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Impact of farm exclosure on woody species abundance and carbon stock in Tigray, Northern Ethiopia

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Impact of farm exclosure on woody species abundance and carbon stock in Tigray, Northern Ethiopia

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Abstract: Trees on farm provide numerous supporting and regulating services. Some services are biodiversity conservation and enhancement of carbon stock storage. This depends upon the exclusion of livestock intervention to farmlands. In Ethiopia, exclosure has been implemented on communal grazing lands which brought better abundance and enhanced carbon stock than open grazing lands. Recently, the idea of exclosure has been implemented on farmlands. This study investigated the impact of farm exclosures on woody species abundance, diversity and carbon stock. Two farm types, such as farm exclosure, where there is exclusion of livestock throughout the year, and open farms, where livestock freely graze in the winter, were selected in the districts of Hawzen and Hintalo Wajirat, Tigray, Ethiopia. Eighteen farm sample plots having an area of half a hectare (100*50) were chosen randomly from each farm type, totaling 36 plots. Height, diameter at breast height and diameter at stump height were recorded for trees and shrubs found in the sample plots. Fifteen woody species representing 10 families were recorded in farm exclosures and nine species representing seven families were recorded in the open farms. Higher abundance, basal area, vegetation biomass and vegetation carbon stock were found in farm exclosures than open farms. The species diversity remained the same for both farm types. This is due to farmers sticking to a few species that are good for crops growing under the trees. In general, protected farms have a considerable contribution to increasing carbon storage but not diversity.
stock were observed in the farm exclosures. Mean abundance of all woody species was 21.34 and 13.44 trees ha\(^{-1}\); basal area, 0.55 and 0.18 m\(^2\) ha\(^{-1}\); species richness, 2.72 and 2.11; Shannon diversity, 1.64 and 1.74; and vegetation carbon stock, 4.57 and 1.18 ton ha\(^{-1}\), for farm exclosures and open farms, respectively. The result showed that there is a significant difference in mean abundance (\(p < 0.05\)), basal area (\(p < 0.01\)) and carbon stock (\(p < 0.01\)) between the farm exclosures and open farms. Thus, exclosures applied in farmlands have a considerable contribution in increasing woody species abundance, basal area and vegetation carbon stock.

Subjects: Biodiversity; Biodiversity & Conservation; Ecology - Environment Studies

Keywords: Woody species; farm exclosures; abundance; carbon stock

1. Introduction

Nowadays, the earth is facing global warming due to anthropogenic and natural factors which causes substantial changes in the world’s climate. A gradual change in the global climate has brought visible and evident effects across the world in many aspects such as finance, health, agriculture and so on. Developing countries, specifically dry lands, experience most adverse impacts of climate change (Stern, 2007). Like other developing countries, Ethiopia is vulnerable to climate change due to its exposure, sensitivity and poor adaptive capacity (Conway & Schipper, 2011). The northern part of the country, Tigray region, is identified as a vulnerable area to climate change (Hadgu, Tesfaye, Mamo, & Kassa, 2015).

The level of community’s vulnerability is determined by the sensitivity and adaptive capacity of the community (Stern, 2007). Indeed, adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities or to cope with the consequences (Vincent et al., 2013). Many pieces of literature have earlier indicated the role of trees growing in farmland coping up the climate change impacts.

Trees planted in farmlands help to adapt climate change by reducing the vulnerability to climate impacts and through reducing the effect of weather extremes (Rao, Verchot, & Laarman, 2007). Trees could also ensure mutual relationship with crops through decreasing nutrient loss from the soil and nitrogen fixation (Sanchez, Buresh, & Leakey, 1997). Incorporating trees on farmlands have often both economic and environmental benefits (Nair et al., 2012). Trees on farmlands improve soil fertility through control of erosion, maintenance of soil organic matter and physical properties (Kandji et al., 2006). Besides, some social benefits of trees on farmlands include the provision of products that include fuelwood, construction materials, fodder for livestock and additional sources of farm income generation (De Leeuw, Njengo, Wagner, & Iiyama, 2014). Planting trees, in general, provides an example of a set of adaptation practices that are intended to enhance productivity in a way that often contributes to climate change mitigation through enhanced carbon sequestration (Gebrehiwot & Van Der Veen, 2013).

However, the abundance, diversity and potential trees to sequester carbon depends upon the management practice (Chaturvedi, Raghubanshi, & Singh, 2011; Chaturvedi and Raghubanshi, 2015a; Montagnini & Nair, 2004). For example, exclosures have significantly higher abundance and carbon stock potential when compared to the open grazing lands (Mekuria, 2013; Tesfaye, 2011). Exclosure is an approach in which degraded lands are rehabilitated through excluding of human and livestock interventions to the enclosed area (Aerts, Nyssen, & Haile, 2009). Exclosures are usually established in steep, eroded and degraded areas that have been used for grazing in the past (Mekuria, 2013; Tucker & Murphy, 1997). Over the past three decades, exclosures have been widely implemented in northern Ethiopia, Tigray, and their impact on the restoration of the native vegetation, species abundance, richness, diversity and carbon stock is well documented (Birhane, Teketay, & Barklund, 2006; Mekuria,
Veldkamp, Corre, & Mitiku, 2011; Mengistu, Teketay, Hulten, & Yemshaw, 2005; Tesfaye, 2011). Exclosures have many benefits such as lessen land degradation, reduce run-off, reduce soil erosion, improve the microclimate and water infiltration, restore soil nutrients, sequester carbon, provide livestock fodder and fuelwood and enhance biodiversity and are a land management option with relatively low cost (De Leeuw et al., 2014; Mengistu et al., 2005).

However, exclosures are applied in the communal grazing land but not in the farmland where extensive grazing occurs in most of Ethiopia during the winter season (Nyssen et al., 2010). Therefore, implementing exclosure in grazing areas without implementing it in farmland may lead to increased grazing pressure on farmland (Baudron, Mamo, Tifessa, & Argaw, 2015) which may result in degradation of biodiversity and reduced carbon stock. The concept of farmland exclosure is a new approach introduced by the Ethiopian Ministry of Agriculture, and it applies the principles of zero-grazing to farmland, with the aim of halting farmland degradation and increasing productivity (Lenaerts, 2013). Although the impact of exclosure in communal grazing areas on species abundance, diversity and carbon stock is well documented, studies on farmland exclosure are limited. Thus, this study was conducted to examine the impact of exclosures established in farmlands on the abundance, diversity and vegetation carbon stock.

2. Materials and methods

Hintalo Wajirat is a district found in Southern Tigray and geographically located at 12°54’00” and 12°22’00” north of latitude and at 39°17’30” and 39°46’00” east of longitude (Figure 1). The mean monthly temperature ranges from 17.08°C to 21.9°C. The average annual rainfall of a 30-year data (1980–2009) is 568.96 mm ranging between 283.76 and 900 mm. Rainfall in the district has a unimodal pattern which covers the summer season from the end of June to mid-September with a length of growing period of 89 days. The altitude of the district ranges from 1,221 to 3,200 m above sea level. According to traditional Ethiopian agro-ecological zoning, 67.6% of the...
district is categorized as dry woina dega. And as to Ethiopian Ministry of Agriculture agroclimatic zoning, the district is categorized as tepid to cool sub moist mid highlands.

Hawzen is located at eastern zone of Tigray and geographically situated between 13°58'39" north and 39°25'45" east (Figure 1). The mean monthly temperature ranges from 16.6°C to 18.2°C. The average annual rainfall of a 30-year data (1980–2009) is 543.9 mm ranging between 340.5 and 886.1 mm. Rainfall in the district has a unimodal pattern which covers the summer season from the end of June to mid-September with 100 days of Length of Growing Period (LGP). The altitude ranges from 1,554 to 2,919 m above sea level. According to traditional Ethiopian agro-ecological zoning, 85.8% of the district is categorized as dry woina dega. And as to Ethiopian Ministry of Agriculture agroclimatic zoning, the district is categorized as tepid to cool sub moist mid highlands.

2.1. Study area selection
The study was conducted in two districts, one with exclosed farms and the other with open farms. The data about the farmlands in the districts were taken from the agricultural office of each respective districts. Accordingly, in Hawzen district, the farmlands were protected from livestock intervention for 13 years (2002–2015). In Hintalo Wajirat, the farmlands were not protected from livestock intervention, and free grazing was allowed. Hence, all the farm exclosures were sampled from Hawzen district and all open farms were sampled from Hintalo Wajirat district. Accordingly, the comparison was made between farm exclosures and open farms. These two districts constituted similar agroclimatic zones, rainfall, temperature and length of the growing period. A reconnaissance field survey revealed that Acacia trees, Cordia africana, Olea europea, Carissa edulis and Maytenus senegalensis were among the trees that can naturally grow in all the study sites in common.

2.2. Sampling technique
One farm plot of 0.5 ha (50 m*100 m) belonging to an individual farmer was used as a sample plot for biomass estimation and diversity assessment. A plot of half a hectare was selected as it was a common plot area among most of the farmers in the study districts. The inventory of scattered tree on farmlands was done from randomly selected 36 plots of rectangular shape. Rectangular plots were chosen as they are more representative than circular or square plots in encompassing heterogeneity within plot (Hairiah et al., 2001). All tree/shrub species found within the plot were named, counted and measured their Diameter at Breast Height (DBH) (1.3 m above-ground level), Diameter at Stump Height (DSH) (30 cm above-ground 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 (Ponce-Hernandez, Koohafkan, & Antoine, 2004). Plant identification was done in the field using their local name and useful trees and shrubs for Ethiopia (Bekele-Tesemma & Tengnäs, 2007).

2.3. Data analysis

2.3.1. Woody species composition and diversity
Woody species density, relative density, frequency and relative frequency (RF) for each individual species were calculated according to Argaw, Teketay, and Olsson (1999). The basal area (BA), relative dominancy and the importance value index (IVI) of each woody species having DBH >2.5 cm were calculated using Kent (2012). The diversity values of woody plants from the three villages were calculated using the Shannon diversity index (Magurran, 2004; Krebs, 1999).

2.3.2. Living carbon stock estimation
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). Considering the similarity in agro-climate and land use, the equation developed by Kuyah and Rosenstock (2015) was adopted for this study to estimate the above-ground biomass (AGB). After having the AGB, the carbon stock was calculated assuming it constitutes 50% of the total AGB (Chaturvedi & Raghubanshi 2015b; Nair, 2012).
Equations developed by Woody Biomass Inventory and Strategic Planning Project (WBISPP, 2000) in Dry Weyn-adega agro-ecological zone of Ethiopia were also used for estimating tree carbon stock for trees having DBH less than 2.5 cm.

\[
\text{AGB} = 0.091 + \text{DBH}^{2.472} \quad (\text{Kuyah and Rosenstock 2015})
\]

\[
\text{AGB} = 0.3197 + \text{DSH} + 0.0383 \times \text{DSH}^{2.6}
\]

The below-ground living biomass 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% to 40% of above-ground living tree biomass (Nair, 2012). Penman et al. (2003) estimated the below-ground living biomass as 27% of the AGB.

\[
\text{BGB} = \frac{\text{AGB}}{0.27}
\]

2.4. Statistical analysis
All the data were first checked for normality and equality of variance before directly progressing to further parametric statistical analysis. The management of farms was the independent variable, while density, BA, species richness, species diversities and vegetation carbon stock were considered as dependent variables. Vegetation data of each district were compared using T-test with software package (SPSS 20). Differences were considered significant at \( p < 0.05 \) level.

3. Results and discussion

3.1. Woody species diversity
The total number of woody plant species recorded in the study area, in both the farm exclosure and open farm area, was 17, among which 7 were naturally growing species and 10 were planted. In the farm exclosure, 15 plant species representing 9 families were recorded. Out of the total woody species encountered in the study quadrats, 82.8% were trees, 14.5% fruit trees and the rest were shrubs (Table 1). In the open farms, nine species were recorded representing seven families. Here, wood trees constituted 86.7%, shrubs 8.3% and fruit trees 5%. About seven species were recorded both in the exclosure and open farms, while eight species were found only in the exclosure area.

Variations were observed in terms of the RF of trees/shrubs in plots (Table 1). In the exclosures, *Faidherbia albida* (34%) and *Acacia etbaica* (18%) were the most frequently found. *Eucalyptus camaldulensis* (32%) and *Faidherbia albida* (16%) were the tree species with high RF in the open farms.

IVI is a measurement of dominance. According to IVI, *Faidherbia albida, Acacia etbaica, Acacia abyssinica* and *Eucalyptus camaldulensis* were the dominant species in the exclosures. *Eucalyptus camaldulensis, Faidherbia albida* and *Schinus molle* were the dominant species in open farms.

T-test showed that there were significant differences in the mean number of stem (abundance) per plot \( p < 0.05 \). The farm exclosures have a significantly higher number of trees per hectare

| Table 1. Species composition of the sampled plots in farm exclosures and open farms |
|---------------------------------|--------|--------|
|                                | Farm exclosures | Open farms |
| Total tree/shrub stems         | 190     | 120     |
| Species                        | 15      | 9       |
| Family                         | 10      | 7       |
| Wood tree (%)                  | 82.8    | 86.7    |
| Shrub (%)                      | 2.7     | 8.3     |
| Fruit tree (%)                 | 14.5    | 5       |
| Dominant species               | *Faidherbia albida* | *Eucalyptus camaldulensis* |
than the open farms (Table 2). This is due to the exclusion of livestock to farmland encourages the vegetation to grow, through reduction of being eaten and trampled by livestock. A study in central Ethiopia also revealed that farm enclosure had far a significantly greater number of trees than that of open farms (Baudron et al., 2015). In Ethiopia, seedling survival and growth got to be negatively affected by the presence of livestock (Wassie, Sterck, Teketay, & Bongers, 2009). Exclosure has a positive impact on the density of species (Birhane et al., 2006). In China, Yong-Zhong, Yu-Lin, Jian-Yuan, and Wen-Zhi (2005) demonstrated that excluding livestock grazing enhances vegetation recovery. BA per plot also showed a significant difference (p < 0.01). Farm enclosure had a higher BA (m$^2$/plot) than open farms. The farm enclosure had a higher BA as it constituted a lot of Faidherbia albida tree with high DBH. Studies from other land-use types revealed that enclosed lands had better tree species abundance and BA than open grazing lands (Birhane et al., 2006; Mekuria, 2013; Mengistu et al., 2005).

Species richness and Shannon diversity index were not significantly different. This is due to the deliberate selection of ideal trees to integrate with crops in farm enclosures. For instance, Faidherbia albida was the dominant tree in the farm enclosures which was most preferred by farmers due to its multiple purposes in addition to improving soil fertility. In addition to this Shannon, diversity did not show significant difference as this index gives more weight to rare species (Birhane et al., 2006; Negash, Yirdaw, & Luukkanen, 2012).

### 3.2. Above-ground and below-ground carbon stock of trees and shrubs

In the farm enclosures, it is dominated by Faidherbia albida trees ranging DBH from 8 to 60 cm and the density ranges from 8 to 36 stems ha$^{-1}$ (Table 3). The estimated total tree and shrub carbon stock (TTSCS) in the farm enclosure was 4.57 ton C ha$^{-1}$ (Table 3) This is similar to the study of Chiemela, Noulakou, Zenebe, Abadi, and Birhane (2018) in Zongi, Central Tigray, where there is a good tradition of practicing scattered trees on farm. The total biomass C stock is within the range reported for Agroforestry systems in sub-Saharan Africa (4.5–19 ton C/ha) (Unruh, Houghton, & Lefebvre, 1993). The TTSCS for open farms was 1.18 ton C ha$^{-1}$. Here, the TTSCS was out of the specified range for AF systems in sub-Saharan Africa. This is due to livestock intervention to farms which has a negative impact on naturally regenerating trees and artificially planted trees as well. In this study, the farm enclosures had significantly (p < 0.01) higher TTSCS than open farms. This agrees with Luedeling, Sileshi, Beedy, and Dietz (2011) which described carbon stock ha$^{-1}$ increased with increasing tree density. In agroforestry systems, the standing stock of the carbon above ground is usually higher than the equivalent land use without trees (Altieri & Nicholls, 2017).

### Table 2. Mean woody species basal area, abundance, richness and Shannon index (H’)

|            | No. of plot | Richness | BA (m$^2$/plot) | Abundance/plot | Shannon index |
|------------|-------------|----------|-----------------|----------------|---------------|
| Farm exclosure | 18          | 2.72$^a$ | 0.55$^a$        | 10.67$^a$      | 1.74$^a$      |
| Open farms  | 18          | 2.11$^a$ | 0.18$^c$        | 6.72$^b$       | 1.64$^a$      |
| p Value     | 18          | NS       | <0.01           | <0.05          | NS            |

Different letters in the same row are significantly different. NS: not significant.

### Table 3. Above-ground biomass (AGB), below-ground biomass (BGB), above-ground carbon stock (AGCS) and below-ground carbon stock (BGCS) in farm types (ton C ha$^{-1}$)

| Farm type | AGB       | BGB       | TB       | AGCS     | BGCS     | TCS       |
|-----------|-----------|-----------|----------|----------|----------|-----------|
| Exclosure | 6.68 (±5.48)$^a$ | 2.47 (±2.03)$^a$ | 9.16 (±7.50)$^a$ | 3.34 (±1.01)$^a$ | 1.24 (±2.74)$^a$ | 6.58 (±3.75)$^a$ |
| Open farms| 1.73 (±1.72)$^a$ | 0.64 (±0.64)$^a$ | 2.37 (±2.36)$^a$ | 0.86 (±0.86)$^a$ | 0.32 (±0.32)$^a$ | 1.18 (±1.17)$^a$ |

Different letters in the same row are significantly different at p<0.01.
Hence, the higher carbon stock in the farm enclosure is associated with higher tree abundance and higher biomass which brought as a result of the exclusion of livestock from farmlands.

4. Conclusions
The vegetation on the farm enclosure has significantly higher woody vegetation abundance and BA than the open farms. This showed that exclosed farm has a positive impact on density and BA. However, it did not have a significant variation on species diversity and richness. This could be due to farmer’s deliberate selection of the ideal tree to integrate with crops. Farm enclosures have also significantly higher vegetation carbon stock than open farms. Generally, farm enclosures do positively contribute to woody vegetation abundance, BA and carbon stock. Hence, the establishment of enclosure on farmlands is needed for better woody tree resource conservation and storing carbon stock.

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