Comparison of carbon stock potential of farmland trees in the midlands of Hawzen, Northern Ethiopia

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ABSTRACT
In addition to the provisioning and supporting ecosystem services, trees on agricultural landscape provide regulating services. Storing carbon in different carbon pools is one of the regulating services offered by trees on farm. However, the carbon storing potential varies with variation in altitudinal class. This study compared the carbon stock potential of farmland trees considering two altitudinal classes, Weina-kola (1500–2000 meter.) and Weina-dega (2000–2500 meter.) in Hawzen district, northern Ethiopia. These traditional altitudinal classes are interpreted as warm and tepid, respectively. Twelve farm sample plots having an area of half a hectare were chosen randomly from both the study sites. A total of 24 composite and 24 undisturbed soil samples were collected from the sample farm plots from 0–15 cm and 15–30 cm soil depths for soil organic carbon (SOC) and bulk density (BD) analysis, respectively. The result showed that total biomass carbon was significantly higher (p < 0.01) in farmland trees of Weina-kola than the Weina-dega. The total biomass carbon was estimated 8.43 and 3.25-ton C ha−1 in Weina-kola and Weina-dega, respectively. Total soil carbon and total carbon did not show significant variation between the two altitudinal classes. The reason for this could be the differences in soil types, environmental variables and management regimes. Hence, this study concluded that altitudinal variation determines the type, number and size of trees grew in each class and brought significant difference in total biomass carbon stored in farmland trees.

Introduction
Trees in agricultural landscape have a potential to capture atmospheric CO₂ and store the carbon in different plant parts and soil (Nair, 2012). It is also a cost-effective strategy for climate change mitigation and lessen the adverse impacts (Mbow et al., 2014). For smallholder agroforestry in the tropics, potential carbon sequestration rates range from 1.5 to 3.5-ton C ha−1 yr−1 (Montagnini & Nair, 2004). Soil carbon sequestration has much to offer climate change mitigation, land and livelihood protection and resilience to climate change (Team et al., 2007). Selling carbon credits may provide another source of income for farmers, diversifying their agricultural portfolio further. For these reasons, agroforestry systems may prove to be very useful component of agricultural adaptation as both an economically feasible adaptation strategy for smallholder farmers vulnerable to climate change as well as a profitable greenhouse gas mitigation opportunity.

The total amount sequestered carbon greatly depending on a number of factors including the region, the type of system, site quality, woody species composition, ages of trees, altitude, agroecological conditions and previous land-use (Nair, 2012; 2016). Taking land use as an example, trees on farmland could significantly sequester higher carbon stocks than annual crops and lesser than that of managed forests (Henry et al., 2009). Properly managed farmland trees have immense capability in storing atmospheric carbon. In Tigray region, northern Ethiopia, farmers have a habit of managing trees like Faiderbiha albida as this species is very crucial for enhancing soil fertility (Gelaw et al., 2015; Hadgu et al., 2009). Specifically, in Hawzen district of the study area, Faiderbiha albida grew on the farm lands are well managed, resulted in higher amount of carbon stock (Haftom et al., 2019). However, the amount of carbon stock could be affected by altitude. Altitude is one of the main factors that affect the magnitude of carbon stock.
to be sequestered by trees on farmland (Körner, 2007; Leuschner et al., 2007; Wang et al., 2010). Nevertheless, the impact of altitude on carbon storing potential of trees on farm remained unstudied in our study area.

Hence, the aim of this study is to investigate the impact of altitude on the woody vegetation carbon stock and soil organic carbon of farmland trees considering two altitudinal classes, 1500–2000 meter and 2000–2500 meter in Hawzen district, Tigray, Northern Ethiopia.

**Methodology**

**Description of the study sites**

The study was conducted in two kebeles of Hawzen district in northern Ethiopia. Hawzen district is located in the tepid to cool sub moist mid highlands agro-climatic zone of Tigray, the Northern region of Ethiopia (Figure 1). The study was conducted in two different elevation classes, traditionally known as Weina-kola (1500–2000 meter) and Weina-dega (2000–2500 meter) (Table 1). It is interpreted as Warm and Tepid, respectively. Hence, the comparison was made between the warm and tepid elevation classes on carbon stock potential of farmland trees, hereafter referred to as Weina-kola and Weina-dega.

**Sampling technique**

Floristic composition, above and below ground carbon and soil carbon stock for both sites were tested. A total twelve farm plots were sampled for floristic composition and biomass estimation. Each plot has an area of 0.5 hectare (50 m×100 m) and has a rectangular shape as rectangular plots are more representative than circular or square plots in embodying within plot heterogeneity (Hairiah et al., 2001). All tree/shrub species found within the plot were identified, counted and measured their

![Figure 1. Map of Hawzen district.](image_url)

**Table 1. Description of the study sites**

| Description         | Weina-kola          | Weina-dega         |
|---------------------|---------------------|--------------------|
| Geographical location | 39°23′47″E and 13°54′09″N | 39°27′55″E and 13°59′20″N |
| Elevation           | 1900–2000 meter.     | 2200–2300 meter.   |
| Precipitation       | 400–800 mm/year      | 400–800 mm/year   |
| Average temperature | 19°C                | 18°C               |
| Crops               | Barley, Wheat, Sorghum, Maize | Barley, Wheat, Sorghum |
Diameter at Breast Height (DBH) (1.3 m aboveground level), Diameter at Stump Height (DSH) (30 cm aboveground level), height and crown diameter. Clinometer, caliper and tape meter were used to measure height, DBH(DSH), and crown diameter of a tree/shrub respectively. Plant identification was done in the field using their local name and useful trees and shrubs for Ethiopia (Bekele-Tesemma & Tengnäs, 2007). Composite soil samples were taken from four corners and center of the plot. Soil samples were collected from two different depths; 0–15 cm and 15–30 cm because change in soil organic matter in the mineral soils mostly occurs in the upper 30 cm layer (Hairiah et al., 2001). Besides, separate soil samples were taken from the same points using sample ring for bulk density determination as used by Grossman and Reinsch (2002).

**Living tree biomass carbon estimation**

All trees laid with in the plot were identified and counted. To estimate the above ground biomass of the standing trees, DBH (DSH) measurement of the sample trees were taken. In agricultural landscapes, biomass estimation using DBH alone has a change of 1.3% from the biomass estimated using DBH, height and specific wood density (Kuyah & Rosenstock, 2015). They recommend that to use DBH measurement alone in studies of limited budget. After having the above ground biomass, the carbon stock was calculated assuming it constitutes 50% of the total AGB (Nair, 2012).

\[
AGB = 0.091*DBH^{2.472} \quad \text{(Kuyah & Rosenstock, 2015)}
\]

The equations developed by Woody Biomass Inventory and Strategic Planning Project WBISPP (Woody Biomass Inventory and Strategic Planning Project) (2000) for all woody species in Dry Kola and Moist Kola agro-ecological zone of Ethiopia were also used for estimating tree carbon stock

\[
AGB = 0.3197*DSH + 0.0383*DSH^{2.62}
\]

As it is difficult and complex to measure the below ground living biomass, it is commonly derived from the above ground living tree biomass using the root to shoot ratio (Nair, 2012). Depending on the nature of the plant and ecological conditions, the below ground living biomass ranges from 25–40% of above ground living tree biomass (Nair, 2012). (Penman et al., 2003) estimate also as 27% of AGB.

\[
BGB = AGB*0.273
\]

**Soil carbon estimation**

A laboratory analysis was made to measure organic carbon concentration using the method of Black and Walkley (1934). Soil organic carbon were calculated using Pearson et al. (2007): SOC = %OC × ρ × D * 1004

\[
SOC = \text{Soil Organic Carbon [tC/ha]}, \% \text{OC} = \text{Carbon Concentration [%]}, \rho = \text{Bulk Density [g cm}^{-3} ], \ D = \text{Depth of the Soil Sample [cm]}, \ 100 \text{ is the conversion factor from g/cm}^{2} \text{ to ton/ha.}
\]

**Statistical analysis**

Data were initially subjected to normality test and equality of variance, prior to conducting parametric statistical analysis. The elevation class was the independent variable while density, basal area, biomass carbon stock, soil carbon stock and total carbon stock were the dependent variables. All data were compared using T-test with software package (SPSS 23) and differences were considered significant at p < 0.05 level.

**Results and discussion**

**Floristic composition**

A total of 10 woody species, belong to 6 families, was recorded in both sites where scattered trees on farm were practiced. Among the species, wood trees constituted 75.2% (5 species), fruit tree 20.7% (5 species) and shrubs 4.1% (2 species). This does not sum up to 10 (total type of species recorded) as some species occur in both shrub and tree form. Native species accounted for 50% (5 out of 10 species) and the rest (50 %) were non-native (5 out of 10 species). The family Fabaceae and Rutaceae contained the highest number of woody species represented by three species each. The rest families such as Anacardiaceae, Boraginaceae, Myrtaceae and Rhamnaceae were represented by one species each.

Variations were observed in terms of the relative frequency trees/shrubs in plots. In the Weina-kola Faiderbiha albida (40%) and Acacia abyssinica (26.7%) were the most frequently found. Faiderbiha albida species was highly preferred by farmers in the study site for amelioration of soil fertility, fodder and shade. Faiderbiha albida (27.8 %) and Psidium guajava (16.7%) were the tree species with high relative frequency in Weina-dega farmlands.

No significant difference was found in Density (number of stems per hectare) in three sites. The basal area of the Weina-kola farmland trees showed significance
difference (P < 0.05) when compared to the Weina-dega farmland trees (Table 2). 84.77% of the basal area in Weina-kola was contributed by *Faiderbiha albida*. This is due to the presence conducive climatic environment for growing the *Faiderbiha albida* tree and they do not cut it whenever it naturally regenerates in their farmlands. The average DBH of *Faiderbiha albida* in the Weina-kola site was 35.5 cm and extends up to a maximum of 60 cm. They are properly managed and widely spaced, which made them significantly different in basal area but not in density when compared with Weina-dega farmland trees.

**Biomass carbon stocks**

There was a significant variation in the mean vegetation carbon stock between the farmland trees located in the Weina-kola and Weina-dega altitudinal classes (Table 3). The total biomass carbon stock for the Weina-kola and Weina-dega was 8.43 and 3.26, respectively. This was similar to the study of Chiemela et al. (2018) in Zongi, Central Tigray where there is a good tradition of practicing scattered trees on farm, with the study of Gebrewahid et al. (2018) in Western Tigray and with the study of Haftom et al. (2019). The total biomass C stock is within the range reported for agroforestry systems in sub-Saharan Africa (4.5–19-ton C/ha) (Unruh et al., 1993). The above and below ground carbon stock stores by trees on farm in Weina-kola is significantly (p < 0.01) higher than that of stored by the trees on the farm of Weina-dega. This is similar to a study conducted in northern Ethiopia explaining that the trees on the farm of Weina-kola stored significantly more carbon than the trees on farm of Weina-dega (Gebrewahid et al. 2019). Leuschner et al. (2007) and Wang et al. (2010) also reported that above and below ground biomass carbon decrease with increasing altitude.

**Carbon stock potential of the soil**

The total potential soil C stock up to 30 cm depth for the Weina-kola and Weina-dega were 34.66 tons/ha and 33.17 tons/ha, respectively (Table 4). The surface layer (0–15 cm) contributed 53.2% to the total (0–30 cm) soil organic carbon stock for both Weina-kola and Weina-dega classes. The total soil carbon stock of the study area was in line with the specified range for agroforestry soil carbon, 13–300 tons of carbon per hectare (Kumar & Nair, 2011).

The total soil organic carbon stocks (ton C ha⁻¹) to 30 cm depth did not significantly vary between the two elevation classes, though the Weina-kola has higher above and below ground vegetation carbon stock. The reason for undermined the impact of farmland trees on soil organic carbon might be attributed to differences in soil types, environmental variables and management regimes. Soil carbon stock has strong dependency on environmental conditions; particularly soil type is the main determinant for soil carbon stock (Lueldeling et al., 2011). Kumar and Nair (2011) stated that the amount of carbon stored in soils depends on soil qualities. A study in West Africa revealed that different soil types under the same land use type showed a large difference in soil carbon stock (Batjes, 2001).

### Table 2. Floristic composition of the study sites

| Elevation class | Composition | Density (Stem/ha) | BA (m³)/ha | Dominant species          |
|-----------------|-------------|------------------|------------|---------------------------|
| Weina-kola      | 4           | 25.67 ± (8.3)    | 2.06 ± (0.7) | *Faiderbiha albida*       |
| Weina-dega      | 9           | 22.00 ± (6.1)    | 0.58 ± (0.4) | *Psidium guajava, Faiderbiha albida* |

Different letters in the same column are significantly different (P < 0.05).

### Table 3. Biomass carbon stock of the study sites

| Elevation class | AGB (m³) | BGB (m³) | TB (m³) | AGC (m³) | BGC (m³) | TBC (m³) |
|-----------------|----------|----------|---------|----------|----------|----------|
| Weina-kola      | 12.31 ± (4) | 4.55 ± (1.5) | 16.86 ± (5.4) | 6.16 ± (2) | 2.28 ± (0.7) | 8.43 ± (2.7) |
| Weina-dega      | 4.74 ± (4.6) | 1.75 ± (1.7) | 6.49 ± (6.3) | 2.37 ± (2.3) | 0.88 ± (0.8) | 3.25 ± (3.1) |

* Different letters in the same row are significantly different at the 0.05 level.

### Table 4. Soil carbon stock of the study sites

| Elevation class | SOC_15 (m³) | SOC_30 (m³) | Total SOC (m³) | TVCS (m³) | TCS (m³) |
|-----------------|-------------|-------------|----------------|-----------|----------|
| Weina-kola      | 18.44 ± (4.6) | 16.21 ± (3.7) | (34.66 ± 8) | 8.43 ± (2.7) | 43.1 ± (6.1) |
| Weina-dega      | 17.64 ± (4.5) | 15.53 ± (3.6) | (33.17 ± 8) | 3.25 ± (3.1) | 36.42 ± (7.4) |

* Different letters in the same row are significantly different at the 0.05 level.
**Total carbon stock**

The total carbon stock of the Weina-kola and Weina-dega altitudinal classes is 43.1 to 36.42 ton C ha\(^{-1}\), respectively. This is within the range of 7.9–105-ton C ha\(^{-1}\) stated for tropical agroforestry (Montagnini & Nair, 2004). Total carbon stock did not show significant variation between the Weina-kola farmland trees and Weina-dega farm land trees (Table 4). This is due to high amount of the total carbon stored in soil organic carbon. In this study, 80.4% (Weina-kola) and 90.1% (Wein-dega) of the total carbon are stored as soil organic carbon. The soil carbon stock contributed more to the total carbon stocks than that of biomass carbon stock in both altitudinal classes. Mathew et al., 2016 also described that soil carbon constitutes higher ratio than biomass carbon in trees on agricultural system across all altitudinal gradient. In the contrary, higher proportion of carbon resides in the biomass than the soil when it is in an intensive agroforestry system (Negash & Starr, 2015). However, our study focused on scattered trees on farm and many studies found that, in such system the soil stored more carbon than the biomass (Baral et al., 2013; Gebrewahid et al., 2018; Matew et al. 2016; Haftom et al., 2019).

**Conclusion**

The trees on agricultural landscape in the study area are not meant only for the enhancement of crop production but also for climate change mitigation through storing carbon. 43.1 and 36.42-ton C ha\(^{-1}\) were stored in the system in Weina-kola and Weina-dega, respectively. This could be a good opportunity to the farmers regarding the carbon financing in the future. The farmland trees in Weina-kola stored more biomass carbon than that of Weina-daga farmland trees, indicating that the elevation has influence on vegetation composition and then on the biomass carbon. Soil organic carbon stock was significantly higher than the biomass carbon stock of the scattered trees on farm. This may call up for intensification of the agroforestry system to boost vegetation cover in the farmlands, management of grazing system and control of illegal cutting of trees.

**Competing interests**

The authors declares no competing interests.

**Disclosure statement**

No potential conflict of interest was reported by the author(s).

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**Notes on contributor**

H. Haftom has a BSc degree in General Forestry and MSc degree in Climate and Society. Together with colleagues, he has eleven publications in peer reviewed journal mainly related to species distribution model. He is now attending his second masters in geo-information science and earth observation at university of Twente, the Netherlands. He is interested in forest carbon estimation, biodiversity assessment and vegetation structural mapping using the combination of field and remote sensing methods.

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**Public interest statement**

Trees grew in agricultural landscape provides ecosystem services like food, fodder, soil conservation, microclimate amelioration, biodiversity conservation and carbon storage. These services can be categorized as provisioning, supporting and regulating service. This study focuses on one of the regulating services of trees which is carbon storage. This article investigates the carbon storage capacity of on farm trees across altitudinal gradient. It compared the carbon storage potential of on farm trees considering two altitudinal classes which are Weina-kola (1500-2000 meter.) and Wein-dega (2000-2500 meter.) in Hawzen district, northern Ethiopia. The result revealed that farmland trees in Weina-kola has better capacity of storing carbon than that of the Weina-dega farmland trees. However, the carbon stored in the soil has not shown significant variation in those altitudinal classes. This might be due to soil types, environmental factors and variation in management regimes.

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