ha^{-1} was recorded at 25m while very low teff yield of 14.3 quintal ha^{-1} was measured very close to the tree trunk at 1.5 m. Likewise above ground biomass showed increased trend with increasing distance from the tree trunk (Table 4).

Table 4 *the effects of F. albida on teff yield and yield components*

Parameters	Radial Distance (m)									
	1.5	3.5	5.5	12.5	25	Cv	LSD	F value	(Pr > F)	LS
Height in m	1.22[c]	1.39[ab]	1.38[ab]	1.41[a]	1.34[b]	3.4	0.06	14.2	3.9e-05	***
Number of tillers per plant	9.8[a]	10.2[a]	9.6[a]	8.0[b]	6.4[b]	6.9	0.82	27.3	1.4e-07	***
Number of tillers per m^2	840.0[b]	992.2[b]	1170.2[a]	969..2[b]	923.2[b]	5.3	69.8	33.3	5.6e-07	***
Spike length in cm	48.05[b]	53.1[a]	51.9[a]	52.7[a]	48.06[b]	7.7	3.71	4.1	0.0177	*
yield in quintal per ha	14.30[c]	17.24[bc]	14.88[c]	20.04[b]	25.46[a]	20.7	5.11	7.2	0.0017	**
Agb in ton ha^{-1}	8.40[c]	8.78[b]	9.20[a]	9.20[a]	9.32[a]	1.4	0.16	49.9	7.7e-09	***
Yield loss	**-78.1%**	**-47.7%**	**-71.1%**	**-27.1%**						

*=(*P<0.05*), **= (*P<0.01*), ***= (*P<0.001*), CV= coefficient of variation, LS= Level of significance, LSD= list significant difference, Agb = above ground biomass

3.1 Effects of F. albida on grain yield and yield components of Maize and Wheat

Study results demonstrated, unlike that of teff whereby competitive interaction observed, *F. albida* has facilitative effect when intercropped with wheat and maize. The yield benefits of cereal crops when grown under parkland management such as *F. albida* have been extensively documented by other researchers ranged from slight decreases to doubling of yields (Nyamadzawo, 2015). Results of the present study revealed that presence of *F. albida* significantly improved yield and yield components of maize. Maize crop had longer height, more stem per m^2 and longer ear length, higher grain yield and higher straw yield under the tree canopy than far from it. The study results goes well with finding of Saka et al. (1994) who found 100% grain gain of maize beneath the tree trunk than the open area in Malawi. Our results are also comparable with similar studies by Poschen (1986); who found 76% maize grain gain in Eastern Ethiopia. Results of this study is in agreement with the finding of Jiru (1997) who found higher maize yield gain of 67% than far from the tree trunk when maize was inter-cropped with lopped *F. albida*in Central Ethiopia. Our study showed that 30.1% yield increment of maize (Shone Varity) at 1.5 m, and 11.2% at 12.5 m, compared to the control. Maize above ground biomass also showed an increment of

33.5% at 1.5 m, and 12.5% at 12.5 m, compared to the control (25 m).

At harvest, the wheat crop had taller height, longer spike, more tillers per m^2 and per plant, higher grain yield and higher straw yield under the tree canopy (1.5m) than far from it (25m). Results of the present study showed that yield increment for wheat (Shorima Varity) was increased by 24.3% at 1.5 m, and 3.4% at 12.5m compared to the control. Also higher wheat aboveground biomass was recorded which was increased by 23.8% at 1.5 m, and 9.7% at 12.5 m (Table 2). Results in this study complement and support the findings of other researchers in Ethiopia (Jiru, 1997; Gosaye, 2010; Shiferaw et al. 2014; Tesfaye, 2017). For instance, Jiru (1997) found higher wheat yield of 40% under canopy than as compared to outside the canopy in central Ethiopia when wheat grown under lopped *F. albida*, Shiferaw et al. (2014) also found higher wheat yield of 23% in rift valley of Ethiopia. Similar study by Gosaye (2010) also found higher wheat yield of 244.11% at 0.5m, and 100% at 10m from tree trunk than the sole cropping. These results also agree with similar study by Tesfaye (2017) who found significantly higher ($P < 0.001$) plant height, total aboveground biomass, and wheat grain yield, when wheat was intercropped with *F. albida* compared with sole wheat in Ethiopian central rift Valley. Moreover, study conducted by Hadgu et al. (2009) found higher barely yield of 49% in Northern Ethiopia.

There has been extensive scientific documentation on scientific literature that has extensively documented the remarkable positive effect of trees on efficiency of nutrient recycling due to their deeper root system and nitrogen fixing ability. For instance, its deeper root system improved its complementarity in resource use as it can take up subsoil nutrients that are beyond the reach of crops and recycle them to the surface through litter-fall (Komicha, 2018). The combined effects of improved soil fertility, soil water and microclimate modification such as reduction of air and soil temperature have been documented by Shiferaw et al. (2014). Tesfaye (2017) and ICRAF (1989) also observed that yield and yield components improvement of cereals could be associated with soil fertility improvement through different tree soil interaction process of nitrogen fixation, nutrient recycling, accumulated soil organic matter. The tree can also ameliorate microclimate and thereby improve water availability through different ecological processes such as hydraulic redistribution and improve water use efficiency of understory crops (Bayala et al. 2015). The yield improvement could also resulted due to the applied tree management practices of pollarding, consequent reduction of tree competition for growth resources mainly for light, water and nutrient. Study by Kho et al. (2001) noted that the lower temperature under the canopy of *F. albida* could play an important role for enhancing cereal productivity especially in dry land.

3.1 Effects of F. albida on grain yield and yield components of Teff

On contrast to maize and wheat, teff yield and above ground biomass showed an increasing trend with increasing distance form tree trunk. At harvesting time, the teff crop had lower grain and straw yield under the tree canopy than far from the canopies. Our result agree with finding of Jiru (1997) who found yield loss for teff when it was intercropped with lopped *F. albida* trees close to tree trunk than open area in central Ethiopia. Results of the present study showed that teff yield was decreased by 78.04% at 1.5 m, and 27.1% at 12.5 m compared to outside of the canopy. Likewise low above ground biomass of 11% at 1.5m, 6.2% at 3.5m, and 1.3% at 5.5m and 12.5m were measured compared to open area. The reduction of teff yield and yield components with decreasing distance from open area may indicate incompatibility of teff to integrate with *F. albida*. Our field observation revealed, overtopping of teff was occurred under the tree than open area before maturity age due to tinny and weaker teff stem close to tree than outside. As a result, teff stem close to the tree could not support upright the plant. This overtopping caused interruption of air flow and cross pollination for seed preparation and finally massy teff tiller was unproductive and weightless. As a result, yield and yield component of teff were lower at the base of the tree compared to outside the canopy.

4. Conclusion

The findings from the three experiments clearly showed that yield and yield components of wheat and maize decreased with increasing distance from tree trunk. Whilst, teff yield and yield components decreased with decreasing distance from control to tree trunk. Plant height, number of tiller per plant, spike length, total aboveground biomass and grain yield were all significantly higher ($P < 0.05$) for maize and wheat associated with *F. albida* compared to outside the canopy. Whereas, results from teff showed lower yield and above ground biomass close to the tree trunk compared to outside the canopy. Hence, response of cereal crops for presence of pollarded *F. albida* tree may be dependent on crops types and their resources use efficiency and availability of resources like, light, nutrients and water. It could also be inferred that the observed increment in yield of wheat and maize are associated with improved soil properties and microclimate under and near the canopy, characteristics of crop and applied tree management (pollarding). However, reduction of teff yield and yield components with decreasing distance from open area to tree trunk may be associated with the presence of *F. albida* and consequent overtopping of crop before maturity age.

In general, based on the present results, large seeded cereal crops like maize is the first alternative crop suitable for cultivation with pollarded *F. albida*. The second alternative crop with potential for cultivation under *F. albida* is wheat. The combination of small seeded crops like teff with *F. albida* is incompatible as it was confirmed by the observed low crop yield and yield components beneath canopies of *F. albida* compared to the control.

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Conflict of interest

The author(s) declare that they have no competing interests

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Appendixes

Appendix Table A. Tables presented in this appendix provide Result of Analysis of variance for data on maize yield under experimental tree recorded in the study area.

Sources	DF	Sum Sq.	Mean Sq.	F-value	Pr > F	LS
REP	4	76.9	19.23	1.67	0.206	-
TRT	4	1031.9	257.98	22.41	2.16e-06	***
Residuals	16	184.2	11.51			

REP= Replication, TRT=Treatments, LS= Level of significance, *** (*P<0.001*)

Appendix Table B. Tables presented in this appendix provide Result of Analysis of variance for data on maize above ground biomass under experimental tree found in the study area.

Sources	DF	Sum Sq.	Mean Sq.	F-value	Pr > F	LS
REP	4	19.57	4.89	2.046	0.136	-
TRT	4	192.05	48.01	20.075	4.45e-06	***
Residuals	16	38.27	2.39			

REP= Replication, TRT=Treatments, LS= Level of significance, *** (*P<0.001*)

Appendix Table C. The effects of *F.*albida on under-story maize yield in quintal ha−1.

No	Number of treatments	Mean grain yield in quintal ha−1 (average of five replication)	Yield difference from the mean	Yield increments in % over the control	STD
1	T1 (1.5 m)	60.88[a]	+7.972	42.98%	1.92
2	T2 (3.5 m)	57.64[ab]	+4.732	35.37%	1.19
3	T3 (5.5 m)	54.06[b]	+1.152	26.96%	5.82
4	T4 (12.5 m)	49.38[c]	-3.528	15.96%	5.06
5	T5 (25 m)	42.58[d]	-10.328	-	0.81

STD = standard deviationSTD

```
Statistics
MeanCVMS errorLSD    alpha   test               treat.Pr(>F)
  52.908 6.412782 11.5116 4.548983    0.05 Fisher-LSD2.16e-06 ***
```

Appendix Table D. The effects of *F.*albida on understory maize above ground biomass (abg) in toneha−1.

No	Number of treatments	Mean abg in toneha−1 (average of five replication)	abg difference from the mean	abgincrements in % over the control	STD
1	T1 (1.5 m)	23.40[a]	+4.016	50.39%	1.92
2	T2 (3.5 m)	21.52[a]	+2.136	38.30%	1.19
3	T3 (5.5 m)	18.66[b]	-0.724	19.92%	5.82
4	T4 (12.5 m)	17.78[b]	-1.604	14.27%	5.06
5	T5 (25 m)	15.56[c]	-3.824	-	0.81

STD = standard deviationSTD

```
Statistics
MeanCVMS errorLSD    alpha   test               treat.Pr (>F)
  19.384 7.978209 2.39165 2.073458    0.05 Fisher-LSD4.45e-06 ***
```

Appendix Table E. The effects of *F.*albida on understory maize height in meter.

No	Number of treatments	Mean maize height in meter (average of five replication)	Height difference from mean	height increments in % over the control	STD
1	T1 (1.5 m)	2.692[a]	+0.1188	10.87%	0.037
2	T2 (3.5 m)	2.664[a]	+0.0908	9.72%	0.059
3	T3 (5.5 m)	2.548[b]	-0.0252	4.94%	0.054
4	T4 (12.5 m)	2.534[b]	-0.0392	4.36%	0.091
5	T5 (25 m)	2.428[c]	-0.1452	-	0.0712

STD = standard deviation

```
Statistics
```

```
MeanCVMS errorLSD       alpha    test        treat.Pr (>F)
2.57321.8044750.0021560.062254510.05 Fisher-LSD7.057e-07 ***
```

Appendix Table F. The effects of *F.*albida on understory maize ear length in centimeter.

No	Number of treatments	Mean maize ear length in centimeter (average of five replication)	Ear length difference from mean	ear length increments in % over the control	STD
1	T1 (1.5 m)	27.4[a]	+1.16	28.04%	1.14
2	T2 (3.5 m)	28.0[a]	+1.76	30.84%	0.70
3	T3 (5.5 m)	28.4[a]	+2.16	32.71%	0.54
4	T4 (12.5 m)	26.0[b]	-0.24	21.49%	1.22
5	T5 (25 m)	21.4[c]	-4.84	-	2.07

STD = standard deviation

```
Statistics
MeanCVMS errorLSD      alpha    test     treat.Pr (>F)
  26.24 3.645413 0.915 1.2824990.05 Fisher-LSD1.778e-08 ***
3.92e-05 ***
```

Appendix Table G. Tables presented in this appendix provide Result of Analysis of variance for data on wheat yield under experimental tree found in the study area.

Sources	DF	Sum Sq.	Mean Sq.	F-value	Pr > F	LS
REP	4	50.3	12.57	1.599	0.223	-
TRT	4	604.0	151.00	19.219	5.91e-06	***
Residuals	16	125.7	7.86			

REP= Replication, TRT=Treatments, LS= Level of significance, *** ($P<0.001$)

Appendix Table H. Tables presented in this appendix provide Result of Analysis of variance for data on wheat above ground biomass under experimental tree found in the study area.

Sources	DF	Sum Sq.	Mean Sq.	F-value	Pr > F	LS
REP	4	4.07	1.017	1.466	0.259	-
TRT	4	69.47	17.369	25.050	1.02e-06	***
Residuals	16	11.09	0.693			

REP= Replication, TRT=Treatments, LS= Level of significance, *** ($P<0.001$)

Appendix Table I. Tables presented in this appendix provide Result of Analysis of variance for data on teff yield under experimental tree found in the study area.

Sources	DF	Sum Sq.	Mean Sq.	F-value	Pr > F	LS
REP	4	27.3	6.82	0.471	0.75653	-
TRT	4	415.4	103.85	7.163	0.00167	**
Residuals	16	232.0	14.50			

REP= Replication, TRT=Treatments, LS= Level of significance, ** ($P<0.01$)

Appendix Table J. The effects of *A.albida* on under-story wheat yield in quintal ha−1.

No	Number of treat-ments	Mean grain yield in quintal ha−1 (average of five replication)	Grain yield differ-ence from mean	Yield incre-ments in % over the control	STD
1	T1 (1.5 m)	49.18[a]	+5.784	32.06%	3.51
2	T2 (3.5 m)	48.48[a]	+5.084	30.18%	3.36
3	T3 (5.5 m)	43.54[b]	+0.144	16.92%	3.69
4	T4 (12.5 m)	38.54[c]	-4.856	3.57%	1.65
5	T5 (25 m)	37.24[c]	-6.156	-	1.99

STD = standard deviation

Statistics

```
MeanCVMS errorLSD    alpha   test            treat.Pr (>F)
43.396 6.459158  7.8569 3.758132      0.05 Fisher-LSD5.91e-06***
```

Appendix Table K. The effects of F.*albida* on understory wheat above ground biomass (agb) in toneha−1.

No	Number of treatments	Mean above ground biomass (Agb) in toneha−1 (average of five replication)	Agb Difference from mean	agb increments in % over the control	STD
1	T1 (1.5 m)	18.34[a]	+2.072	31.19%	1.20
2	T2 (3.5 m)	18.04[a]	+1.772	29.04%	1.33
3	T3 (5.5 m)	15.58[b]	-0.688	11.44%	0.30
4	T4 (12.5 m)	15.40[b]	-0.868	10.16%	0.51
5	T5 (25 m)	13.98[c]	-2.288	-	0.44

STD = standard deviation

```
Statistics
MeanCVMS errorLSD    alpha   test                treat.Pr (>F)
16.268 5.118493 0.69335    1.1164070.05 Fisher-LSD1.021e-06 ***
```

Appendix Table L. The effects of *F.albida* on understory wheat height in centimeter.

No	Number of treatments	Mean wheat height in centimeter (average of five replication)	height difference from mean	height increments in % over the control	STD
1	T1 (1.5 m)	85.62[a]	+7.296	23.48%	1.60
2	T2 (3.5 m)	81.68[b]	+3.356	17.79%	3.50
3	T3 (5.5 m)	80.08[b]	+1.756	14.49%	4.17
4	T4 (12.5 m)	74.90[c]	-3.424	8.02%	5.21
5	T5 (25 m)	69.34[d]	-8.984	-	4.35

STD = standard deviation

```
Statistics
MeanCVMS errorLSD       alpha     test         treat.Pr (>F)
78.324 3.19905 6.27815      3.3594050.05 Fisher-LSD1.943e-07 ***
```

Appendix Table M. The effects of *F.albida* on under-story wheat spike length (SL) in centimeter.

No	Number of treatments	Mean wheat spike length in centimeter (average of five replication)	SL difference from mean	SL increments in % over the control	STD
1	T1 (1.5 m)	8.54[a]	+1.06	30.18%	0.59
2	T2 (3.5 m)	7.76[b]	+0.28	18.29%	0.71
3	T3 (5.5 m)	7.56[b]	+0.08	15.24%	0.80
4	T4 (12.5 m)	6.98[c]	-0.5	0.64%	0.83
5	T5 (25 m)	6.56[d]	-0.92	-	0.82

STD = standard deviation

```
Statistics
MeanCVMS errorLSD      alpha    test     treat.Pr (>F)
7.48 2.966891 0.04925 0.29754290.05 Fisher-LSD2.39e-09 ***
```

Appendix Table N. The effects of F.*albida* on under-story wheat numbers of tillers ¯1m².

No	Number of treatments	Mean wheat numbers of tillers ¯1m² (average of five replication)	Tillers difference from mean	tiller increments in % over the control	STD
1	T1 (1.5 m)	634.4	+78.8	39.24%	0.54
2	T2 (3.5 m)	639.2	+83.6	40.23%	0.54
3	T3 (5.5 m)	577.4	+21.8	26.73%	0.54
4	T4 (12.5 m)	471.4	-84.2	3.47%	0.83
5	T5 (25 m)	455.6	-100	-	0.44

STD = standard deviation

```
Statistics
MeanCVMS errorLSD      alpha    test     treat.Pr (>F)
555.6 12.20058    4595 90.884370.05 Fisher-LSD0.000767 ***
```

Appendix Table O. Tables presented in this appendix provide Result of Analysis of variance for data on teff above ground biomass under experimental tree found in the study area.

Sources	DF	Sum Sq.	Mean Sq.	F-value	Pr > F	LS
REP	4	0.060	0.0150	1.017	0.428	-
TRT	4	2.944	0.7360	49.898	7.74e-09	***
Residuals	16	0.236	0.0148			

REP= Replication, TRT=Treatments, LS= Level of significance, *** (*P<0.001*)

Appendix Table P. The effects of *A.albida* on understory teff yield in quintal ha−1.

No	Number of treatments	Mean grain yield in quintal ha−1 (average of five replication)	Grain yield difference from mean	Yield increments in % over the control	STD
1	T5 (25 m)	25.46	+7.076	78.04%	0.91
2	T4 (12.5 m)	20.04	+1.656	40.14%	5.32
3	T2 (3.5 m)	17.24	-1.144	29.4%	1.44
4	T3 (5.5 m)	14.88	-3.504	4.06%	5.70
5	T1 (1.5 m)	14.30	-4.084	-	1.00

STD = standard deviation

```
Statistics
MeanCVMS errorLSD      alpha  test      treat.Pr (>F)
18.384 20.71155 14.4979    5.1050380.05 Fisher-LSD0.00167**
```