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Integrating *Faidherbia albida* trees into a sorghum field reduces striga infestation and improves mycorrhiza spore density and colonization

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Abstract Integrating agroforestry trees such as *Faidherbia albida* (*F. albida*) into cropland improves soil fertility and maintains persistence of associated beneficial microorganisms such as Arbuscular Mycorrhizal Fungi (AMF) that protects crops from striga colonization. *Striga hermonthica* (striga) is an obligate root hemi-parasitic weed of maize and sorghum, which stunts growth and causes low grain yield. Data on physico-chemical properties of the soil, yield components of sorghum, striga infestation and spore abundance and colonization of AM fungi were collected from underneath and away from the *F. albida* canopy. The experiment was composed of four treatments and six replications in a randomized complete block design (RCBD) with 24 plots, each with 15 m^2 size. Soil and root samples were also collected from under and outside of the *F. albida* canopy and sorghum crops. Soil organic matter, total N, available P, CEC, and total K were significantly higher under the *F. albida* canopy than away from it ($P < 0.05$). Similarly, yield of sorghum was also significantly higher under the *F. albida* canopy than away from it ($P < 0.05$). The highest striga count was recorded away from the *F. albida* canopy. In contrast, minimal striga infestation was found under and at the periphery of the *F. albida* canopy. The spore density and colonization of AMF were higher under and at the periphery of the *F. albida* canopy than away from it ($P < 0.05$). There was a significant and negative correlation between AMF fungi spore density and colonization, and striga counts at the early stage of sorghum growth. Integrating *F. albida* into agricultural fields with sorghum crops improves productivity and maintains AM inoculum which may control striga weed infestation.

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Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is an important staple food crop in Africa, South Asia and Central America. It is the fifth major cereal crop in the world in terms of tonnage yield after maize, wheat, rice and barley (FAO 2004). It is also one of the most widely grown cereal crops in Ethiopia (Asfaw 2007). Sorghum grows in a wide range of agro-ecologies but, most importantly, in moisture-stressed areas where other crops are unproductive and food insecurity is prevalent (Asfaw 2007). Despite its drought tolerance, sorghum growth and yield are reduced by parasitic weeds such as *Striga hermonthica* (Del.) Benth (hereafter striga). Striga is a parasitic weed of the Scrophulariaceae family and considered to be one of the greatest biotic constraints to cereal crop production in Sub-Saharan Africa (Esilaba and Ransom 1997; Sauerborn 1991). In particular, it affects resource-poor small-scale farmers unable to access different control options (Odendo et al. 2001).

In sub-Saharan Africa, it has become not only a biological constraint to food production but also a socio-economic problem for resource-poor farmers (Ikie et al. 2007). Striga causes severe crop damage in 21 countries in Africa, seriously affecting the livelihoods of some 300 million people (Berner et al. 1996). Lagoke et al. (1991) reported that striga infestation in East Africa caused cereal crop yield losses from 65 to 100 %. Similarly, striga has been reported colonizing over 86,000 ha of cropland in Ethiopia resulting in an estimated maize yield loss of more than 76,000 tons per year, equivalent to almost US$ 15.8 million per year (Woomer and Savala 2008). Severe striga infestation sometimes leads to complete abandonment of cereal crop fields, particularly maize and sorghum. Declining soil fertility favors increased striga infestation. The presence of this weed is considered by farmers in the tropics as an indicator of low soil fertility (Avav et al. 2009).

The infestation problem of striga can be reduced by preventing its germination and establishment through introducing improved farming practices including intercropping of cereals and legumes, crop rotation, adding nitrogenous fertilizer and use of herbicide (Hess et al. 1992; Kim et al. 1997a, b; Carsky et al. 2000; Kureh et al. 2000; Schulz et al. 2003). The use of nitrogen-fixing trees as a substitute for inorganic fertilizers has been reported to be a viable alternative for soil fertility replenishment particularly for low input smallholder farmers in Africa (Makumba et al. 2007). Although farmers are aware that soil fertility depletion promotes striga infestation and therefore application of inorganic fertilizer reduces loss, often these are unaffordable for poor rural farmers (Lameck et al. 2003). Alternatively, soil fertility could be improved by incorporating a nitrogen-fixing legume into the cereal crop, improving soil N status as well as providing greater ground cover than a mono-cropping system. The incorporation of *F. albida* perennial trees is one such option (Poschen 1986).

Intercropping of annual crops with perennial trees has been demonstrated to reduce the striga seed bank through an increase in soil fertility (Kanampiu et al. 2002; Khan et al. 2007, 2008). It has also been reported that the addition of fertilizer not only stimulates growth of the host but also reduces germination, attachment and subsequent development of the parasitic weed (Abunyewa and Padi 2003).

Arbuscular Mycorrhiza (AM) Fungi form mutualistic symbioses with plant roots, including those of cereal crops. AM fungi can inhibit germination of striga and reduce its growth while enhancing growth and development of sorghum. In sorghum, colonization by AM fungi is associated with increased growth, increased nutrient uptake, and more efficient water utilization (Simpson and Daft 1990; Raju et al. 1990; Osnubi 1994; Ortas et al. 1996) compared with uncolonized plants. In agroforestry systems, tree root mycorrhizae might provide additional benefits by maintaining active mycorrhizal propagules in the soil which can then rapidly colonize the developing crop root system (Diagne et al. 2000) and maintain a high inoculum potential in the soil (Godbold and Sharrock 2003). AM fungi have also been reported to decrease damage by soil-borne pathogens (Azcón-Aguilar and Barea 1996).

Any inhibitory effect of AM fungi on the growth of parasitic plants, such as striga, in sorghum systems would improve control. This might also have multiple advantages by also improving soil fertility thus potentially increasing yield. Considerable research has been conducted on the control of striga using integrated nutrient management. However, there is lack of knowledge on the relationship between agroforestry tree proximity and mycorrhizal colonization effects on sorghum growth and striga control in Ethiopia. The focus of this paper is, therefore, to investigate the effect of *F. albida* tree proximity on soil physico-chemical properties, sorghum yield, AM colonization and striga infestation under and away from the *F. albida* canopy in an agroforestry system in Ethiopia.

Materials and methods

Study area

The study site is located in *TahtayMaychew* district, central zone of Tigray region in the Northern part of Ethiopia, between 37°30′ and 39°00′ longitude and 14°00′ latitude. The study area is characterized by semi-arid climatic conditions. Mean seasonal temperature varies between 20 and 25 °C and temperatures can exceed 35 °C from January to May (Tarekgn 1997). The mean annual rainfall is 700 mm, with the main rainy season between June and September. The main soil texture in the area is characterized as clay with a thin layer of humus. The dominant natural vegetation type is deciduous and evergreen shrub (Gidey 2009) with scattered trees such as *Faidherbia albida* Del.A.Chev. *Cordia africana* Lam., *Croton macrostachyus* Hochst. ex Delile, *Eucalyptus camaldulensis* Dehnh., *Eucalyptus globulus* Labille., *Acacia lahai Benth.,* and other *acacia* species. The local population depends mainly on mixed farming involving both cultivation of crops and livestock production (Gidey 2009). Agroforestry practice is common in the area and is predominantly *F. albida* based with sorghum, a major grain crop locally.

Treatments and experimental layouts

To understand the effect of distance from *F. albida* trees on soil fertility parameters, AM spore density and colonization, striga infestation, and sorghum growth and yield, soil, root, AM Fungi association information, sorghum biomass and yield measurements were taken from four treatments. *Sorghum bicolor* was planted using similar management practices to those of local smallholder farmers. Measurements were taken from three distances away from the trees *(F. albida*) (under the canopy, at the periphery of the canopy and 3 m away from the periphery) and from an adjacent control (without any trees). The experiment was composed of 24 experimental units: three distance treatments plus a control, replicated six times using the randomized complete block design (RCBD). The *F. albida* trees selected for the study had the same age and canopy size with the same soil type and management. Trees were 10 years old and mean canopy diameter was approximately 6 m. The size of the experimental plots was 15 m^2 (3 × 5 m rectangular plot).

Soil sampling and analysis

Composite soil samples were taken from 0 to 30 cm depth from 24 plots (1) before the start of the experiment and then (2) after the harvest of the crop. In total, 48 soil samples were analyzed at Mekelle University Soil Laboratory. Soil pH was measured with a pH meter in a 1: 2.5 soil suspension (W/V), soil organic carbon (SOC) was analysed using the Walkley–Black Method (Nelson and Sommers 1982) and cation exchange capacity (CEC) by extraction in an ammonium (sodium) acetate, determined using flame photometer (van Reeuwijk 2002). Total nitrogen and available phosphorus were determined using the Kjeldhahl and Olsen methods (Ryan et al. 2001) respectively.

Planting and crop management

Land preparation for the experiment was done prior to the onset of the rains and was ploughed twice using oxen-plough. The selected sorghum variety is locally known as "*wediaker*" and is widely grown in the study area and known for its high grain yield relative to other sorghum varieties yet high susceptibility to striga (personal communication, TARI). Sorghum was planted at the beginning of the rainy season (15 June 2012), sorghum was planted with two seeds per pocket at 0.25 m intra-row and 0.75 m inter-row pocket spacing- Plants were thinned to 1 plant per pocket at 2 weeks after planting. Weeds except striga were removed weekly to avoid confounding effects on striga and sorghum growth. Sorghum was harvested at physiological maturity from the middle three rows per plot to avoid border effects. All measurements were conducted on the three middle rows per plot to avoid border effects.

Striga emergence and aboveground biomass

Striga infestation was estimated by recording the number of striga shoots emerged per plot (3 × 5 m) during the vegetative stage of sorghum at 65 days after planting (DAP) and at the heading stage of the planted sorghum at 95 DAP. The first striga count was at 65 DAP as this was the expected time of maximal emergence (Kim et al. 1997a). Aboveground biomass of striga was estimated by collecting striga shoots at 95 DAP and air drying to constant mass for 4 days then calculating on a per hectare basis.

Sorghum growth and yield parameters

At harvest, plant height (m): was measured from the base of the stem at ground level to the tip of the head from 5 randomly selected plants per plot. To measure the grain yield, grain heads from all plants in the three middle rows were collected, air-dried, threshed, cleaned and grains weighed at 10 % moisture content. Aboveground stover was estimated by air-drying for 7 days all remaining aboveground material (excluding grain) to constant mass.

Mycorrhiza spore and colonization

Soil and root samples were collected to determine spore analysis and AM fungal colonization. For collecting soil and root samples, each *F. albida* tree was replicated six times. The soil samples were collected in four directions (at a depth of 0–30 cm using a cylindrical soil corer with internal diameter of 10 cm) at each lateral distance from the tree trunk and mixed thoroughly to form a composite soil from each sample. In total, twenty-four composite soil samples, 4 composite soil samples per tree were collected. To analyze AM fungal spores, sub-samples of 400 g were taken from each soil sample. Similarly, mycorrhiza spores were determined by extracting sub-samples of 100 g of air-dried collected from each radial distance of the tree trunk. The sub-samples were wet sieved and decanted, followed by the method of flotation-centrifugation in 50 % sucrose (Brundrett et al. 1996). Mycorrhiza colonization was measured by collecting live fine roots of *F. albida* trees under the canopy and at different distances for each treatment described above. Collected live fine roots from each *F. albida* tree were chopped down into 1 cm long segments which were stored in 50 % ethanol, and kept at room temperature until they were cleared and stained (Brundrett et al. 1996). The stained root segments were then evenly distributed in a 9 cm diameter round petri-dish marked gridlines (1 cm^2) and using the gridline intersect method to estimate root colonization of individual species (Giovannetti and Mosse 1980).

Statistical analysis

Before making the analysis of variance to assess treatment effects, assumption of normality and homogeneity of variance were checked using the Shapiro–Wilk and Levens test, respectively. Significant differences between means was determined by LSD at 5 % probability level. The effect of *F. albida* on soil parameters, sorghum yield parameters, striga infestation level, number of spores and AM fungi colonization were analyzed using one way analysis of variance using GenStat statistical software.

Results

Soil fertility status of experimental plots at different canopy distance

The levels of organic matter, total nitrogen, and available phosphorus reduced with increasing radial distance from the *F. albida* tree. Significantly ($P < 0.05$) higher soil organic matter (SOM), CEC, total N and available phosphorous were recorded in plots under the canopy and at the periphery of the canopy than away from the canopy of *F. albida*. As compared to the control plots, SOM under the canopy and at the periphery of the *F. albida* tree was 19.8 and 13.7 % higher, respectively (Table 1). Similarly, total N was 56 and 71 % higher under the canopy and at the periphery of the canopy, respectively compared to the control plots. Available P under the canopy of *F. albida* also 13.6 % higher than in control plots (Table 1). There was no significant difference in soil pH among treatments.

Table 1 Treatment effects on pH, total N (%), SOM (%), CEC (meq 100 g^{-1} soil), available P (ugg^{-1}), Available K ($cmol^{+}$ kg^{-1}) under the canopy and outside the canopy of *F. albida* trees

Treatments	pH	N	SOM	CEC	P	K
Under	6.11	0.025ab	1.26a	0.73a	3.32a	3.60a
Periphery	6.06	0.035a	1.17ab	0.68ab	3.14ab	3.63a
Away	5.95	0.032ab	1.15ab	0.67ab	2.87b	2.43c
Control	6.05	0.011b	1.01b	0.58b	2.87b	2.97b
LSD (5 %)	NS	0.000069	0.156	0.22	0.245	0.171
CV	2.5	13.2	11.3	6.2	2.3	2.5
SEM±	0.022	0.00001	0.015	0.03	0.03	0.019

Values along column followed by the same letter(s) are not significantly different (P > 0.05). Under: Soil under the canopy of *F. albida*, Periphery: Soil at the periphery of *F. albida*, Away: Soil 3 m away from the periphery of *F. albida*, Control: Soil outside the canopy of *F. albida*

Growth, grain yield and above ground biomass of sorghum

Days to heading, days to maturity, plant height, aboveground biomass and grain yield of sorghum showed significant differences according to distance from the trees (P < 0.05). Days to heading and maturity of sorghum decreased as the distance increased from the *F. albida* tree trunk (Table 2). The longest days to maturity was 119 for sorghum crops under the canopy and the shortest days to maturity was 89 days for sorghum crops without *F. albida* (Table 2). Sorghum plants were taller under the canopy (216.67 cm) than those at the periphery of the canopy (195.83 cm), than those at 3 m away from the periphery of the canopy (183.33 cm) and plants were shortest in the control plots (149.67 cm).

Table 2 Days to 50 % heading and maturity and plant height (cm) at different distances from and within the canopy of *F. albida* trees

Treatments	Heading (days)	Maturity (days)	Plant height
Under	84.67a	118.50a	216.67a
Periphery	78.00b	98.00b	195.83b
Away	74.50c	94.50b	183.33b
Control	67.67d	88.67c	149.67c
LSD (5 %)	2.323	4.263	12.48
CV	2.5	1.5	5.4
SEM±	3.56	12	102.8

Values on the same column followed by the same letter(s) are not significantly different at P > 0.05. See Table 1 for treatments

Grain yield was significantly affected by distance to trees (P < 0.05) (Table 3). Sorghum grain yield under the canopy of *F. albida* was higher (4.4 ton ha^{-1}) than in the control (2.3 ton ha^{-1}) (Table 3). Plots at the periphery of *F. albida* canopy had significant (P < 0.05) and higher grain yield than plots in the controls and 3 m away from the periphery of the canopy. The aboveground biomass response of sorghum showed a similar trend to that of grain yield. Plots under the canopy had significantly (P < 0.05) higher aboveground biomass than the control plots (P < 0.05), but were not significantly different from those at the periphery of the canopy.

Emergence and above ground biomass of striga

Striga emergence was significantly different according to position relative to the trees (P < 0.05) (Table 4).

Table 3 Effect of *F. albida* tree canopy on grain yield and aboveground biomass on sorghum

Treatments	Grain yield (ton ha^{-1})	Aboveground biomass (ton ha^{-1})
Under	4.45a	100.13a
Periphery	4.05a	97.00a
Away	3.23b	89.23a
Control	2.35c	75.76b
LSD (5 %)	0.30	9.02
CV	0.78	0.89
SEM±	0.56	488

Values along column followed by the same letter(s) are not statistically significantly different (P > 0.05). See Table 1 for treatments

Table 4 Striga infestation level at 65 and 95 days after planting (DAP) of sorghum growth and aboveground biomass at 95 DAP at different distance of *F. albida* trees

Treatments	No of striga per plot (15 m^2)		Striga aboveground biomass (ton ha^{-1})
	65 DAP (vegetative stage)	95 DAP (heading stage)	
Under	0.04c	0.09c	0.01c
Periphery	0.06c	0.12c	0.02c
Away	1.17b	14.12b	0.03b
Control	5.00a	40.83a	0.10a
LSD (5 %)	0.41	9.23	0.01
CV	21.3	5.4	3.21
SEM±	0.11	56.31	0.0009

Values along column followed by the same letter(s) are not statistically significantly different (P > 0.05). See Table 1 for treatments

Striga number was highest in the control yet was significantly low under and at the periphery of the *F. albida* canopy both at 65 DAS and at 95 DAS. The highest number (41) of striga shoots was recorded at 95 DAS (heading stage) in the control plots. Dry weight of striga was significantly different among the different distances from the canopy. Similarly, significantly higher number of striga dry weight and biomass were recorded in the control plots than in the plots under and at the periphery of *F. albida* (Table 4).

AM fungi spore abundance and root colonization

There was significantly ($P < 0.05$) higher spore count at the periphery of *F. albida* than all other positions while there was no significant difference in AM fungi spore counts between positions (Table 5). AM fungi hyphal structures were the most abundant of the three fungal structures followed by vesicles and arbuscules. The proportion of root segments bearing both arbuscules and vesicles were generally low (32–39 %). Level of root colonization (%) was significant different ($P < 0.05$) between the positions and generally decreased with increasing distance from trunk of the tree species (Table 5).

AM fungi root colonization was significantly and positively correlated with spore abundance. However, both AM fungi root colonization and spore abundances were significantly but negatively correlated

Table 5 Spore abundance at different horizontal distances from the tree trunk of *F. albida*

Treatments	Spore abundance (100 g^{-1} of dry soil)	Root colonization (%)
Under	36.00b	65.00c
Periphery	69.00a	71.20b
Away	29.33c	73.00a
Control	28.6bc	–
LSD (5 %)	5.13	1.38
CV	10.2	1.4
SEM±	17.38	0.92

Values along column followed by the same letter(s) are not statistically significantly different (P > 0.05). See Table 1 for treatments

with striga infestation (Table 6). There was a positive and highly significant correlation between distance from tree trunk and grain yield (Table 6). Phosphorous availability was highly but negatively correlated with percent of root colonization ($r = -0.68$) and an increased number of striga shoots emergence at both 65 and 95 DAS ($r = -0.72$) (Table 6). Root colonization of AM fungi was significantly but negatively correlated with an increased number of striga shoots emergence at both 65 DAS ($r = -0.86$), whereas it was highly and positively correlated with the number of spores (100 g^{-1} of dry soils) ($r = 0.84$) (Table 6). The total number of spores (100 g^{-1} of dry soil) was also positively correlated with grain yield of sorghum ($r = 0.55$) (Table 6).

Discussion

The study indicated that *F. albida* tree presence was significantly associated with higher soil fertility and with lower fertility in treeless control plots. The higher SOM and nutrients concentrations under and close to the tree canopy could be attributed to the litter fall inputs from the tree (Nair 1984). Soil organic matter was 25 % higher under as compared to outside the canopy. The results were similar to those obtained by Woomer and Swift (1994) and Lal (2006) who reported a strong fertility gradient from bare soil to soils under the canopies of *F. albida* in Senegal. Other studies (e.g. Kater et al. 1992) reported higher concentration of carbon, exchangeable magnesium and potassium contents in the upper soil layers under

Table 6 Pearson correlation of AM fungi spore abundance (100 g^{-1} dry soil) and root colonization with sorghum grain yield, biomass and striga infestation

Correlation coefficient (r)	GYS (q ha^{-1})	AGBS (q ha^{-1})	NS (65 DAP)	NS (95 DAP)	AGBSR (95 DAs)	SD (number 100 g^{-1} dry soil)	Rootcolonization (%)	P availability (ugg^{-1})
GYS (q ha^{-1})	1.00	0.22^{ns}	-0.245^{ns}	-0.04^{ns}	−0.37*	0.59**	0.17^{ns}	0.56**
AGBS (q ha^{-1})	–	1.00	-0.141^{ns}	−0.55**	0.216ns	-0.1^{ns}	0.2^{ns}	0.48*
NS (65 DAP)	–	–	1.00	-0.006^{ns}	0.58**	−0.41*	−0.86***	−0.72**
NS (95 DAP)	–	–	–	1.00	0.51**	−0.04	-0.3^{ns}	−0.41*
AGBSR (95 DAs)	–	–	–	–	1.00	-0.1^{ns}	−0.427*	−0.52*
SD (number 100 g^{-1} dry soil)	–	–	–	–	–	1.00	0.84***	0.24^{ns}
Root colonization (%)	–	–	–		–		1.00	−0.68**
P availability (ugg^{-1})								1.00

DAP days after planting, *r* persons' correlation coefficient, *** highly significant), ** significant), * significant, *ns* not significant (r from 0.5 to 1.0 positive correlation), (r from −0.5 to −1.0 negatively correlated), (r from −0.4 to 0.4 not significant correlation), *SD* spore density, *NS* number of striga, *AGBSR* above ground biomass of striga, *GYS* grain yield of sorghum

the canopies of both *P. biglobosa* and *V. paradoxa* than in the open fields (a tendency also observed in parkland agroforestry in Ethiopia (Hailemariam et al. 2013).

Soils under and close to the *F. albida* also have higher soil N than soils outside of the canopy. This could be because of, higher litter fall and decompositions under and close to the *F. albida* than the outside. This result agrees with Young (1997) who reported mature *F. albida* trees (at densities of 100 per hectare) contribute N inputs equivalent to 4420 kg N ha^{-1}. Phosphorous availability was also higher in soils under and close to *F. albida* canopy than outside of the canopy. In contrast, Atta-Krah (1990) and Hagger (1994) reported lower available P in plots under the canopy of legume crops and tree than in the open plots.

As distance decreases from the *F. albida* tree trunk, plant height as well as the days to maturity and the days to heading increase. The results agrees with the reports of Hossain et al. (2007), that better rice height and the highest number of effective tillers per hill from plots under the canopy of *F. albida* as compared to the plots under the control.The vigorous growth of sorghum, and the delay to maturity and heading could be attributed to the highest SOM and total N of the soils under and at the periphery of the *F. albida* canopy. However, findings by Nyathi and Campbell (1995) contradict to the pronounced response of sorghum grain yield and aboveground biomass under and at the periphery of the *F. albida* canopy than the control. The same authors elucidated that *F.albida* is rich in N but low in P and leads to yield reduction because *F. albida* trees immobilize P. This finding contradicts our results which show grain yield increments of 90 % under *F. albida* canopy compared to control plots. In addition to low SOM and total N of soils in the control plots, the low grain yield is associated with the high infestation of *striga hermonthica* weed. This is in agreement with the findings reported by Diriba et al. (2002). This study also documented an increase of aboveground biomass of sorghum by 22 % in plots under the canopy of *F. albida* over the control plots which could be because of nitrogen *F. albida* which improves plant height, stem diameter and number of effective tillers (Maranville and Clark 1979).

The number of striga in plots under the canopy of the *F. albida* tree was significantly lower than outside of the canopy. This agrees with Avav et al. (2009) that the highest numbers of striga stands emerge in plots with no legume trees and in plots without chemical fertilizer application. Esilaba et al. (2000) reported that sorghum fields with *F. albida* and N fertilizer decrease striga emergence and infestation on sorghum. Lower striga infestation in the field with *F. albida* and N fertilizer could be associated with ammonium nitrate which reduces production of stimulatory compounds which impede germination and subsequent growth of the weed (Cechin and Press 1993). Similar study (Gurney et al. 1999) demonstrated that highest number of striga infestation was occurred at early stage, at 65 DAS, in the control plots and cause more negative effect on the host plant than late infestation. Presence of trees in agricultural lands may reduce weed populations because of the shading effect of trees, availability of less space for their growth, shifts in species composition, and altered environmental conditions (Liebman and Staver 2001; Sileshi et al. 2006). The number of striga is significantly lower under the canopy of *F. albida* trees than in the open. Other studies have also reported that agroforestry has potential in combating striga infestation, for example, from pearl millet fields (Gworgwor 2007) and lower its floristic diversity (Libert and Eyog-Matig 1996). Another study in western Kenya by Gacheru and Rao (2001) indicated that striga infestation decrease by 40–72 % while maize yield increase by 224–316 % in moderately infested *Desmodium distotum, Sesbania sesban, Sesbania cinerascuns, Crotalaria grahamiana, and Tephrosia vogelii* fallows when compared to plots with continuous maize. In addition to role of tree shade in suppressing the growth of striga at plots near to the tree trunk, N-fertilizer also delay striga emergence, promote growth of maize and reduce striga damage (Kureh et al. 2003). The same authors also argued that an increase in crop vigor enables the crop to tolerate striga attack and decreases toxic effects of striga seeds and seedlings as well as reduces stimulant production by the host plant. Jama et al. (1991) also demonstrated that alley cropping with *Leucaena leucocephala* (Lam.) de Wit reduces weed density by 90 % and increases maize yield by 24–76 %.

AM fungi spore abundance was higher under and at the periphery of *F. albida* canopy than outside the canopy. This could be attributed to higher root density of *F. albida* as colonization of roots is associated with density of fine roots of the tree (Bolan 1991). Hailemariam et al. (2013) also reported higher number of spores in maize fields under the canopy of *F. albida* trees than outside the canopy. Spore abundance under the canopy of *F. albida* tree was lower than at the periphery of the canopy and generally spore abundance decreases with increasing distances away from the tree trunk of *F. albida*. However, other studies contradict these results and reported that distance from the tree trunk has no influence on the number of spores although more spores were observed close to the tree trunks of *Cordia africana* and *Millettia ferruginea* (Hochst) Baker and *Terminalia superba* Engl. et Diels (Musoko et al. 1994).

Root colonization increases near the trunks of *F. albida* and decreases with an increasing radial distance from the tree trunk. This is also confirmed in other studies made for trees in dry Afromontane forests of southern, northern and north western Ethiopia (Birhane et al. 2010; Wubet et al. 2003). The proportion of hyphae in this study was far higher (65–73 %) than the proportion (26–50 %) reported by Wubet et al. (2003) for the dry afromontane tree species and Birhane et al. (2010) for the dry deciduous woodland species. The observed differences in the proportion of AM fungi in the roots of tree species could be due to the difference in edaphic factors and climatic factors (Lambert et al. 1980; Rabatin and Stinner 1991). The pattern of root colonization varies depending on the distance from the *F. albida* trunk. The variations could be created due to roots which might extend up to the edge of the crown with uniform distribution of AM fungal infection. A high density of fine roots can stimulate high root colonization, increasing inflow rate of P into mycorrhiza up to six times than that of the root hairs (Bolan 1991). Mycorrhiza plants greatly increase uptake of many nutrients (Wiedenhoeft and Hopkins 2006). Studies also reported that agroforestry is an important practice that should be prompted for maintaining the mycorrhizal inoculum potential in farming systems (Mason and Wilson 1994; Shepherd 1992). Grime et al. (1987) also indicated that transfer of assimilates from one plant to understory component is facilitated through a common mycorrhiza network that may necessitate more AM fungal colonization.

This study indicated that mycorrhiza root colonization of *F. albida* trees is significantly but negatively correlated with the number of striga which shows that striga population is suppressed under the canopy of the trees. This is because the inoculum in the soil under the canopy of the trees may seem to have been sufficient in terms of mycorrhiza colonization levels and growth enhancement of the cereal, which suggests that high mycorrhiza colonization rate has beneficial effects in managing striga (Lendzemo et al. 2007). Through their metabolites, which either stimulate or inhibit striga germination in sorghum, mycorrhizal fungi increase plant biomass and compensate for damages caused by *Striga hermonthica* (Lendzemo and Kuyper 2001). This implies that *F. albida* delays striga germination which can be attributed to the mycorrhiza colonization during the active growth stage of sorghum which enables the crop to uptake nutrients for its robust growth. This study also reported that aboveground striga biomass was reduced by 41 and 37 % under and at the periphery of the canopy plots, respectively, compared to the control plots. Other studies (Lendzemo and Kuyper 2001; Gworgwor and Weber 2003; Lendzemo 2004) found that AM fungal inoculation reduces the number and biomass of striga shoots emerging on the cereal crops and these findings are consistent with results from other studies conducted under controlled conditions.

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