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Role of *Acacia seyal* on selected soil properties and sorghum growth and yield: a case study of Guba-Lafto District, North Wollo, Ethiopia

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Report summary

Acacia seyal is one of the multipurpose parkland agroforestry tree species in most eastern and southern Africa. It is a common on-farm tree in the rift valley of Ethiopia predominantly in Guba-Lafto district of northern Ethiopia but information is limited on its effect on soil property and sorghum growth and yield. The study was conducted to evaluate the effects of *Acacia seyal* on selected soil properties, sorghum growth and yield at Jarsa Kebele. Six isolated and closely comparable *Acacia seyal* trees growing on sorghum farms were purposely selected and plots were marked under the canopy of trees with three radial distance (0-2m, 2-4m and 4-6m) and one outside of the tree canopy (10 meters away from any tree). Soil samples from each distance zone were taken from 0-20 cm and 20-40 cm soil depths for analysis of selected soil physicochemical properties. Four quadrates with 1m*1m at each distance zone in four directions were laid for sorghum growth and yield attribute valuation. Results showed that only total nitrogen (TN) was significantly higher ($P<0.05$) at subsoil layer under the canopy compared to an open area. The other parameters electrical conductivity (EC),soil organic carbon (SOC), soil PH, Cation exchange capacity (CEC), available phosphorus (P), moisture content (MC), bulk density (BD) and texture didn't vary significantly under the canopy and in the open. Sorghum biomass yield ($p=0.006$) and grain yield ($p=0.025$) were significantly lower under the canopy of the tree than in the open area. However, the total sorghum height and count of sorghum stands were not statistically affected ($p>0.05$) by the tree. Generally, *Acacia seyal* had little effect in improving soil properties and showed a negative effect on sorghum yield and growth. Further research on its effect under wide area coverage of parkland system and optimum on farm density need to be determine to bring radical shift on the intercropping farming system.

Introduction

The population growth rate in the sub-Saharan Africa is increasing rapidly despite the lower rate of food production which needs alternative solutions for parallel growth in food production (Mwangi, 1996). On the other hand, climate change is a major constraint for declining agricultural productivity which created food crisis particularly for smallholder farmers; needs climate mitigation action and climate-resilient agricultural strategy (Syed & Jabeen, 2018). High chemical fertilizer input and fast-tracked soil fertility loss is also becoming another challenging factor for sustainable agricultural land productivity and wide environmental problems (Mwangi, 1996; EEA, 2005; Biala *et al*., 2007). Inorganic or artificial fertilizer applications are also risky for the environment and found inhibiting the naturally important nodulation and nitrogen fixation and symbiotic associations which again affect nutrient recycling (NZDL, 1991; Pender and Ehui, 2006).

So, agricultural productivity reduction and food crisis challenge call for creating a multifunctional agricultural system that fulfils both intensified crop productivity improvement and socio-economical valuable farming system (Waldron *et al*., 2017; Garibaldi *et al*, 2017). Improving the current farming system as climate-smart agriculture and sustainable productivity is important for sustainable development and food security via increasing agricultural productivity and enhancing the resilience of livelihoods and ecosystems to climate change (Schaller *et al*., 2017; Lipper, 2014).

Among the different existing options, agroforestry is one of the environmentally friendly approaches that help farmland soils improved and checked in smallholder farmers (Schaller *et al*., 2017; Fahmi *et al*., 2018). It has many provisional, regulating and cultural services and considered as climate-resilient and adaptation mechanism (Udawatta *et al*., 2017; Belay *et al*., 2017; Altieri and Nicholls, 2017; Udawatta *et al*., 2017; Vermeulen *et al*., 2012). Maintenance and improving existing practices and incorporation of MPTs on farms are recognized as critical interventions to increase agricultural productivity in a sustainable way (Schaller *et al*., 2017; Fahmi *et al*., 2018). Trees are advantageous on protecting environmental degradation, reducing external input costs; generally consider as means for organic farming which assure agricultural sustainability (Jouzi *et al*., 2017). Moreover, nitrogen-fixing legume trees get attention for nitrogen fertilizer enhancement thereby enhance crop productivity and create an opportunity for sustainability (Amanuel *et al*., 2000; Biala *et al*., 2007; Pender and Ehui, 2006).

Acacia seyal is one of drought-tolerant agroforestry tree species found in most Eastern and Southern Africa and native trees to the Sahelian zone of Africa (Orwa *et al*., 2009; Lal and Stewart, 2014). It has a typical drought avoidance strategy and adaptable to water stress conditions (Merine *et al*., 2015). Unlike other most legume tree species it nodules with both fast-growing (Rhizobium) and slow-growing (Brady rhizobium) bacteria strains which strengthen its role in nitrogen fixation and soil improvement ability (Dreyfus and Dommergues, 1981). Limited research investigations were carried out so far on *Acacia seyal* effect and its social contribution in various countries at different levels (Abdalla and Fangama, 2015; Woldu *et al*., 1999; Mariod *et al*, 2014). In the study area, different thicket of *Acacia* spp. are growing in undulating hills and farmlands. The farming communities allow *Acacia seyal* grow in their farmlands. The species seems well synchronized with the farming communities. However, its contribution to soil fertility and sorghum productivity had been least studied.

Therefore, this study was designed to investigate the effect of *Acacia seyal* on selected soil properties and sorghum growth and yield attributes in farmlands during the main rainy season in Guba-Lafto district, North Wollo Zone.

Materials and methods

Study area Description

Study area is located in Guba-Lafto district, North Wollo Zone of Amhara National Regional State, Ethiopia which is between 39^{0}6'9" to 39^{0}45'58'' East and 11^{0}34'54'' to 11^{0}58'59'' North and ranges 1379 to 3200 m.a.s.l). It is situated 521 km North from Addis Ababa. The soil texture of the area is dominated by sandy clay (46%), clay-loam-brown (39%) and small percentages of sandy soil (8%) and silt soil (7%) (Mengistie and Kidane, 2016). Lithic Leptosols (92.2%) are dominated soil type in the district followed by Eutric Cambisols (3.9%) and Eutric Leptosols (3.5%) (FAO, 1997). It is majorly described with mid (Woina-Dega) agro-ecological condition (46%). Rainfall is poor in distribution to the area and it receives bimodal rainy season with summer and short winter season. Mean annual and monthly rainfall and temperature range from 800 - 1050 mm and 21 °C to 25 °C respectively (Mengistie and Kidane, 2016). Subsistence agriculture is the main livelihood system of the rural population with commonly mixed, crop and livestock farming systems. Agricultural land is limited, which is 36 % of total land and landholding size per household ranges from 0.4 to 1.93 ha (Lemma, 2010). Among various cereals and pulses, sorghum and teff were commonly cultivated crops, especially during the summer rainy season.

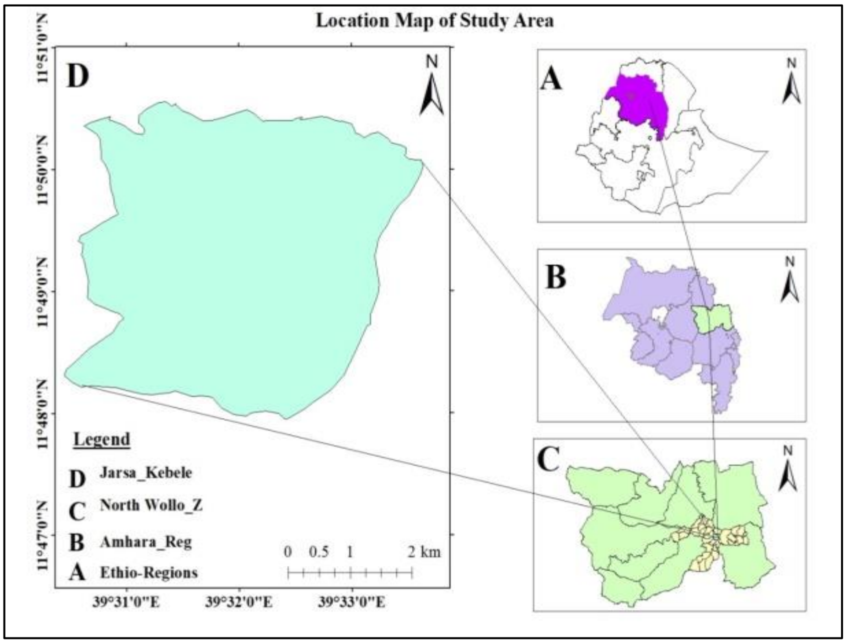

Figure 1: Geographical map showing the location of the study site

Experimental design and treatment

Sorghum (var *Jamyo*) farmlands with similar crop history and management were systematically selected from farm communities at household level. Then, six *Acacia seyal* (var fistula) trees were selected randomly from systematically selected trees along with sorghum farms. Tree height, diameter at breast height (DBH), and canopy diameter were measured. The diameter at breast height was measured over bark in cm via caliper, the canopy radius were taken by measurement of crown width using meter tape in both directions and take average value in meter (m) and the height measurement was taken via Suunto clinometer and expressed in meter (m). Soil sampling and sorghum growth and yield measurements were taken under three concentric radial distance (subplot) of the selected *Acacia seyal* and one from open area-near the base (0-2m), under the canopy (2-4m), edge of the canopy (4-6m), and control plot with 10 m away from tree base in four directions.

Soil sampling and analysis

Soil sample was taken from each of three radial distance of tree (naming: D1, D2, and D3) and from open area (D4), via stainless auger (Wilding, 1985) in four directions with two soil depths of 0 - 20cm and 20 - 40 cm (Hartz, 2007; Estefan *et al*., 2013) at the end of long rainy cropping season. A total of 48 composite soil samples (6 plots x 2 depths x 4 concentric distance zone) were sampled and analyzed at Sirinka regional research center soil Lab. Soil pH was determined by using pH meter in a 1:2.5 soil: water suspension and soil electrical conductivity (EC) was measured using conductivity meter in saturated paste extract. Total nitrogen (TN) was determined by Kjeldahl acid digestion method (Jackson, 1958); available phosphorus was determined via absorbance on spectrophotometer following Olsen (1954); Cation exchange capacity (CEC)was determined after extraction of soils with ammonium acetate method at pH 7 following Chapman (1965); soil organic carbon was determined via oxidation method (Walkley and Black, 1934); soil bulk density (BD) estimated via oven-dry method (Brady and Weil, 2002); moisture content (MC) by Gravimetric method (Blake and Hartge, 1986); texture determine by Bouyoucos methods using hydrometer (Bouyoucos, 1962).

Growth and yield parameters of sorghum were collected from each subplot of 1 m x 1 m. Sorghum plant stock height and panicle length were recorded using meter tape from 10 randomly selected sorghum plants of the net quadrant at harvest time. Total numbers of sorghum plants counted on each subplot were taken and used their average value. Above-ground biomass of sampled sorghum was sun-dried to constant weight and biomass yield (kg/m^2) was estimated in kg ha^{-1} basis. The standing sorghum plants panicles were collected and manually threshed; the grains were cleaned and weighted at 12.5% moisture level and the yield was estimated per hectare basis. 1000 kernels weight in gram (gm) were manually counted and weighted. The sorghum yield (kg/ha) was estimated as a total sum of biomass and grain yield. Harvest index of sorghum was determined as a fraction of grain yield in the unit of measurement to total yield and expressed in percentage (Harvest index (%) = Grain yield / Biological yield (grain + straw) x 100) (Yoshida, 1981).

Statistical analysis

Assumption of normality and homogeneity of variance were first checked via Shapiro-Wilk test and Levene test, respectively (Zar, 2009) for meaningful interpretation. Post-hoc LSD test was used to determine the significance difference between treatments at 5% probability level. Characteristics of trees, soil physiochemical properties and sorghum growth and yield parameters were described by using mean and standard deviation via descriptive statistics. The effect of tree on soil properties and sorghum growth and yield were tested by using a one-way analysis of variance and split file method. Two-way analysis of variance was employed to check the interaction between radial distance and soil depth treatments by using Wilks' Lambda test (Pallant, 2007). Selected soil properties mean value variation along soil depth was also tested by Independent T-test along each radial distance of tree. SPSS Version- 20 software (SPSS Corp., Chicago, USA) used for analysis.

Results and discussion

Effects of *Acacia seyal* on soil properties

Soil physical properties

Soil particle fractions did not significantly vary ($p>0.05$) with distance from tree showing that the soil properties were less affected by management practices (Gupta, 2006; Miller and Donahue, 1995; White, 1997). Similar findings were reported for the case of different parkland tree species such as *Acacia seyal*, *Ziziphus spina-christi* and *Acacia senegal* (Tanga *et al*., 2014; Wolle *et al*., 2017; Githae *et al*., 2011).

Table 1: Mean values (±SD) of selected soil physical parameters under two soil depths in *Acacia seyal* parkland system

Soil properties	Soil depth	Distance from tree				P value
		near tree bole	under canopy	edge of canopy	Far from canopy	
Clay (%)	1	55.25^{a} ±1.73	56.25^{a}±4.47	56.17^{a}±3.25	55.0^{a}±7.86	0.958
	2	56.67^{a}±5.79	56.83^{a}±6.13	58.58^{a}±3.56	55.42^{a}±9.44	0.871
Silt (%)	1	22.83^{a}±3.02	23.58^{a}±1.36	21.42^{a}±2.13	23.75^{a}±3.45	0.418
	2	23.17^{a}±4.86	24.75^{a}±2.21	20.83^{a}±2.62	23.75^{a}±3.45	0.272
Sand (%)	1	21.92^{a}±2.94	20.83^{a}±3.47	22.42^{a}±4.23	21.25^{a}±5.9	0.921
	2	20.17^{a}±4.6	18.42^{a}±5.65	20.08^{a}±3.92	20.83^{a}±7.3	0.891
MC (%)	1	34.64^{a}±1.16	35.06^{a}±1.06	35.72^{a}±2.02	34.77^{a}±1.83	0.649
	2	35.09^{a}±1.44	34.90^{a}±0.32	35.18^{a}±1.04	34.86^{a}±0.89	0.937
BD (gm/cm^{3})	1	1.06^{a}±0.04	1.06^{a}±0.03	1.03^{a}±0.08	1.07^{a}±0.08	0.63
	2	1.05^{a}±0.06	1.04^{a}±0.03	1.05^{a}±0.04	1.06^{a}±0.04	0.94

Rows with the same superscript letters are not significantly different at $p < 0.05$; soil depth with 1and 2 represents 0-20 cm and 20-40 cm respectively

Moisture content was not significantly affected by the species along both soil depths ($p>0.05$) at harvesting season (Table 1). However, the lowest (34.64%) and highest (35.72%) moisture contents were recorded near the tree base (D1) and the edge of the canopy (D3) respectively for the topsoil layer (Table 1). Normally, tree species are expected to maintain soil moisture, via reducing rain speed and increasing infiltration rate (Kessler and Breman, 1991). However, such was not the case with Acacia seyal, and this might be due competition effect of small diameter and superficial lateral roots of the species (Seghieri, 1995). Similar results were found by Kassa *et al*., (2010), Akpo *et al*., (2005) and Wolle *et al*., (2017) for *Balanites aegyptiaca*, *Acacia tortilis* and *Ziziphus spina-christi* species respectively on crop farm. Bulk density (BD) was statistically in par across the distance from tree and soil depths (Table 1). It might be due to low organic carbon availability under the canopy of a tree which directly influences soil aggregate stability which again affects the bulk density of soil.

Soil chemical properties

Soil pH and electrical conductivity (EC) found not significantly influenced by the presence of *Acacia seyal* under both soil layers (Table 2). But, Electrical conductivity (EC) was a bit higher, ranged from 0.053 to 0.077 ds/m at subsoil layer than surface soil which ranges from 0.048 to 0.063 ds/m (Table 2) which means, surface soil looks less saline than subsurface (soil survey staff, 2014). Even though not significant, it was also relatively higher around tree bole than an open area. This might be due to microbial association and low leaching problems of base-forming cations around a tree (Manga *et al*., 2017). The result agreed with Kassa *et al*. (2010) and Wolle *et al*. (2017) who reported non-significant effect of *Balanites aegyptiaca* and *Zyziphus spina Christi* over EC, at arid area of Humera and Hibru district of Ethiopia, respectively.

Table 2: Mean values (±SD) of selected soil chemical parameters under two soil depths in *Acacia seyal* parkland system

Soil properties	Soil depth	Distance from tree				P value
		near tree bole	under canopy	edge of canopy	Far from canopy	
pH	1	6.3^{a} ±0.21	6.27^{a} ±0.16	6.25^{a} ±0.19	6.25^{a} ±0.29	0.99
	2	6.25^{a} ±0.19	6.25^{a} ±0.21	6.22^{a} ±0.25	6.27^{a} ±0.24	0.98
EC (ds/m)	1	$.063^{a}$ ±0.018	$.053^{a}$ ±0.013	$.048^{a}$ ±0.011	$.051^{a}$ ±0.013	0.19
	2	$.077^{a}$ ±0.02	$.053^{a}$ ±0.02	$.054^{a}$ ±0.01	$.069^{a}$ ±0.02	0.13
P (ppm)	1	23.81^{a} ±2.92	24.52^{a} ±3.40	24.16^{a} ±2.56	24.73^{a} ±4.28	0.66
	2	26.18^{a} ±4.72	23.71^{a} ±3.26	24.84^{a} ±4.39	25.91^{a} ±4.9	0.75
OC (%)	1	$.66^{a}$ ±0.23	$.59^{a}$ ±0.15	$.66^{a}$ ±0.15	$.63^{a}$ ±0.17	0.91
	2	$.59^{a}$ ±0.19	$.65^{a}$ ±0.12	$.5^{a}$ ±0.199	$.66^{a}$ ±0.21	0.4
TN (%)	1	$.15^{a}$ ±0.04	$.13^{a}$ ±0.02	$.11^{a}$ ±0.06	$.10^{a}$ ±0.05	0.26
	2	$.18^{a}$ ±0.09	13^{ab} ±0.04	$.14^{ab}$ ±0.029	$.09^{b}$ ±0.032	0.03
CEC (meq/100gsoil)	1	39.0^{a} ±14.78	49.0^{a} ±4.17	42.2^{a} ±10.22	45.27^{a} ±3.98	0.33
	2	37.0^{a} ±15.9	47.3^{a} ±6.92	43.03^{a} ±4.74	48.27^{a} ±3.88	0.17

Rows with the same superscript letters are not significantly different at $p < 0.05$; soil depth with 1and 2 represents 0-20 cm and 20-40 cm respectively

Soil organic carbon (SOC) was expected to be significantly higher under the tree canopy, as most perennial trees contributed for organic matter input via litter fall and fine root turnover; but not for our case and this might be due to lower contribution of litter decomposition for soil carbon (Bernhard-Reversat, 2002). It was in line with finding for an integrated system of *Acacia seyal* with sorghum cropping system in Sudan (Deng *et al*. (2017).

TN was significantly affected by the presence of *Acacia seyal* tree species (p = 0.035) under the sub-soil layer (20-40 cm) with p≤0.05 (Table 2). *Acacia seyal* showed a positive significant effect (p=0.035) of the available nitrogen of the subsurface soil (Table 2), and a decreasing trend was observed from tree base to the open area. The pattern was expected since most legume tree species including *Acacia seyal* have a positive effect on soil total N (Wolde-meskel *et al*., 2004; Sinare and Gordon, 2015). It may also be associated with under tree organic carbon availability via litter fall and fine root turnover from trees and droppings of animals resting under the tree (Tilahun, 2007). Likewise, higher, (42% more), nitrogen availability under the canopy of *Acacia seyal* compared to the open area was reported in the rift valley of Ethiopia (Tanga *et al*., 2014). Others also supported similar findings on different agroforestry tree species (Boffa *et al*., 2000; Birhane *et al*., 2016). Available phosphorus found not affected by the species and this might be due to lower litter accumulation potential of the species which related to organic phosphorus availability

Numerically, CEC had lower mean value around the root zone for both soil depths compare to open area (Table 2) but was not statistically different. In agreement with this, Deng *et al*. (2017) reported lower but statistically similar CEC values under *Acacia seyal* on the sorghum intercropping system. Different parkland species like *Balanites aegyptiaca* and *Zyziphus spina-christi* were reported as having similar effect but other species like *Acacia tortilis* and *Faidherbia albida* showed a positive significant effect on CEC (Kassa *et al*., 2010); Wolle *et al*., 2017); Tanga *et al*., 2014). This might be due significant effect of those species on SOC which are directly related with CEC and in other way SOC were statistically similar in our cases (Tilahun, 2007).

Figure 2: soil sampling under tree canopy

Effect of Acacia seyal on Sorghum growth and yield

The presence of *Acacia seyal* had a significant negative effect on above-ground biomass (p=0.006) and grain (p=0.025) yields of sorghum (Figure 3). But, other growth and yield attributes were not statistically affected (p>0.05). This might be due to the shading effect of the trees on seed emergence and seedling survival and could also be due allelopathic and superficial root competition effects of the species (Hassan *et al*., 2018, Seghieri, 1995). It could also due shade intolerance character of sorghum (Wilson *et al*., 1998) which highly affected its under canopy performance (Hassan *et al*., 2018).

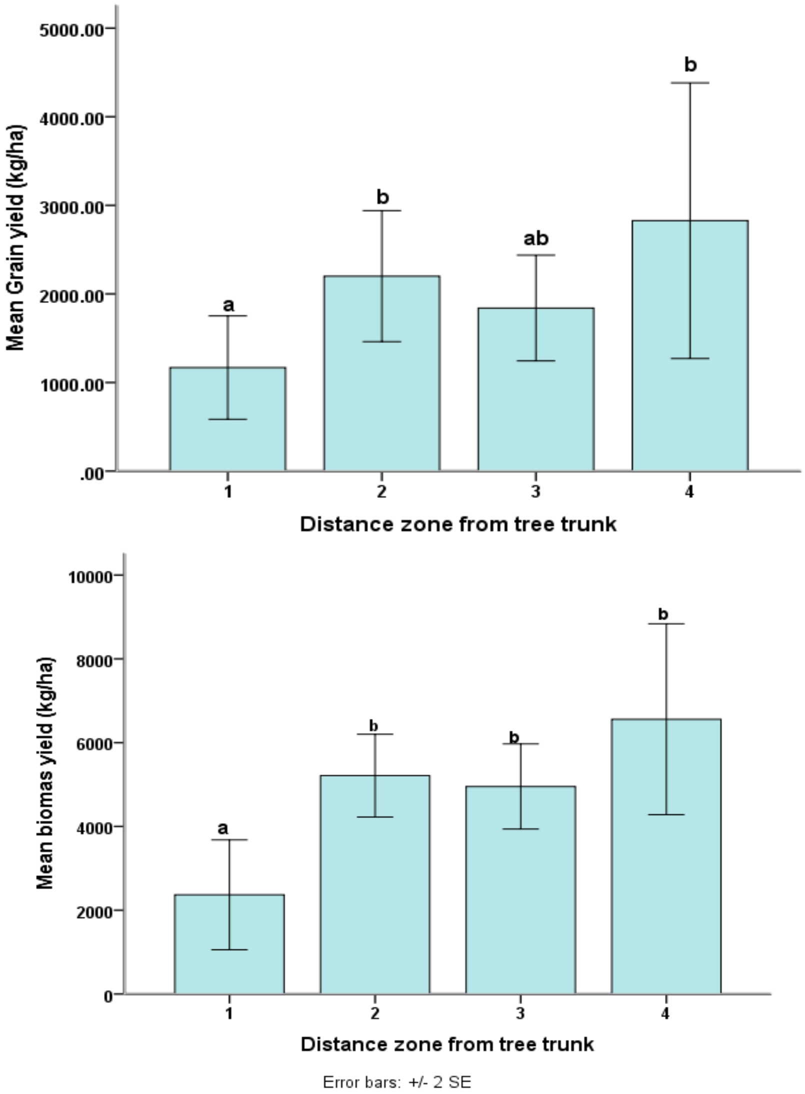

Figure 3: Effect of *Acacia seyal* on sorghum grain and biomass yield (kg/ha)
Graph with the same superscript letters are not statistically different at (P > 0.05)

Sorghum above-ground biomass (AGB) and grain yield were found affected by the presence of *Acacia seyal* ($p<0.05$). AGB was lower at D1 (2368.33 kg/ha) compared to D4 (6558.33 kg/ha) with more than fold amounts (177%). It might be correlated with number of sorghum stands counted and its growth performance (Wilson *et al*., 1998). Grain yield was also observed to be higher (142% more) at D4 compared to D1 (Figure 5). The result was unexpected since the symbiotic and nitrogen-fixing ability of *Acacia seyal* is believed to boost yield by enhancing soil fertility (Dreyfus and Dommergues, 1981). But, this might be due to the shading effect of *Acacia seyal* and its allelopathic effect on sorghum survival and growth performance which directly related to yield (Hassan *et al*., 2018, Seghieri, 1995). Superficial small diameter roots at surface layer and underground root competition of the species also contributes for yield reduction effect (Van Noordwijk *et al*., 2015). The result was in line with Deng *et al*. (2017), who reported a negative effect of *Acacia seyal* intercropping on sorghum yield and growth performance in South Sudan ($p=0.001$). However, other species like *Faidherbia albida* was found having a positive contribution to sorghum yield in case of Tahhtay Maichew district of northern Ethiopia (Birhane *et al*., 2016).

Conclusions and implications

The study showed that the widely grown *Acacia seyal* in the study area had little effect on selected soil physicochemical properties for both surface and sub-surface soil layers. The positive effect was observed only on the sub surface total nitrogen availability. The species had negative effect on biomass and grain yield of sorghum. The negative effect possibly might be due to the combined effect of the above-ground canopy and root competition of the species. Even though, it was found less important in soil improvement and sorghum production enhancement, farmers extensively manage the species on their farms and the reason might be interest for its other production benefit like fuel wood and cash values. So, it needs investigation on its off-farm socio-economic benefits for understanding its alternative roles. The current research experiment work might not represent to the whole *Acacia seyal* parkland system and was conducted on farmers crop land which may not had similar management practices. So, it is recommended for further research investigation to the wide area coverage or with controlled environment to bring radical shift on species intercropping system. Tree density and its management system also affects the productivity of companion crops on farm land so, study for the determination of optimum tree density and its appropriate management for the species is essential.

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