DATA NOTE

Effect of planting density on root biomass and distribution, and soil organic carbon stock of *Acacia decurrens* stands in Northwestern Ethiopia [version 1; peer review: awaiting peer review]

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Abstract

Background: The expanding *Acacia decurrens* woodlots in Northwestern Ethiopia is recognized for carbon storage *via* root biomass and soil organic carbon (SOC) enhancement but its planting densities have varied considerably. This study evaluated the effect of planting density on the root biomass, SOC stock, and vertical distributions in the stands.

Methods: Five planting densities (0.5 m x 0.5 m, 0.75 m x 0.75 m, 1 m x 1 m, 1.25 m x 1.25 m, and 1.5 m x 1.5 m) were replicated four times with randomized complete block design. Soil core (6.67 cm diameter) and pit (900 cm^2 area) methods were used to collect fine and coarse root samples within 0–50 cm soil depth (having five soil layers in 10 cm intervals), respectively. Fine root biomass samples were classified as live and dead (necromass) and further as tree and herbaceous root. All root biomass samples were washed, oven-dried, weighed, and standardized into gram per meter square ($g\ m^{-2}$) for root biomass comparisons for each planting density and soil depth, then summed up for 0–50 cm depth as a total root biomass. The vertical distributions of fine and coarse root biomass at each depth were expressed as a percentage (in decimal) of the total root biomass (0–50 cm).

Conclusions: Planting density had significant effects on root biomass, SOC stock, and root distributions ($P < 0.05$) but inconsistent for the percentage of SOC stock at all soil layers except at 40-50 cm. Planting *A. decurrens* with high density is recommended to increase root biomass, SOC, and percentage of roots in deep soil layers. Further study is suggested for the effects of stand age on root biomass dynamics and SOC stock with large scale.

Open Peer Review

Approval Status *AWAITING PEER REVIEW*

Any reports and responses or comments on the article can be found at the end of the article.

Keywords
Acacia decurrens plantation, planting density, root biomass, root distribution, soil depth, soil organic carbon

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Introduction

Acacia decurrens (Wild) has been expanded as a woodlot system in northwestern Ethiopian highlands with 4–6 years of rotation due to the growing demands for fuel and charcoal products, high biomass production, and demands for soil improvement (Matthies & Karimov 2014; Nigussie *et al.*, 2016; Menale & Wolde 2018; Yigez *et al.*, 2018). Contrary to previous trends, most farmlands in Fageta Lekoma District have changed into *A. decurrens* woodlot, and as a result, its forest cover has increased by 1.2% yearly from 1995 to 2015 (Menale & Wolde 2018). This system has been recognized for the enhancement of soil health, especially soil organic carbon (SOC) (Nigussie *et al.*, 2016; Weber *et al.*, 2011; Yigez *et al.*, 2018; Zerfu, 2019) due to its belowground biomass and nitrogen fixation (Mckay, 2011; Chen *et al.*, 2015). The presence of higher amount of root biomass in deep soil is more advantageous to improve SOC with long residence time (Graaff *et al.*, 2006; Lal, 2007).

Hence, root biomass study is vital to understand the contribution of roots in soil carbon accumulation (Berhongaray & Ceulemans 2015). However, there are multiple silvicultural practices in short rotation plantation (SRP) to optimize its productivity (Gonçalves *et al.*, 2009), which might affect the root biomass, distribution, and carbon accumulations (Finér *et al.*, 2011). Regulation of stand density in SRP is a primary silvicultural practice, which further enables the enhancement of SOC stock (Marziliano *et al.*, 2015). Variations in stand density has also affected the root biomass and depth wise distribution of stands (Persson & Baitulin 1996; Crow 2005) due to competition for resources (Kucbel *et al.*, 2011; Zhang *et al.*, 2015; Zhou *et al.*, 2018). For example, the root biomass and depth wise distributions for *Acacia mangium* have increased with stand density (Kunhamu *et al.*, 2010; Rocha *et al.*, 2017). Similarly, the SOC storage of *Acacia zanzibarica* (Sitters *et al.*, 2013) and *Acacia lenticularis* stands (Chaturvedi *et al.*, 2008) have increased with stand density. Consequently, high intraspecific competition is expected in the surface soil layers with closer spacing to access sufficient resources (Persson & Baitulin 1996).

In our case, the planting density of *A. decurrens* woodlots in Northwestern Ethiopia (Fageta Lekoma District) varied between 2 m x 2 m and 0.5 m x 0.5 m of spacing (Takele, 2019), suggesting effects on competition for resources and differences in rooting distribution, intensity and depth across this gradient of planting density. Yet, the root biomass, SOC stock and distribution of *A. decurrens* stands under different densities have not been quantified in the area. Therefore, the objectives of this research were to estimate root biomass, SOC stock and vertical distribution of this short rotation forest system under different planting densities.

Methods

Site description

The research was conducted at Endehua Kebele in the Fageta Lekoma District, Northwestern Ethiopia (Figure 1). It is situated at 11°01’12” N latitude and 36°55’23” E longitude with 2761 meter elevation. The area belongs to the moist subtropical agro-climatic zone (Bireda, 2015) having about 16.8°C of mean annual temperature and 1,702 mm of mean annual rainfall between 2010 and 2019 based on the Addis Kedam weather station in Northwestern Ethiopia Metrological Center (NWMSC, 2020).

Cropland (52.3%), forest land (25. 6%), grassland (21.3%), and villages (0.8%) are the major land uses with high land conversion rates to *A. decurrens* woodlots (Menale & Wolde 2018). According to the Food and Agriculture Organization (FAO 2015b) classification, Acrisol and Nitosol are the predominant soil types in the area and known with low productivity (Bireda 2015). The district’s total population was projected to be about 151,220 in 2017 with a density of approximately 226 inhabitants km^{-2} (Central Statistics Agency (CSA), 2013). The major sources of income for community's livelihood are crop and livestock production and tree products mainly *A. decurrens* (Yigez *et al.*, 2018). Recently, about 90% of the population has been involved in *A. decurrens* charcoal production chains (Bireda 2015).

Experimental design

The experimental *A. decurrens* stands were established in July 2015 using four month-old seedlings. The land use history of the site was only cropland. A randomized complete block design (RCBD) was used having five planting density as treatments (Treatment 1 (T_1): 0.5 m x 0.5 m; Treatment 2 (T_2): 0.75 m x 0.75 m; Treatment 3 (T_3): 1 m x 1 m; Treatment 4 (T_4): 1.25 m x 1.25 m; and Treatment 5 (T_5):1.5 m x 1.5 m) with four replications. The number of seedlings planted initially per plot was about 196 for T_1, 100 for T_2, 49 for T_3, 36 for T_4, and 25 for T_5. Each plot has a surface area of 49 m^2 with 2 and 3 m distance between plots and blocks, respectively.

All stands were neither fertilized nor irrigated but hand weeding was applied every two months during the first half-year. Data were collected when the stands were 4.5 years old, within the ranges of stand rotation period (4–6 years) in the area (Takele, 2019). The stand characteristics for each treatment during data collection are illustrated in Table 1.

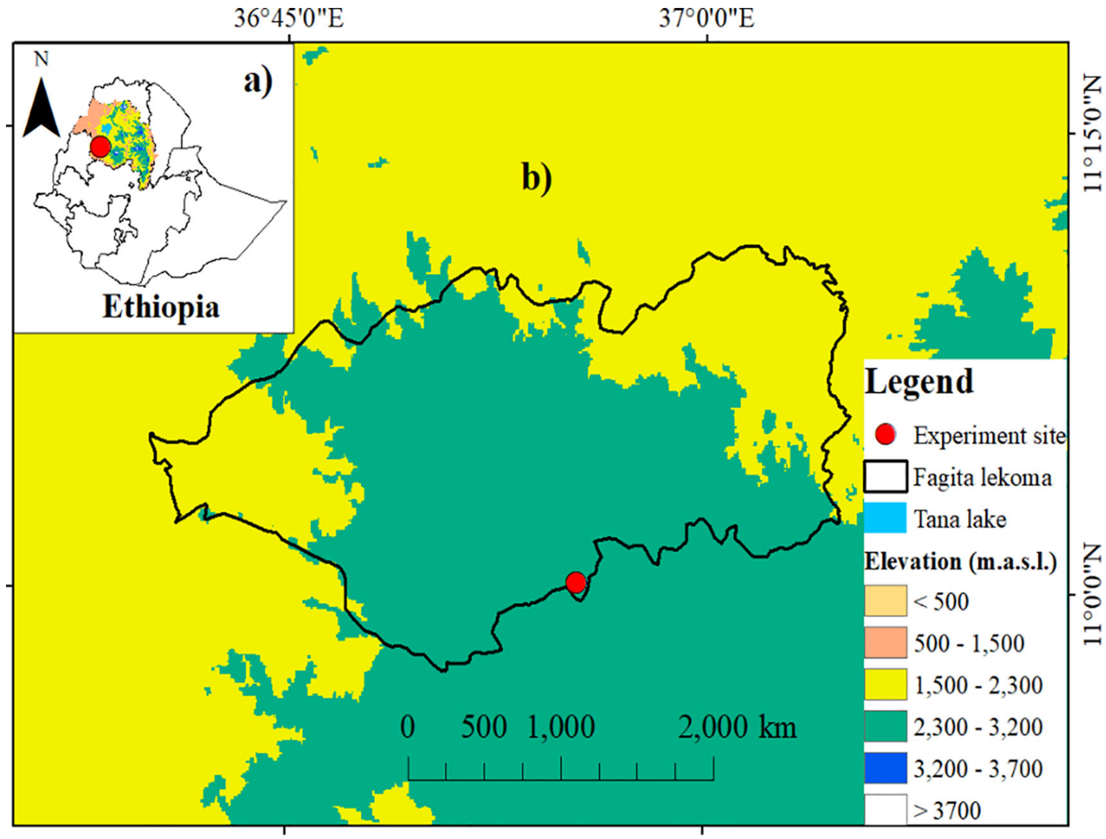

Figure 1. Location map of the study area (Fageta Lekoma District), Northwestern Ethiopia.

Table 1. Characteristics of experimental *Acacia decurrens* stands for different planting densities (treatments). Mean values and standard errors are indicated (n = 4).

Planting density	Height (m)	DBH (cm)	Survival rate (%)	Basal Area (m^2 ha^{-1})
0.5 m x 0.5 m	8.87±0.21	4.64±0.13	79.21±2.55	67.68±3.78
0.75 m x 0.75 m	10.04±0.44	6.56±0.47	81.50±2.33	69.97±10.28
1.0 m x 1.0 m	10.43±0.45	6.46±0.19	85.71±2.50	32.80±1.88
1.25 m x 1.25 m	10.99±0.35	8.01±0.18	81.94±4.01	37.06±1.60
1.5 m x 1.5 m	10.04±0.29	7.60±0.36	91.00±1.91	23.31±2.21
Mean	10.08±0.21	6.65±0.29	83.87±1.45	46.16±4.82

Where DBH is Diameter at breast height, m is meter, and cm is centimeter.

Data collection methods

Fine root sampling and processing

During December 2019, fine roots (<2 mm in diameter) were collected using a soil core method, because such methods are relatively easy to apply in the field, cost-effective, and accurate while having rather limited disturbances of the site (Ravindranath & Ostwald, 2008; Addo-danso *et al.*, 2016). Before coring, sample points were selected randomly at each plot and their litter layer of surface soil were removed. About 100 root and soil core samples were taken by a stainless corer (6.67 cm diameter) up to 50 cm depths at all selected points (5 spacing x 4 replicates x 5 soil depth class = 100). Sampling was done down to 50 cm because most species likely extend their root system down to 50 cm due to competition for soil nutrients and water and reach the bedrock. All individual core samples were separated into five depth classes (0–10, 10–20, 20–30, 30–40, and 40–50 cm) and then composites were made per plot and depth class and labeled in a separate plastic bag.

Table 2. Methods and/or equations used to estimate the collected data for each parameter.

Parameters	Methods or Equations Used	Source
Root biomass	Standardized into root biomass per unit of area	Santantonio *et al.* (1977); FAO (2015a)
Root distribution	$\frac{\text{root biomass for each soil depth class}}{\text{total root biomass within } 0{-}50 \text{ cm depth}}$	Chenk & Jackson, (2002); Jaramillo *et al.*, (2013)
SBD	$\text{SBD} = \frac{Sdw}{Sv}$	Han *et al.*, (2016)
CF (%)	$\frac{\text{materials} > 2 \text{ mm diameter in soil samples}}{\text{total oven}-\text{dried material in soil core samples}}$	Bandyopadhyay *et al.*, (2012)
SOC (%)	Walkey-Black wet oxidation	Walkley & Black (1934)
SOC stock	$\frac{C}{100} * SBD * d * \left(1 - \frac{CF}{100}\right) * 100$	IPCC (2003)

Where SBD is soil bulk density (g cm^{-3}), Sdw is oven-dried soil weight (g) and Sv is soil core volume (cm^3), SOC stock is soil organic carbon stock (Mg C ha^{-1}), C is SOC content determined in the laboratory (%), d is sampled soil depth (cm), CF is coarse (>2 mm diameter) fraction content (%), 100 converts the unit into Mg C ha^{-1}.

Fine root samples were sieved with 0.15 mm mesh size to separate roots from the soil. The roots were collected and then the sieve was rinsed with tap water to remove the remaining soil particles attached to the roots; then the roots were picked up and the soil handled for further analysis (Ravindranath & Ostwald 2008). All fine roots were separated as live and dead by visual observation (Dessie *et al.*, 2017). This was based on the principle that live roots have usually brighter color, are elastic and have unbroken root tips, while dead roots are dark brown or black, broken root tips, are easily breakable, often shriveled (Duncker *et al.*, 2012; Jiang *et al.*, 2018). The roots were further grouped as tree or herbaceous roots, whereby herbaceous roots possess a higher branching capacity than tree roots (Jiang *et al.*, 2018). All root samples were oven-dried at 70°C for 24 hours and then weighed using a sensitive balance (10^{-4} g accuracy).

Coarse root sampling and processing

About 100 coarse root (diameter >2 mm) samples were also taken using the soil pit method that represents a compromise between sampling cost and efficiency (Ravindranath & Ostwald 2008; Addo-danso *et al.*, 2016). Two pits with a surface area of 900 cm^2 (30 x 30 cm) were established down to a depth of 50 cm in each plot. One soil pit was dug in the center of the plot and the second one at a distance of 1 m further east to permit to take into consideration the sampling design. Then, all soil samples within each pit were taken separately with 10 cm intervals and composited per 10 cm depth interval. They were also passed through 2 mm sieve and handled by a separate plastic bag. The remaining sample processing was similar to that applied by fine roots.

Soil sampling and processing

About 100 Volumetric soil cores (5 cm diameter) were taken for soil bulk density determination. Thereafter, each sample was oven-dried at 105°C for 24 hours, weighed and then, sieved by 2 mm mesh size. Accordingly, the remaining soil fractions (>2 mm diameter) were also weighed to determine the coarse fraction content. The soil samples (taken on five depth classes of each plot) separated from the roots during root processing were also further analyzed for SOC content determination. For each depth class, soil samples were air-dried, ground and a further 20 g of soils were taken for SOC content laboratory analysis (IPCC, 2003).

Data estimation methods

The oven-dried root biomass samples were standardized into gram per meter square (g m^{-2}) for root biomass comparisons for each planting density and soil depth, then summed up for 0–50 cm depth as a total root biomass. The vertical distributions of fine and coarse root biomass at each depth were expressed as a percentage (in decimal) of the total root biomass (0–50 cm). Methods used for data estimations for each parameter are listed in Table 2.

Data availability

Underlying data

Figshare: Effect of Planting Density on Root Biomass and Distribution, and Soil Organic Carbon Stock of Acacia decurrens stands in northwestern Ethiopia. https://doi.org/10.6084/m9.figshare.21521112 (Endalamaw Mekonnen, 2022).

This project contains the following underlying data: coarse root biomass (g m^{-2}), fine root biomass (g m^{-2}), tree fine root biomass (g m^{-2}), herbaceous fine root biomass (g m^{-2}), live fine root biomass (g m^{-2}), dead fine root biomass (necromass) (g m^{-2}), soil organic carbon content (%) and soil organic carbon stock (Mg $^{-ha}$), and accordingly its vertical proportional distribution (in decimal) for five soil depth classes (0–10, 10–20, 20–30, 30–40, and 40–50 cm).

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