

Aspect and root trench effect of Eucalyptus globulus boundary plantation on barley yield and soil physicochemical properties in the Gumer district, Central highlands of Ethiopia

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Abstract

*The expansion of *Eucalyptus globules* boundary plantation (EGBP) along farm boundaries considered to have effects on yield of underneath crops. Tree root pruning or trench is a potential tool for managing belowground competition. We evaluated aspect and trench distance effect of EGBP on barley yield and soil physicochemical properties in Gummer woreda, central Ethiopia. Two months before sowing, on one side of each aspect of EGBP trenches were prepared at distances of 0.5m, 1m and 1.5m using split-split plot design with three replications. At 1.5m trench distance, the North faced field showed 20.4% to 31.2% additional yield variation respectto South, East and West faced fields. Also 15.2% to 43% additional yield was observed as the field distance from EGBP increased from 3m to 12m. Relative to un-trenched field, trenched fields showed 31.9% to 73.4% additional yield variations. Regarding to soil physicochemical properties, aspect of EGBP had no significant effect. However, except for texture, pH and extractable potassium, trench showed a significant difference on soil organic matter, total nitrogen, available Phosphors and CEC status. Relative to un-trenched fields of 6m and 9m, 1.5 m trenched field of 3m field distance showed 48 % and 15% additional yield variations. That means root trench minimized on average 24% of the field distance effect of EGBP on barley yield. Therefore, root pruning at 1.5m distance from EGBP using 0.5m x 0.5 m trench is an applicable and advisable method that will help farmers to maximize barley yield with higher land-use efficiency.*

Introduction

Eucalyptus globules is one of the dominant exotic tree species that covers most of the landscape of the Ethiopian highland with distinct characteristics (Kidanu et al., 2005; Zerga, 2016; Zewdie, 2008). The capability of growing in degraded land with less management, fast-growing with higher coppicing ability, having short harvesting period (Pohjonen & Pukkala, 1990) and its ability of adapting a wide range of site conditions makes it to be more preferable and economic tree of the poor. In the central highland of Ethiopia (Kidanu, 2004), especially in mount Gurage (Asfaw & Woldu, 1997; Zerga & Woldetsadik, 2016), east–west and north–south aligned plantation of *Eucalyptus globules* with one-meter inter-row spacing becomes more dominant. Because boundary plantation used as a bench mark between farms or fence and soil and water conservation mechanism (Kidanu, 2004; Prasad et al., 2010).

However, the implanting of *Eucalyptus globules* along farm boundaries, homesteads, and roadsides with various spatial patterns considered to have ecological effects (Aklilu et al., 2019; Kidanu et al., 2005; Zegeye, 2010; Zerga, 2016; Zewdie, 2008). For example, compared to other tree species, *Eucalyptus globules* desiccates watercourses (Alemie, 2009; Bauhus et al., 2000; Kidanu et al., 2005) and suppresses germination of understory plants through its allelochemicals (Akbar et al., 1990; Asmare, 2020; Lisanework & Michelsen, 1993). The evergreen canopy and high lateral root density nature (António Fabião et al., 1990) makes it to be competitive tree than the native once (Armel Thongo M' Bou et al., 2008; Fabiao et al., 1994; Jaleta et al., 2017)

To manage and reduce these ecological impacts, and maximize the productivities of the practices, alternative options like above and belowground tree and soil management (A Fabião et al., 2002; Khan et al., 2020; Zewdie, 2008), inter and intra spacing as well as alignment management of plantation (Kidanu et al., 2005; Prasad et al., 2010) becoming mandatory. Because as studies revealed, the effects of *Eucalyptus globules* on adjacent crop yield mainly depend on tree line orientation (Carneiro et al., 2013; Kidanu et al., 2005), tree age, and canopy cover (Kidanu et al., 2005; Zewdie, 2008). According to Nuno & Manuel, (1996) and Kidanu et al. (2005) applying proper soil management substantially increased crop yield, availability of soil nutrients, and microbial population dynamics

under *Eucalyptus globules* based agroforestry practice. The Empirical evidence revealed that crop yield and biomass substantially decreased toward the base of Eucalyptus trees, and the effect may extend from 12 m up to 20 m away from the tree base (Kidanu et al., 2005), and accounts for 4.9-to-13.5-ton ha⁻¹ loss of maize biomass (Alemie, 2009). In other study, applying a trench using a mesh with 0.5 m depth and 0.5 m width, did show a substantial yield increment by 52% and 157% on the respective trees and crops (WAJJA-MUSUKWE et al., 2008).

Although this wealth of evidence is available, still there is no verified application standard to implement these management options in *Eucalyptus globules*-based agroforestry system of central Ethiopia. In addition to solving the *Eucalyptus globules* tree effect on adjacent crop yield and soil physicochemical properties, evaluation of optimal trenching distance (TD) at which trench to be installed under *Eucalyptus globules* boundary plantation (EGBP) based agroforestry system is the basic concern of the present study. Because, a single intervention (management option) is not overcoming a multifactor with interaction effects of the system. So, evaluation of the interplay of factors that affect crop production which has rarely been conducted in Ethiopia is required. Therefore, the present study was conducted to evaluate the aspect, trench, and field distance (FD) effect on barley yield and soil physicochemical properties under EGBP based Agroforestry system of central Ethiopia.

Materials and methods

The study was conducted in upper part of Woyera watershed specifically at Denber kebele (7° 56' 20" N, 38° 04' 42" E and 3280 m a.s.l.) in Gumer district of Gurage highland. About 220 km south of Addis Ababa. Rainfall of the district is bimodally distributed with annual mean of 1350 mm. March-April the "belge" and June to August "Mehire" which is the main rain season of the study site. Mean minimum and maximum annual temperatures are 9.25°C and 17.5°C, respectively. The soil is loam, averaging 26.3% Clay, 38.1% Silt, and 35.6% Sand with a pH of 6.02 and an organic content of 2.8% in the top of 0 to 0.3m. The trial was set as a linear simultaneous agroforestry system under existing eight-year-old EGBP, with four separate fixed aspect of fields (north, south, east, and west) which laid under two line of tree boundaries aligned in North to South and East to West aspects. Split-split plot design with three replications was used on a gentle 5% sloped EGBP based agroforestry system (Kidanu et al., 2005; Rao et al., 1991). Accordingly, first under each aspect of EGBP 540 m² area of cultivated land was demarcated and divided into three equal blocks (main plot). Second, each block (180 m²) was divided into four equal arranged 30 m² areas of subplots. Then roots were pruned by digging a trench with 0.5m x 0.5m width and depth at randomized distances of 0.5 m, 1 m, 1.5 m away from EGBP. EGBP without trench was used as control. Finally, each sub-plot (30 m²) was divided into four equally fixed fields which was sub-sub plotted at 3 m, 6 m, 9 m, and 12 m distances away from EGBP. Each sub-sub plot which had 6 m² size was arranged sequential, perpendicular to the subplots (TD). One meter spacing was leaved between both blocks and plots.

Locally adapted BH-1370 variety of barley with the recommended rate of fertilizers was applied. During sowing, 120 kg/ha⁻¹ barley seed with 0.20 m row spacing and basal application of 60 kg of N and 20 kg of P ha⁻¹ fertilizers were used after weeding. Here, uniform amount of seed and fertilizer rate as well as weeding frequencies were applied to keep the homogeneity of the experimental site. After maturity, yield data was collected from the central 1m x 1m parts of each plot.

Soil sampling and analysis

Totally 64 composite soil samples were collected at the depth of 0–20 cm from the experimental plots using the 'Zigzag' sampling system. Samples from the same treatment plots were aggregated, pooled, and putted into a plastic bag to get a composite sample. After labeling, the 64 samples were taken to soil laboratory and analyzed for selected physicochemical parameters.

Standard procedures and methods were applied to analyze each soil parameter. First, before analysis each sample was air-dried at room temperature and grind then except for TN (0.5 mm) all soil samples were passed through 2 mm size mesh to avoid unwanted materials. Soil texture was analyzed using the bouyoucos hydrometer method (Gee and Bauder, 1986), and Soil moisture content was analyzed using the gravimetric method (Shukla et al., 2014). Soil pH was determined using (a suspension of 1:2.5 soil: water ratio). Total Nitrogen was determined using the Kjeldahl method (Bremmer, & Mulvaney, 1982). Available phosphorous (P) using the Olsen-P method (Olsen et al., 1954). Soil organic carbon content was determined following the Walkley and Black method (Walkley & Black, 1934). Cation exchange capacity and exchangeable basic cations were extracted by 1 M ammonium acetate (pH 7) (Houba et al., 1986), Finally, the organic matter content of the soil was calculated by multiplying the organic carbon percentage by 1.724

Statistical analysis

After checking its normality using the Shapiro-Wilk normality test, the data was subjected to ANOVA using R software version 4.2.1. General linear model, ssp. plot function of R was employed and the treatment mean which showed a significant effect at $p < 0.05$ was separated using Tukey's HSD at 95% confidence interval. Pearson correlation was used to show the relationship among soil parameters. Inferential statistics was used to interpret the result.

Results and discussion

Aspect, TD, and FD effect of EGBP on barely yield

Aspect on yield

As Table 1 clearly shows, aspect of EGBP had a significant effect on barley yield at ($p < 0.05$). The North-faced field showed 20.4%, 27.7%, and 31.2% additional yield variations than the South, East, and West-faced fields respectively. This might be the availabilities of optimal light intensity over the North faced field for photosynthesis and plant growth. The optimal light intensity at which barely growth become satisfied is $160 \mu\text{mol}/\text{m}^2/\text{s}$ (YEŞİL et al., 2020).

Table 1. Mean yield value of barely at each aspect, trench and field distance levels and their respective variation at ($p < 0.05$)

Yield at different aspect		Yield at different TD		Barely yield at different FD	
Field aspects	Mean (kg)	Gradients (m)	Mean (kg)	Gradients (m)	Mean (kg)
North	2336.2 ^a	0	1417.8 ^d	12	2539.8 ^a
South	1939.9 ^b	0.5	1869.3 ^c	9	2154.6 ^b
East	1830 ^c	1	2142.6 ^b	6	1744.9 ^c
West	1781.1 ^d	1.5	2457.5 ^a	3	1447.9 ^d

Note: The same letters in the same column does not show a significant difference. TD and FD represent the trench and field distance gradients at which yield data were collected.

Our result is consistent with the findings of Kidanu et al. (2005) reported that the highest wheat and teff yields were obtained from the North-faced field of EGBP. According to (Alemie, 2009), the North-South faced fields in East-West oriented Eucalyptus plantation showed the highest light intensity records. This may be associated with the variation in radiation reached over the directions (Fett-Neto et al., 2001). Because, such variations of radiation incidents on surface can be modified by tree canopy cover (Alemie, 2009). So, micro climatic modification role of a tree can prevent overheating that causing photo-inhibition of photosynthesis by reducing the leaf protein content which are essential for growth and production of underneath plants (Long et al., 1994). Contrary to the present study, (Ishnava et al., 2013) Chauhan et al. (2012) and Alebachew et al. (2015) reported that aspect of tree boundary does not significantly affect understory crop yield. This may be due to the variation in tree morphologies, locations, soils, or the nature of interaction effects that exist between the respective tree spp. and crop varieties.

Trench distance on yield

The trench established at different distance from EGBP significantly reduced belowground competition between components. Applying trench plays a crucial role in reducing competition for nutrients (WAJJA-MUSUKWE et al., 2008). The results obtained supports this conclusion, the trenched fields did exhibit a significant improvement in the barley yield ($p < 0.05$), as given in Table 2. When compared to un-trenched, the fields trenched at 0.5 m, 1 m, and 1.5 m away from EGBP provided 31.8%, 51.1%, and 73.3% additional yields respectively. Also, field trenched at 1.5m distance provided higher yield than the other trench levels. That means trench has significant role to access and use available nutrients for growth and yield performance of crops. This result in line with the work of (WAJJA-MUSUKWE et al., 2008) who found 20% to 55% additional yield from the field near to trenched tree boundary.

Field distance

FD showed a significant effect on barley yield at $p < 0.05$. Relative to 12m FD, the barley yield obtained from 3m, 6m and 9m FD respectively showed 43%, 31.3% and 15.2 % yield reduction. In line with this Alemie, (2009), obtained almost 10-fold additional maize yield variation between 1m and 20m FD from Eucalyptus woodlot. Kidanu et al. (2005) also observed 19% up to 62% of wheat yield variation as the distances from the boundary increased from 2m to 15 m. The effects of canopy cover on light intensity and nutrient availabilities may be reason for the yield variation. Unless belowground tree management like trench changes the phenomena; mineralization decreases as the field approach to the boundary of EGBP. Because, presence of higher lignin and toxic content in *Eucalyptus globules* leaf affects the amount soil microbial population which facilitate decomposition, nutrient cycling within the system.

Interaction effects of EGBP on barley yield

Aspect with trench

In all aspects of trenched field, the yield obtained from 3m FD was higher than un-trenched field of 6m and 9m away from the EGBP. However, North faced field with trench at 1.5 m provided the highest barley yield than the other aspect-trench interaction levels. In this regard, trenched field of North aspect showed 16.5% up to 56.7% additional barley yield than the other interaction levels. Because, as the trench minimize belowground competition for nutrients, the light reaching over the North faced field might facilitated the decomposition and mineralization process, and become additional potential to satisfy the nutrient requirement of crops.

Trench with field distance

As the comparison of practices in the present study revealed, trenched fields had additional advantage in using 900 m² ha⁻¹ land that otherwise marginalized from crop production. Because trenched field established starting from 1.5 to 2.5 m gained nearly equal yield that obtains when using the corresponding FD gradients, ranging from 3 to 12 m away from EGBP.

Table 2. Interaction effects of aspect, trench, and field distance on barley yield under EGBP in Gumer district, Gurage highland of Ethiopia (p < 0.05)

Aspect	Levels of TD in meter	Mean SD of yield (kg/h ¹) at different field distance (m)				Mean ± SD of Aspect*TD
		3 m	6 m	9 m	12 m	
North	0	990±18.4	1295±7	2119.3±10.4	2544±9	1737.1±650.4 ^f
	0.5	1538.3±33.8	2023.3±6.1	2352±44.9	2575.0±8.6	2122.2±408 ^{cd}
	1	1858.7±36.1	2704.7±6	2775.3±22.8	2833.3±15.5	2543±415.9 ^b
	1.5	2501.0±12.5	3065.7±61.2	3214.3±22.5	2989.3±30	2942.6±281 ^a
Mean yield value of North at each FD		1722.0 ⁱ	2272.2 ^e	2615.3 ^b	2735.4 ^a	2336.2±636.5
South	0	728.3±34	829±4.6	2021±10.6	2318±3.6	1474.1±735 ^g
	0.5	1340±16.4	1530.3±3.5	1871.3±24	2335.7±21	1769.3±395.5 ^f
	1	1697.7±15.9	1894.7±5	2222.7±10.4	2420.3±3.8	2058.8±293.2 ^{de}
	1.5	2111.3±18.7	2477±4	2536.7±46	2704±6	2457.2±227 ^b
Mean yield value of South at each FD		1469.3 ^l	1682.8 ^h	2162.9 ^f	2444.5 ^d	1939.9±574.7
East	0	559±39.4	693±7	1412.3±10.3	2430.7±3.2	1273.8±775.8 ^h
	0.5	1371.7±77.1	1446.7±9.5	2007.3±11.85	2413±11.5	1809.6±446.47 ^f
	1	1663.3±34.9	1853.7±6	2179.3±9	2516±16.3	2053.1±339.6 ^{de}
	1.5	1749.7±13.8	1877.7±2	2475±4.4	2632±9	2183.6±393.6 ^{cd}
mean yield value of East at each FD		1335.9 ^m	1467.8 ^l	2018.5 ^g	2497.9 ^c	1830±612
West	0	507±11.3	557.7±9.7	1354±9.5	2326±7	1186.2±771.7 ^h
	0.5	1339.7±35.2	1634.3±56	1751.7±33.5	2378.7±28	1776.1±397 ^f
	1	1454.7±47.5	1822.7±60.3	1862.3±34.6	2523±11.2	1915.7±403.7 ^{ef}
	1.5	1755.3±75.7	2213±10.6	2319.3±22.2	2698±15.4	2246.4±352.6 ^c
mean yield value of West at each FD		1264.2 ⁿ	1556.9 ^k	1821.8 ^h	2481.4 ^c	1781±627.6
Total mean yield value of aspect at each FD		1447.9 ^D	1744.9 ^C	2154.6 ^B	2539.8 ^A	

Note: Aspect (tree boundary facing the field), trench distance; and field distance from Eucalyptus globulus boundary plantation. The same letter at the right end column of the table doesn't show a significant difference

in TD. The same letters in each subtotal row don't show a significant difference between FDs in the respective aspect. Here TD and FD represent trench distances and field (plot) distance from the tree boundary, respectively

According to Kidanu et al. (2005), the higher root biomass which have less than 10 mm diameter mainly found in the FD ranging from 5 m up to 10 m away from EGBP. This indicates the belowground process may be more substantial for crop production than the aboveground process since plants uptake nutrients from the soil that otherwise strongly depleted by superficial competitor roots of *Eucalyptus globules*.

Aspect-trench and field distance

The interaction of aspect-TD and field distance had a significant effect on barley yield at $p < 0.05$. In this regard, the highest barley yield (i.e., 3214.3 kg) was obtained from the trenched field of North faced fields (in East-west tree aspect) at 9 m FD away from the EGBP. Relative to trenched North of 9m FD, the remaining interaction levels showed 4.6% up to 84.2% yield reduction. Moreover, relative to un-trenched fields of 6m and 9m, trenched field at 1.5 m distance increased the yield value of 3m FD by 48.2% and 15.3% respectively (Table 2). That means installing trench beneath the boundary can reduce the field distance effects of EGBP by 24.2 percent.

This result in line with the result of Kidanu et al. (2005) who found the highest wheat and teff yields from North-faced fields (i.e., from east–west tree boundary). Hence light intensity level has a significant effect on photosynthesis rates (plant growth processes involving the use of light, carbon dioxide and water), the absence of shading provides an advantage to have adequate light for effective photosynthesis, decomposition, and mineralization over the North field aspect. Regardless of aspect and TD, the FD revealed a substantial change, gained the highest barley yield when the distance was 9 m or 12m away from EGBP. In this regard, the reports of (Alemie, 2009) that showed tenfold maize yield and biomass variation observed between 1m and 20 m FD away from Eucalyptus stand supports our result. This is because the root density of Eucalyptus was higher in field distances between 1m and <10m from the tree boundary.

Therefor before trenching, agro-foresters must know the root structure of a specific species. Because it helps us to understand and determine the specific aspect and distance at which root trench or belowground tree management should be applied. Because, the lignin and phenolic content of leaf, diameter and density of stem and root turnovers, as well as light required for decomposition, accommodation of soil microbial and mineralization were affected by the interaction of the variables. As the comparison between groups of interactions (i.e., Aspect-TD, Aspect-FD, TD with FD, and Aspect-TD-FD) showed in Table 2 the barley yield obtained from Aspect-TD was higher than TD-FD, Aspect-FD, and Aspect-TD-FD. This implies, root trenching (belowground tree management) is crucial to maximize barley yield in EGBP based agroforestry system of central Ethiopian highlands.

Table 3. Aspect, trench, and field distance effects of EGBP on soil physical properties in the Gummer woreda, Gurage highland of Ethiopia ($p \leq 0.05$)					
Variables (treatments)	Levels	Soil physical properties			
		Soil texture mean $\pm$ SD			Soil moisture %
		Clay	Silt	Sand	
The aspect of tree boundary	Northern	26.3 $\pm$ 0.3 ^a	38 $\pm$ 0.7 ^a	36 $\pm$ 0.52 ^a	34.7 $\pm$ 0.9 ^a
	Southern	26.4 $\pm$ 0.8 ^a	38 $\pm$ 0.9 ^a	35 $\pm$ 0.52 ^a	34.9 $\pm$ 1 ^a
	Eastern	26.3 $\pm$ 0.8 ^a	38 $\pm$ 1 ^a	35 $\pm$ 0.52 ^a	34.8 $\pm$ 1.6 ^a
	Western	26.3 $\pm$ 0.5 ^a	38.2 $\pm$ 1 ^a	35 $\pm$ 0.52 ^a	35.5 $\pm$ 1.2 ^{a *}
Trench distances from tree boundary	0 m	26.6 $\pm$ 0.6 ^a	37 $\pm$ 1 ^a	35 $\pm$ 0.52 ^a	34.7 $\pm$ 1.5 ^a
	0.5 m	26.4 $\pm$ 0.6 ^a	37 $\pm$ 0.9 ^a	35 $\pm$ 0.52 ^a	35 $\pm$ 1 ^a
	1 m	26.2 $\pm$ 0.5 ^a	39 $\pm$ 0.2 ^a	34 $\pm$ 0.52 ^a	35 $\pm$ 1.2 ^a
	1.5 m	26 $\pm$ 0.5 ^b	38 $\pm$ 0.9 ^a	36 $\pm$ 0.52 ^a	35 $\pm$ 1.2 ^a
Plot(field) distances from tree boundary	3 m	26.5 $\pm$ 0.4 ^a	36.6 $\pm$ 1 ^b	35 $\pm$ 0.54 ^a	33.6 $\pm$ 0.8 ^a
	6 m	26.5 $\pm$ 0.7 ^a	37.1 $\pm$ 1 ^a	35.3 $\pm$ 0.2 ^a	34.3 $\pm$ 0.7 ^a
	9 m	26.3 $\pm$ 0.7 ^a	38.6 $\pm$ 1.5 ^a	36 $\pm$ 0.6 ^a	36 $\pm$ 0.4 ^{a *}
	12 m	26 $\pm$ 0.5 ^b	38.2 $\pm$ 1.5 ^a	36 $\pm$ 0.7 ^a	35.9 $\pm$ 0.9 ^{a *}
Mean		26.33	38.1	35.56	34.95
C.V		2.16	2.54	1.47	1.8
<i>Note: The same letters within a column of the same variable category do not show a significant difference ($p < 0.05$)</i>					

Effect on soil physicochemical properties

Effect of aspect, TD and FD on soil physical properties

Soil texture class at all levels of aspect, trench distance and field distance from the tree boundary were loam. As the result of soil analysis revealed, soil texture did not show any significant different across all treatments ($p < 0.05$).

It may be resulted from the soil parent material, and the potential of the variables to change the texture within a short period of time i.e., one year is low. This result coincides with the work of (Alemie, 2009) who reported the absence of significant variation in the comparative analysis of soil textural class and bulk density at different distances and depths.

As Table 3 shows the individual and interaction effects of aspects, TD, and FD on soil moisture were not statistically significant at $p \leq 0.05$. The extended accumulation of water in trenched structure throughout the season may be the main reason for the absence of significant effect. The result of aspect and field distance in lines with the studies of Sharma et al. (2007), Chanie, (2009) and Chauhan et al. (2012). The study of (WAJJA-MUSUKWE et al., 2008) supports TD result of the present study. TD showed a direct relationship with soil moisture. However, FD from the tree boundary showed a negative correlation with soil moisture.

Effect of aspect, TD and FD on soil chemical properties

As Table 4 shows aspect, TD, and FD had no significant effect on pH and Ex. K. However, their effect on SOM, TN, av. P and CEC showed a significant effect at $p \leq 0.05$. The value of all SOM available in the study area is less than 4 %. That means SOM is in minimum range. The amounts of SOM exist ranges from 2.7% at FD 12m to 3.6% at FD 3m. Which means the value of SOM decreased with increasing distance from tree boundary. Here, SOM positively correlated with TN and CEC. But inversely correlated with av. P. This implies that, the presence of direct radiation of sunlight and higher accumulation of leaf litter and root turnover over the trenched field of North aspect were affecting the availabilities of TN, P, the amount of SOM and exchangeable cations.

Relative to the north aspect, the percentage of total nitrogen in the western, eastern, and southern aspects decreased by 10.2 %, 12.4%, and 18.6% respectively. Similarly, relative to the control, in TD 0.5 m, 1m, and 1.5 m the value of total nitrogen increased by 1.9%, 15.4%, and 16.9% respectively. Moreover, relative to the un-trenched field, the trenched field showed 11.4% incremental variation. The value of total nitrogen decreases with increasing distances from the EGBP (Table 4). Relative to the northern aspect, the amount of av. P in the western, southern, and eastern aspects decreased by 21.8%, 12.7%, and 12%. Here, the trenched field showed a 15.2% incremental variation over the un-trenched field. Moreover, the availability of P decreased with decreasing distance from EGBP. Except for TD, effects of aspect and FD showed a significant difference on the number of exchangeable cations. The highest (32.1) and the least (28.4) values of CEC were recorded in the North and South aspects respectively. Like total nitrogen and SOM, the amount of CEC decreased with increasing distance from EGBP.

Table 4. Aspect, trench, and field distance effects of EGBP on soil physicochemical properties in the Gummer woreda, Gurage highland of Ethiopia ($p < 0.05$).

Treatments	Levels	Mean $\pm$ SD value of soil chemical properties					
		pH (H ₂ O)	SOM %	TN %	Av. P ppm	Ex. K ppm	CEC(meq/100g)
Aspect of fields	North	6.05 $\pm$ 0.3 ^a	3.52 $\pm$ 0.3 ^a	0.32 $\pm$ 0.06 ^a	13.3 $\pm$ 3.2 ^a	1.6 $\pm$ 0.05 ^a	32.1 $\pm$ 1.5 ^a
	South	6 $\pm$ 0.24 ^a	3.06 $\pm$ 0.5 ^c	0.26 $\pm$ 0.05 ^c	11.6 $\pm$ 2.3 ^b	1.6 $\pm$ 0.03 ^a	28.41 $\pm$ 2 ^d
	East	6.04 $\pm$ 0.3 ^a	3.3 $\pm$ 0.32 ^b	0.28 $\pm$ 0.06 ^b	11.7 $\pm$ 3.3 ^b	1.6 $\pm$ 0.02 ^a	31.2 $\pm$ 1.16 ^b
	West	6 $\pm$ 0.22 ^a	3.1 $\pm$ 0.5 ^c	0.29 $\pm$ 0.05 ^b	10.4 $\pm$ 2.8 ^c	1.6 $\pm$ 0.04 ^a	29.4 $\pm$ 1.83 ^c
TD	0 m	5.97 $\pm$ 0.24 ^a	3.2 $\pm$ 0.4 ^b	0.27 $\pm$ 0.05 ^b	10.5 $\pm$ 3.3 ^c	1.4 $\pm$ 0.1 ^a	30.7 $\pm$ 2.26 ^a
	0.5 m	6.02 $\pm$ 0.24 ^a	3.31 $\pm$ 0.4 ^a	0.27 $\pm$ 0.07 ^b	11.8 $\pm$ 2.7 ^b	1.4 $\pm$ 0.06 ^a	30.4 $\pm$ 2.18 ^a
	1 m	6.03 $\pm$ 0.27 ^a	3.32 $\pm$ 0.47 ^a	0.31 $\pm$ 0.06 ^a	12.5 $\pm$ 3 ^a	1.4 $\pm$ 0.05 ^a	30.3 $\pm$ 2 ^a
	1.5 m	6.07 $\pm$ 0.27 ^a	3.23 $\pm$ 0.5 ^{ab}	0.31 $\pm$ 0.05 ^a	12 $\pm$ 3 ^{ab}	1.42 $\pm$ 0.7 ^a	30.2 $\pm$ 2.1 ^a
FD	3 m	5.7 $\pm$ 0.05 ^a	3.6 $\pm$ 0.18 ^a	0.35 $\pm$ 0.054 ^a	8.07 $\pm$ 1.6 ^d	1.4 $\pm$ 0.05 ^a	32.5 $\pm$ 1.3 ^a
	6 m	5.95 $\pm$ 0.1 ^a	3.5 $\pm$ 0.2 ^a	0.31 $\pm$ 0.03 ^b	10.8 $\pm$ 1.4 ^c	1.5 $\pm$ 0.04 ^a	30.8 $\pm$ 1.7 ^b
	9 m	6.16 $\pm$ 0.07 ^a	3.28 $\pm$ 0.2 ^{ab}	0.26 $\pm$ 0.027 ^c	12.9 $\pm$ 1.9 ^b	1.6 $\pm$ 0.05 ^a	29.6 $\pm$ 1.7 ^c
	12 m	6.3 $\pm$ 0.92 ^a	2.7 $\pm$ 0.4 ^c	0.23 $\pm$ 0.03 ^d	15.2 $\pm$ 1.3 ^a	1.5 $\pm$ 0.09 ^a	28.8 $\pm$ 1.7 ^d
Mean		6.02	3.25	0.28	11.7	1.49	30.4
CV		1.2	5.42	7.1	7.9	3.87	2.8

Note: The same letters in the same columns over the same variable category do not show a significant difference. Here TD, FD, SOM, TN, Av. P, Ex. K and CEC stand for trench distance, field distances, soil organic matter, total nitrogen, available phosphors, extractable potassium, and cation exchange capacity respectively.

The observed differences in the above soil physicochemical properties were mostly related to treatment differences. Because the influence of the leaf litter and root turnovers on SOM, TN, and P also on the capacity of exchangeable cation were higher under EGBP. The higher SOM, TN, and CEC status near the tree might be resulted from the addition of a large quantity of leaf litter. Similar finding was observed by (Bhardwaj et al., 2017) who studied in

Eucalyptus agroforestry system of Chain. Contrary to this the reduction of soil pH and av. P closer to the tree boundary might be resulted from the subsequent accumulation of phenolic compound and lower rate of decomposition in organic matter which releases organic acids (Gupta & S. D. Sharma, 2009). The presence of higher leaching moisture after trenching and the immobilization of soil exchangeable bases, especially calcium may be the reason for soil pH reduction near to EGBP.

Our result supports the study of Bailey et al. (2005) that revealed, acidification leads to the depletion of the soil base cations (e.g., K^+ , Mg^{2+} , Ca^{2+}). The depletion arising from the replacement of the basic cations by Al^+ and H^+ ions at the exchange site may be the reason for the absence of significant differences in ex. K and pH.

Interaction effects of EGBP on soil physicochemical properties

In North faced field, decomposition of organic matter affects nutrient availabilities. Because, in this aspect higher amount of TN, Av. P and CEC are showed in Table 4. This may be due to the addition of SOM from the decomposition of litterfalls and trenched root turnovers. The reason for Av. P increment may be attributed by the respective pH value. Unlike the available P and soil moisture; the value of total nitrogen, SOM, and pH showed an increasing trend with increasing distances from the tree boundary. Because the variation of light intensity among aspects, the availabilities of moisture due to root trenching, the dried and putrefied fine roots after trenching at the depth of 50 cm, the existence of higher roots and leaf litter accumulation beneath the tree boundary, and the stimulation of soil microbes as the result of the restriction of phytotoxic chemical releasing from the root (Gupta & S. D. Sharma, 2009) may be the reason for the observed variation on soil physicochemical properties and barely yield.

Conclusion

EGBP becomes the prominent features of the landscape in agroforestry system of central Ethiopian highland. Even if it has higher economic advantages its ecological effects on adjacent crops have been an issue of controversial among biophysical researchers. To overcome this problem, single intervention is not solving the multifactor with interaction effects of the system. So, evaluation of the interplay of factors that affect crop production which rarely conducted in Ethiopia is required to evaluate individual and interaction effect of *EGBP* on barley yield and soil physicochemical properties. As a result, aspect, trench, and field distance gradients showed a significant effect on barley yield. The highest barley yield was recorded at the North faced field. The North-faced field trenched at 1.5 m distance of 9m FD away from EGBP provided the highest mean yield compared to the same aspect with a field distance of 12 m and other aspects with the corresponding trench distances. Moreover, at all aspect levels, the trenched field increased the yield value at 3 m field distance compared with the un-trenched field at 6 m and 9 m.

Aspect of EGBP had a significant effect on SOM, TN, av. P, and CEC. But their effect on pH and Ex. K was not statistically significant. Relative to the North aspect, the respective amount of av. P in the West, South, and East aspects decreased by 21.8%, 12.7%, and 12 percent. Here, the trenched field showed a 15.2% incremental variation over the un-trenched field. Moreover, the availability of P decreased with decreasing distance from EGBP. However, except for TD, the number of exchangeable Cations showed a significant variation due to variation in aspect and FD. The highest OM value was recorded at North-1mTD and 3-6m FD. The highest TN value was observed from N-1m TD at 3m > 6m > 9m > 12mFD. The highest av. P was obtained from North – 1 and 1.5m TD at 12m > 9m > 6m > 3m FD. The highest CEC value was obtained from North-1 and 1.5 m TD at 3m FD. Relative to un-trenched, in

trenched fields except for pH, ex. potassium, and soil texture, SOM, total nitrogen, av. Phosphors and CEC were increased significantly.

This implies that, in EGBP based agroforestry, managing belowground competition for available nutrients is more crucial than aboveground to increase barley yield. Here, knowledge of tree root structure is important to fix the distance and direction of trench applied in agroforestry system. As a result, the present study does not support those studies recommended to leave 6 m to 12 m free land under EGBP without cropping. Because each year, a farmer can lose 600 to 900 m² area of farmland. That means each year a farmer can lose 150 to 225 kg of barley yield. Therefore, applying such types of feasible technology (root trench at 1.5m distance from the boundary) is practical and advisable approach to maximize barley yield in EGBP-based agroforestry system of central Ethiopian highlands.

Recommendations

East to West alignment of tree plantation should be the priority recommendation in EGBP system of Ethiopian highland.

Before cropping, installing 0.5 m depth by 0.5 m width trench at 1.5-meter distance away from EGBP should carried out to minimize belowground competition.

Incorporating trench at distance of 1.5 m away from the tree boundary of the northern-facing field (east to west aspect of tree boundary) was vital to obtain the highest barley yield with optimal soil nutrient loss. However, depending on farm size and position of available land, applying trench at 1 m distance in the north aspect and 1.5 m distance in south, east, and west aspects is an advisable approach to maximize barley yield and the land use efficiency of the system over central Ethiopian highland.

Finally, future year wise validation studies should be carried on growth and biomass of tree as well as about effects of trench on soil properties in EGBP based agroforestry system.

Declarations

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Figures

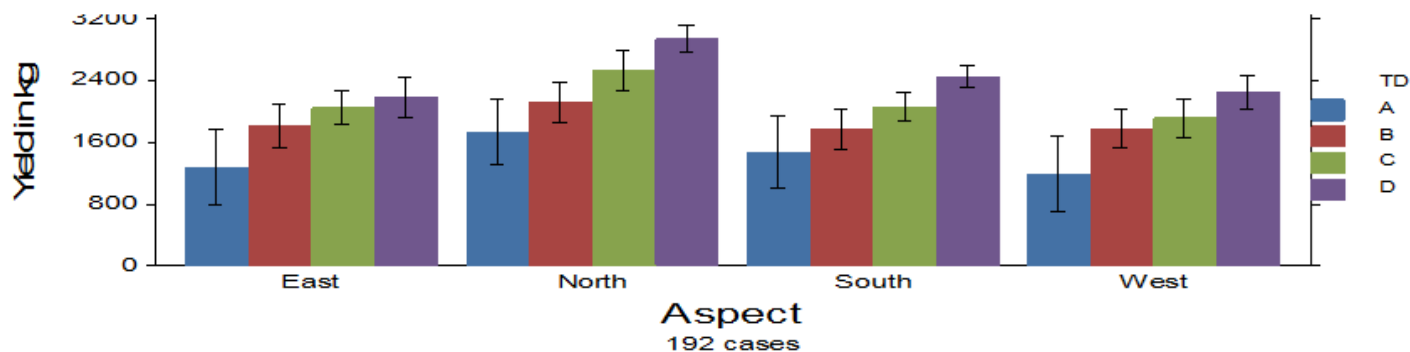


Figure 1

Interaction effects of EGBP on barley yield in Gumer district, central Ethiopia. Here, TD=trench distance from the tree line levelled as A= 0 m, B=0.5 m, C=1 m, D=1.5 m.

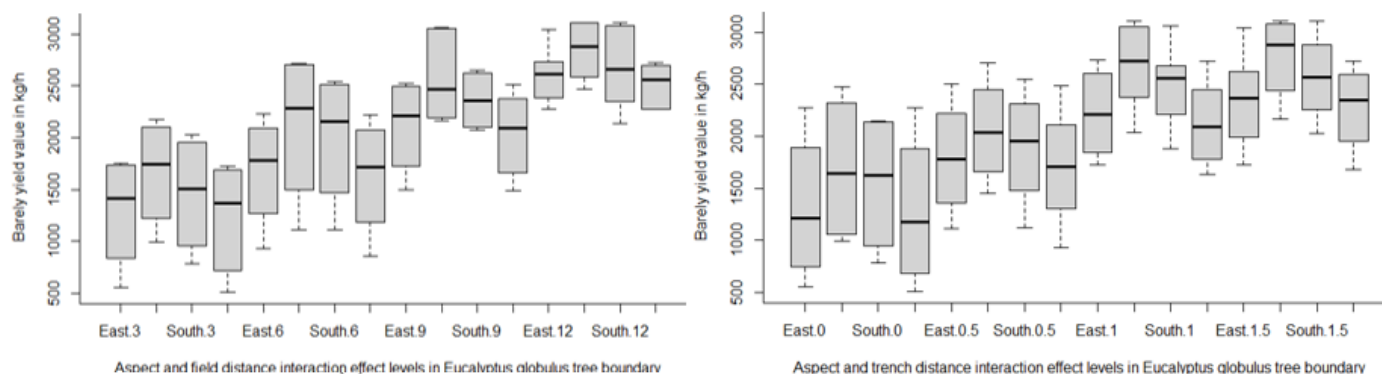


Figure 2

Aspect-trench distance and Aspect- field distance interaction effects of *E. globules* tree boundary on barley yield in Gumer district, central Ethiopian

Note: Interaction effect of aspect and field distance (a) aspect and trench distances (b). Here, PD= Plot distances levelled as 1= (3 m), 2= (6 m), 3= (9 m) and 4= (12 m)