Diversity and composition of farm plantation tree/shrub species along altitudinal gradients in North-eastern Ethiopia: implication for conservation

Meseret Muchea,d,*, Eyayu Mollab, Boris Rewaldc, Berhanu Abraha Tsegayd

a Department of Biology, Woldia University, P.O. Box, 400, Woldia, Ethiopia
b Department of Natural Resource Management, College of Agriculture and Environmental Sciences, Bahir Dar University, Bahir Dar, Ethiopia
c Institute of Forest Ecology, Department of Forest and Soil Sciences, University of Natural Resources and Life Sciences Vienna, Austria
d Department of Biology, Bahir Dar University, Bahir Dar, Ethiopia

ARTICLE INFO

Keywords:
Agroforestry
Conservation
Farmers acuity
Plantation niches
Species diversity

ABSTRACT

On-farm tree plantation is a form of land use where trees are planted at the edge or interspersed with crops. It has been practiced in different parts of Ethiopia due to its contribution to the household economy and soil fertility. This study was carried out to evaluate the variation in tree/shrub plantations along altitudinal gradients and plantation niches, and farmers’ on-farm tree plantation practices at Kobo and Guba Lafto districts, North-eastern Ethiopia. Transect walks and semi-structured questionnaire were administered to appraise farmers’ tree/shrub plantation practices and compositions between August and December 2020. A total of 135 plots along altitudinal gradients (Forty-five sample plots per altitude) and 135 retrieved questionnaires (45 per altitude) were analyzed. At each plot, tree/shrub richness, diversity, stem density, and important value index (IVI) were computed. Multivariate analysis, descriptive statistics, and preference rankings were used to evaluate vegetation data and farmers’ perceptions on tree/shrub plantations. The results showed that most farmers (78.5 %) integrate trees with their crops for household use and soil fertility maintenance. The multivariate analysis revealed a significant reduction in the number of taxa, stem density, richness, and diversity with increasing elevation, from homestead to the boundary and on-farm plantation niches. Ziziphus spina-christi and Cordia africana were the most preferred tree species; Fabaceae was the dominant family representing 18.9 % of the species. The results emphasized considerable variations in relative density, relative dominance, and important value index (IVI) across altitudinal gradients and plantation niches. Acacia seyal and Z. spina-christi contributed the highest IVI at lower and middle elevations, whereas Eucalyptus globulus had high IVI at a higher elevation. In the study districts, the distribution of multifunctional indigenous tree plantations gradually decreases with the entire altitudinal gradients compared to exotic trees/shrubs. This calls for substantial efforts on the propagation and conservation of native tree and shrub genetic resources.

1. Introduction

The world population is expected to exceed 9.3 billion by the mid-century, and thus, the demand for more productive land needs urgent attention (FAO, 2020). Many African countries have continued to experience food insecurity, decline in per capita farm income, soil degradation, and aggravated biodiversity loss (Vlek et al., 2010). In Ethiopia, population pressure has resulted in increasing demand for lands for food, energy, and other resources (Amsalu et al., 2007) leading to the conversion of forests and grazing lands into croplands (Wondie et al., 2011). In the wake of deforestation and degradation of natural vegetation and associated negative impacts on natural resources, the government of Ethiopia has launched an initiative to foster sustainable soil management strategies (Abebe, 2005; Wondie and Mekuria, 2018). In particular, agroforestry (AF) has been identified as part of the solution to address the decline in soil fertility and deforestation (Abebe et al., 2010; FAO, 2020). AF is a dynamic and complex ecological-based natural resource management system where farmers intentionally retain or integrate trees into their farmland in various spatio-temporal arrangements (Nair, 1998; Dhakal et al., 2012; Bucagul et al., 2013). AF systems are the main reservoirs of biodiversity and provide other ecosystem services, such as reduced soil erosion, enhanced carbon sequestration, holding high mitigation, and adaptation potentials under progressing climate change (Pandey et al., 2016; Reang et al., 2021). AF systems can be considered an...
important component of the (regional) reducing emissions due to deforestation and forest degradation (REDD+) strategy while simultaneously sustaining the livelihood of the rural population (Reang et al., 2021).

A complex of factors determine the composition of AF systems (Nogues-Bravo et al., 2008; Dhakal et al., 2012; Solefack et al., 2018; Reang et al., 2021). Among other factors, topographic gradients (slopes, elevation, and aspects), plantation niches, land use management, cultural diversity, and varying-rainfall pattern have been found to affect the functional composition of on-farm tree species (Costa et al., 2017; Pandey et al., 2021; Reang et al., 2021). Notably, elevation and tree plantation niches, such as home gardens, parklands, coffee tree shade systems, scattered trees on farmland, and boundary plantations are the principal factors that considerably affect the distribution of plant species (Molla and Kewessa, 2015; Legesse and Negash, 2021; Pandey et al., 2021). An increasing elevation is usually related to a lower temperature and higher humidity and hence this climatic variability strongly shapes the composition of vegetation in general and trees used for AF purposes in particular (Nogues-Bravo et al., 2008; Solefack et al., 2018).

In Ethiopia, a common AF system integrates *Eutete ventricosum* and *Coffea arabica* as scattered trees on cultivated lands in association with cereal crops such as *Zea mays*, *Eragrostis tef*, *Sorghum bicolor*, etc (Duguma and Hager, 2010; Kebebew and Urgessa, 2011). Farmers are also frequently integrating fruit crops such as *Persea americana* Mill., *Mangifera indica* Wall., *Psidium guajava* L., *Casimiroa edulis* S. Watson, *Ananas comosus* (L.) Merr., and *Musaz spp.*, in their agricultural lands (Negash and Starr, 2015) for food, income, shade, and soil fertility improvements. These tree/shrub plantations in agricultural systems are increasingly promoted as facilitating economic and socio-cultural services, biodiversity conservation, and an array of other ecosystem services benefitting smallholder farmers and rural communities (Nair, 1998; Kebebew and Urgessa, 2011; Abebe et al., 2013). The ecosystem services provided by plantations include rehabilitating degraded lands (Bishaw et al., 2013), thermal comfort and/or shading (Pinho et al., 2012), alleviating temporal shortages of water and energy, and facilitating adaptation to climate change (Bishaw et al., 2013; Ge et al., 2014). Thangata and Hildebrand (2012) and Mbow et al. (2014) asserted that the inclusion of trees in agricultural systems can optimize nutrient cycling and impart a positive effect on soil physicochemical properties. For instance, tree-based AF may increase the soil potassium content three times over croplands without tree integration (Ulery et al., 1995). According to Drechsel et al. (1991), *Cassia siamea* and *Asandra adacthaca indicata* were superior in enriching the sandy-loamy topsoil with calcium and increasing soil pH in central Togo. In Zambia, Yenge et al. (2018) reported an increase in nitrogen by 18 kg ha⁻¹ year⁻¹ and microbial diversity and abundance, by litter inputs of *Faidherbia albida* intercropped with maize. In addition to positive effects on the nutrient cycle, the inclusion of trees within croplands may increase soil organic carbon (SOC) stocks and soil water infiltration rates (Sanou et al., 2010; Chatterjee et al., 2019).

In Ethiopia, few studies have been conducted on the Spatio-temporal variation in crop diversity within AF systems, the practices and benefits of increasing tree diversity in farmed landscapes, and carbon stocks in AF systems (Abebe et al., 2010; Endale et al., 2017; Amare et al., 2019; Birhan and Abebe, 2019; Derero et al., 2020; Betemariyam et al., 2020). Yet, further studies need to be conducted on tree species composition along altitudinal gradients and plantation niches on-farm systems in North-eastern Ethiopia. And thus, the present study was motivated by the fact that exploration of tree plantation practices based on elevation and plantation niches are essentially required for the implementation of conservation and propagation actions of multi-purpose tree species especially crucial for soil fertility improvement. Therefore, the objectives of this study were: (1) to compare differences in species richness, diversity, stem density, and IVI of plantation trees/shrubs on farmlands along with altitudinal gradients and plantation niches; and (2) to assess farmers’ perception of AF systems and its role on the maintenance of soil fertility.

### 2. Methods

#### 2.1. Study sites description

The study was conducted at nine sites along an elevational gradient stretching between two districts: Kobo (11°51′45.63″ to 12°19′24.97″N and 39°19′54.87″ to 39°53′23.33″E) and Guba Lafo (11°34′54″ to 11°58′59″N and 39°6′9″ to 39°45′58″E), both located in the North Wollo Administrative Zone, North-eastern Ethiopia (Figure 1, Supplementary 1). The Kobo district (lowland) is characterized by fertile, plain land (65 %) while 20, 11, and 4 % are hillock landforms, rugged, and gorges, respectively, with an altitudinal range between 972 to 1864 m a.s.l (NWZAD, 2019). In contrast, the Guba Lafo district (mid-altitude lands to highland) holds gorges (15 %), mountainous/hills (35%), escarpments (30 %), and plateau (20 %) terrains with wide relief differences ranging from mid-altitude (1865–2704 m a.s.l.) to highland (2705–3809 m a.s.l.) (NWZAD, 2019, Figure 1). Ten-year climatic data showed that the Kobo district is particularly prone to drought with an erratic unimodal rainfall pattern; holding mean monthly precipitation ranging from 3.3 mm in January to 199.2 mm in August, and an average annual rainfall of 50 mm (ARKWF, 2020). Kobo district features a uniform high temperature throughout the year, with average minimum and maximum temperatures of 15.1 °C and 30.7 °C, respectively (ARKWF, 2020). The Guba Lafo district holds a bimodal rainfall pattern with an erratic distribution in precipitation varying widely across the district and years (NWZAD, 2019). In the midland of the Guba Lafo district, the mean monthly rainfall ranges from 10.8 mm in January to 380.1 mm in August and the average annual rainfall is 98.3 mm. The mean monthly temperature ranges between 12.4 °C and 28.7 °C (ARKWF, 2020). At highlands, the mean monthly rainfall ranges from 47.7 mm in January to 600 mm in August with an average monthly rainfall of 320.2 mm. The mean monthly temperature at highlands ranges between 8.9 °C and 22.7 °C. In the studied districts, the plots on steeper slopes are dominantly covered by shallow soils, mainly Leptosols, Regosols, Fluvisols, and Andosols; the plateaus are covered by clay soils that can be described as Vertisols and Vertic Cambisols (FAO, 1990). Cereals (*Zea mays*, *Sorghum bicolor*, *Eragrostis tef*) and pulses (*Cicer arietinum*, *Psam sativum*, etc.) are the major crop types grown in the study districts, alongside fruit trees such as *Mangifera indica*, *Persea americana*, *Carica papaya*, etc.

#### 2.2. Data collection on on-farm tree and shrub species

In August 2020, a survey was conducted to get a general overview of the tree plantation practices on-farm systems. Transect walks were used to collect data on the tree/shrub plantation compositions and diversity in the selected areas using a two-stage sampling approach. Primarily, Kobo (lowland) and Guba Lafo (midland and highland) districts were purposefully selected based on their tree plantation practices on farmlands, elevation gradients, and plantation niches (on-farm, boundary planting, and homestead plantation) (Figure 1; Figure 2). Then, three sites (i.e. villages) at each altitude were selected using a simple random sampling technique to assess the farmers’ plantation practices and woody vegetation composition of agroforestry (AF) systems (Figure 1; Supplementary 1). During transect walks, trees and shrub species and integrated crops were recorded for a quantitative vegetation data inventory, using prepared field observation data collecting tools (such as the number of tree/shrub taxa (Taxa-S), stem density, richness (R), diversity (H), relative frequency (RF), relative density (RD), relative dominancy (RDo), and Important Value Index (IVI) along the elevation gradient and plantation niches). A total of 135 sample plots (15 plots per site, 45 plots at each altitudinal level) were surveyed for the study. Ecological indices characterizing the tree and shrub vegetation in the AF systems were computed using the formulas in Table 1. At the end of vegetation data inventories, samples of tree/shrub species with their local names were collected across altitudinal gradients and niches, pressed, and dried for species identification. The scientific names were identified and verified.
based on the Natural Database for Africa (NDA) version 2.0 (http://alnapnetwork.com/NDA.aspx), International Plant Name Index (https://ipni.org), and published Floras of Ethiopia and Eritrea (Hedberg and Edwards, 1989; Edwards et al., 1995, 1997; Hedberg et al., 2003).

2.3. Questionnaire survey

Farmer respondents that are practicing tree/shrub plantations on their farmlands were selected at each altitudinal level using a snowball sampling approach. At each elevation level, 45 farmers were selected to administer a semi-structured questionnaire (Supplementary 2), so that a total of 135 farmer informants from different gender and age groups were used for this study. Both the interviews and vegetation data inventory (see above) were carried out simultaneously between August and December 2020. Additionally, ten key informants were questioned to rank the most preferred tree species used for soil fertility maintenance in their farmlands. The key informants were chosen based on traditional knowledge of farmland plantation practices following the suggestion made by the districts developmental association (DAs). The interview questionnaire included the socio-demographic variables (gender, age, educational and marital status, and family size), farmers’ perception of the inclusion of tree/shrub plantation on agricultural lands, and their tree preferences to maintain soil fertility (Supplementary 2). It was administered using the local language, Amharic, and later translated into English. The interview was supplemented by direct observation and transects walks (see above). Furthermore, the study was approved by the research and ethical review board of Woldia University Faculty of Natural and Computational Science with the reference number FNCS 0008/2014. Moreover, all respondents were aware of the purpose of the study and consented to participate in the survey.

2.4. Statistical analyses

The effects of the altitudinal gradient (lowland, mid-altitude, and highland), tree and shrub plantation niches (on-farm/farmland, homestead, and boundary) and their interactive effects on the number of Taxa (Taxa-S), stem density, species richness (R), diversity ($H'$), relative frequency (RF) and density (RD), Important Value Index (IVI), and relative dominance (RDo; Table 1) were analyzed by a General Linear Model (GLM) using SPSS v.24 and PAST v. 3.04 software packages (Hammer et al., 2001). Posthoc comparisons of means were employed using Least Significant Difference (LSD) at $p < 0.05$. Furthermore, preference ranking and descriptive statistics were used to evaluate the farmers’/experts perception of the benefits of AF in general and tree species preferences regarding soil fertility maintenance in specific.

3. Results

3.1. Background information on the characteristics of the respondents in the surveyed districts

The socio-demographic information in Table 2 revealed that among the surveyed households there were more male respondents 102 (75.56%) compared to females 33 (24.44%). The mean age was 48.4 years, in which minimum and maximum ages were 18 and 75 years, respectively. The fact that age was an important variable could tell the farmers’
experiences and knowledge in the identification of major tree and shrub plantations on agricultural systems and the implication for soil fertility maintenance. Concerning education status, 57 (42.22 %) of the respondents had no formal education, while 53 (39.26 %) had primary and secondary schoolings, and 25 (18.52 %) had tertiary education. Most of the surveyed respondents 111 (82.2 %) were married, and only 5 (3.7 %) of the individuals were divorced or widowed. The survey results also showed that the average family size was 6, ranging from 0 to 11 (Table 2). The land is the major asset of the farmers in the study areas to guarantee sustainability and implement the AF practices and thus most of the surveyed farmers (43.7 %) own less than 0.5 ha of land. They further reported that the presence of small-sized farmland is the major problem in practicing AF in the farm systems (Table 2).

Table 1. Indices characterizing trees and shrubs in agroforestry systems in North-eastern Ethiopia by altitude (n = 3), tree niches (n = 3), and study sites (n = 9).

| Ecological indexes | Equation | References |
|--------------------|----------|------------|
| R                  | Menhinick’s R = S/√N | Rejmanek and Randall (1994) |
| H'                 | Shannon-Wiener H = - \( \sum_{i} P_{i} \ln P_{i} \) | Kent and Coker (1992) |
| SD                 | Number of a tree/shrub species SD = Number of a species / Total area sampled | Kent and Coker (1992) |
| RF                 | Number of species RF = Number of occurrence of the spp / Number of occurrence of all spp *100 | Magurran (1988) |
| RD                 | Numerical strength D = Density of the spp / Density of all spp *100 | Magurran (1988) |
| RDo                | Species abundance RDo = Total No of spp encountered / Number of spp occurrence *100 | Magurran (1988) |
| IVI                | Importance of species IVI = RF + RD + RDo | Kent and Coker (1992) |

R, Richness; H', Shannon Diversity Index; SD, Stem Density; RF, Relative Frequency; RD, Relative Density; RDo, Relative Dominancy; IVI, Important Value Index; N = the number of tree species; S = the number of species; Pi = the proportion of individuals of the ith species expressed as a proportion of total cover in the sample, and in = the natural logarithm.

Table 2. Socio-demographic characteristics of sampled households (n = 135) at nine study sites (45 per elevation).

| Household Characteristics | Frequency | Percent |
|---------------------------|-----------|---------|
| Gender Male               | 102       | 75.56   |
| Female                    | 33        | 24.44   |
| Age (yrs) 18-30           | 29        | 21.48   |
| 31-40                     | 35        | 25.93   |
| 41-50                     | 30        | 22.22   |
| >50                       | 41        | 30.37   |
| Educational status Tertiary | 25       | 18.52   |
| Primary & secondary       | 53        | 39.26   |
| No formal schoolings      | 57        | 42.22   |
| Marital status Married    | 111       | 82.2    |
| Unmarried                 | 19        | 14.1    |
| Others                    | 5         | 3.7     |
| Family size 1-5           | 69        | 51.1    |
| 6-10                      | 57        | 42.2    |
| >10                       | 9         | 6.7     |
| Landholding (ha) <0.5     | 59        | 43.7    |
| 0.5-1                     | 53        | 39.3    |
| >1                        | 23        | 17.0    |

Figure 2. An illustration on the tree/shrub plantation inventory and interviewed the farmers on their perception of plantation practices on-farm systems (Photo by Meseret Muche, 2020).
3.2. Effect of altitudinal gradients and plantation niches on tree/shrub composition

3.2.1. Tree species richness and diversity on agricultural lands

The numbers of taxa (Taxa-S), stem density, richness, and diversity of tree plantation in agroforestry systems of North-eastern Ethiopia, as related to elevation and tree niches, are presented in Figure 3. Both numbers of woody taxa and stem density showed a statistically significant reduction along the altitudinal gradient (Table 3), in both cases driven by the lower numbers of taxa (11.3 ± 2.5) and stem densities (29.7 ± 7.6) in highland AF systems (Figure 3). Both parameters varied according to tree niches, with generally greatest numbers of taxa and stem densities at homesteads, followed by boundary plantings and least values of woody plants on-farm (p < 0.001); however, numbers of taxa on mid-elevation plots possess in general less variability and no clear separation according to planting niches (Figure 3a). Both greater numbers of woody taxa and stem densities of on-farm plantations and partially boundary plantings at mid-elevation plots compared to lowland plots seem to drive the significant interaction effects between altitudes and niches (Table 3). Regardless of these variations, A. seyal and Z. spinachristi gained dominance at the low and mid altitudes while E. globulus dominated the highland farms. Concerning the gross numbers of tree plantations on-farm systems, a total of 37 species belonging to 20 families were recorded across elevations. Fabaceae was the most dominant family, represented by 7 (18.9 %) species, followed by Anacardiaceae, Boraginaceae, Euphorbiaceae, Myrtaceae, and Rutaceae (represented by 3 (8.1 %) species each) (Supplementary 3). The result highlighted that tree species richness was statistically (p < 0.01) greater in the lower elevation plots, followed by mid and the highlands, which also had considerable differences (p < 0.01) across plantation niches (Figure 3c; Table 3). Similarly, tree species diversity (H’) was significantly (p < 0.001) lower at highlands AF systems (H’ = 1.9 ± 0.2), with a markable lower diversity on-farm compared to homesteads at low and mid-elevation plots while at highland plots the greatest diversity was found among boundary plantings—likely underlying the significant interaction effect (Figure 3d; Table 3).

3.2.2. Tree plantation occurrences and composition on agricultural lands

The proportion of tree species frequencies, density, and dominance on-farm systems based on elevations are given in Tables 3 and 4. Variation in species, relative tree density (RD), and relative dominance (RDo) were observed among the studied altitudinal gradients within tree
plantation niches ($p < 0.001$). Elevation and types of plantation niches are the main predictors that determine the changes in the RD and RDo of species. Thus, the RD and RDo of tree species are greatly distributed in homestead plantations, followed by boundary planting and on-farm agroforestry systems. In addition, there were marked differences in elevation, where there are higher RD and RDo of farm tree assemblage in agroforestry systems. In contrast, were heavily dominating (RF $\leq 0.001$), Elevation and types of plantation niches and their interactive effects on variables related to woody species assemblage in agroforestry systems of North-eastern Ethiopia. See text for details on variables.

| Variable       | Effect                     | DF | F   | P    |
|----------------|----------------------------|----|-----|------|
| Taxa-S         | Altitudinal Gradients (AG) | 2  | 145.9 | .000 |
|                | Tree Niches (TN)           | 2  | 41.9  | .000 |
|                | AG x TN                   | 4  | 2.99  | .047 |
| Stem density   | Altitudinal Gradients (AG) | 2  | 118.1 | .000 |
|                | Tree Niches (TN)           | 2  | 143.5 | .000 |
|                | AG x TN                   | 4  | 13.4  | .000 |
| Richness       | Altitudinal Gradients (AG) | 2  | 7.5   | .004 |
|                | Tree Niches (TN)           | 2  | 31.2  | .000 |
|                | AG x TN                   | 4  | 4.7   | .009 |
| Diversity      | Altitudinal Gradients (AG) | 2  | 248.9 | .000 |
|                | Tree Niches (TN)           | 2  | 31.3  | .000 |
|                | AG x TN                   | 4  | 4.6   | .010 |
| RF             | Altitudinal Gradients (AG) | 2  | 166.9 | .000 |
|                | Tree Niches (TN)           | 2  | 0.2   | .81  |
|                | AG x TN                   | 4  | 0.1   | 0.9  |
| RD             | Altitudinal Gradients (AG) | 2  | 27.2  | .000 |
|                | Tree Niches (TN)           | 2  | 19.9  | .000 |
|                | AG x TN                   | 4  | 18.6  | .000 |
| RDo            | Altitudinal Gradients (AG) | 2  | 206.1 | .000 |
|                | Tree Niches (TN)           | 2  | 39.9  | .000 |
|                | AG x TN                   | 4  | 39.9  | .000 |
| IVI            | Altitudinal Gradients (AG) | 2  | 247.2 | .000 |
|                | Tree Niches (TN)           | 2  | 23.2  | .000 |
|                | AG x TN                   | 4  | 23.7  | .000 |

The total sum of squares (SS) is the same for all models (4, 26), and effects are thus directly comparable across models. RF, Relative Frequency; RD, Relative Dominancy; IVI, Important Value Index; DF, Degree of Freedom; F, Fisher test; P, Probability Level.

### 3.3. Farmers’ perception of the integration of tree/shrub plantations to the agricultural lands

Among the total respondents (135), 106 (78.5%) farmers integrated trees/shrubs into their agricultural systems. Such knowledge of farm tree plantation was acquired from their parents (i.e., an indigenous knowledge transfer) accounting for 48 (45.3 %), through observation and training from developmental associations 31 farmers (29.2%) and non-governmental organizations 21 farmers (19.8 %). Six (5.7%) of the respondents unveiled that tree species such as Z. spina-christi and A. seyal are often dispersed by birds (locally called: wofe zerash) on their farm-lands without farmers’ involvement. Regarding tree plantation practices and distribution, the highest tree density was reported around home-steads (51.1%), followed by farm boundary (30.4%), and in the-farm lands (13.3%) whilst few (5.2 %) respondents prefer to plant a tree on pastoral and degraded lands. The purpose of tree plantation in on-farm systems is indicated in Figure 4. Out of the 135 respondents, 42 (31.5 %) practiced tree plantation in their farmlands for soil fertility mainte-nance, followed by 21 for food and fodder (15.5 %), and 17 for building, construction, and fence (12.5 %). As indicated in Table 5, Z. spina-christi was found to be the most preferred tree species for soil fertility mainte-nance, followed by Cordia africana and Ficus vasta. However, the lowest ranks were given to Ehretia cymosa and Acacia senegal. Notwithstanding the belief that trees are necessary, farmers in the districts described the distribution of multi-purpose native farm tree species (e.g., Acacia abyssinica, Hagenia abyssinica, Podocarpus falcatu, etc) are gradually declining in the agricultural systems and replaced by some exotic species such as Eucalyptus, which depreciates the soil fertility potential of the agricultural lands. In the study area, farmers’ preference of tree/shrub species to maintain the soil fertility status is varied.

### 4. Discussion

#### 4.1. Composition of tree/shrub plantations across an altitudinal gradient and on-farm niches

The density and distribution of tree species in the farmlands are influenced by various unified factors, including topography, biophysical attributes, and socio-economic conditions (Nogues-Bravo et al., 2008; Negash et al., 2012; Dhakal et al., 2012; Haile et al., 2017; Sharma et al., 2017). Among these, elevation and tree niches have served as important determinant factors for tree plantation and distribution of trees in the agricultural systems (Nogues-Bravo et al., 2008; Haile et al., 2017). In this study, monotonic decreases in stem density and taxon were observed from lower to higher elevation gradients. A similar decrease in numbers of tree species with an increase in elevation could result from poor soil nutrient concentration and organic matter decomposition at the higher altitudinal gradients, caused by lower temperature and higher precipita-tion (Duguma and Hager, 2010; Negash et al., 2012; Haile et al., 2017; Monge-Gonzalezm et al., 2019). In terms of tree niches, the homesteads had a higher number of taxa and stem density in the entire altitudinal gradient as compared with the boundary and on-farm plantations (Table 5). This was in line with other similar studies in Ethiopia (e.g., Abebe, 2005; Tolera et al., 2008; Duguma and Hager, 2010), which described a marked increase in numbers of taxa, stem, and species diversity in the home gardens than in the other land-use types. These studies also showed variations in species heterogeneity with changes in elevation gradients and plantation niches. The reduction in tree species diversity along with elevations (from lower to higher gradients) (Figure 3), could be ascribed to environmental variability in terms of soil characteristics, temperature, species adaptability, and management practices. Similar trends of decreasing tree species diversity with altitu-dinal gradients have been reported in Southern Ethiopia (Tolera et al.,...
### Table 4. Indicators characterizing woody species (trees/shrubs) assemblages in agroforestry systems along an elevation gradient in North-eastern Ethiopia.

| Species          | Family       | 972–1864 m asl (LE) | 1865–2704 m asl (ME) | 2705–3809 m asl (HE) |
|------------------|--------------|---------------------|----------------------|----------------------|
|                  | RF | RD | RDo | IVI | RF | RD | RDo | IVI | RF | RD | RDo | IVI |
| *Acacia saligna* | Fabaceae | 4.9 | 4.8 | 3.4 | 13.2 | 1.9 | 1.1 | 1.9 | 4.9 | 0.03 | 0.02 | 0.04 | 0.09 |
| *Acacia senegal* | Fabaceae | 0.7 | 0.4 | 1.4 | 2.5 | 1.8 | 0.8 | 1.7 | 4.3 | 0.23 | 0.02 | 0.04 | 0.08 |
| *Acacia seyal* | Fabaceae | 5.8 | 10.4 | 6.1 | 22.4 | 5.3 | 10.3 | 7.0 | 22.6 | 0.02 | 0.02 | 0.04 | 0.08 |
| *Acacia tortilis* | Fabaceae | 3.1 | 2.1 | 2.3 | 7.4 | 3.4 | 3.3 | 3.2 | 9.9 | 0.03 | 0.03 | 0.04 | 0.10 |
| *Adhatoda schimperiana* | Acanthaceae | 1.8 | 1.3 | 1.5 | 4.6 | - | - | - | - | - | - | - | - |
| *Albizia schimperiana* | Fabaceae | 1.6 | 0.9 | 1.2 | 3.6 | 3.6 | 3.2 | 3.2 | 10.0 | 0.05 | 0.05 | 0.05 | 0.015 |
| *Carica papaya* | Caricaceae | 4.7 | 5.1 | 3.7 | 13.6 | 4.5 | 5.1 | 4.0 | 13.7 | 0.004 | 0.003 | 0.007 | 0.015 |
| *Carissa spinarum* | Apocynaceae | 1.9 | 1.2 | 2.1 | 5.2 | 2.2 | 1.1 | 1.9 | 6.6 | 0.08 | 0.09 | 0.05 | 0.23 |
| *Catha edulis* | Celactraceae | 1.8 | 1.4 | 2.3 | 5.5 | 1.9 | 1.68 | 3.0 | 6.6 | 0.02 | 0.02 | 0.04 | 0.11 |
| *Citrus aurantifolia* | Rutaceae | 2.9 | 2.1 | 2.5 | 7.5 | 3.2 | 2.2 | 2.4 | 7.9 | - | - | - | - |
| *Citrus medica* | Rutaceae | 3.8 | 3.8 | 3.4 | 10.9 | 5.0 | 5.5 | 4.0 | 14.5 | - | - | - | - |
| *Citrus sinensis* | Rutaceae | 3.8 | 3.5 | 3.1 | 10.4 | 4.7 | 4.5 | 3.4 | 12.7 | 0.002 | 0.001 | 0.004 | 0.02 |
| *Croton macrostachyus* | Euphorbiaceae | 2.3 | 2.1 | 2.5 | 6.1 | 1.6 | 0.8 | 1.7 | 4.1 | 0.04 | 0.03 | 0.03 | 0.1 |
| *Ehretia cymosa* | Boraginaceae | 2.8 | 2.2 | 2.7 | 7.6 | 2.4 | 1.4 | 2.1 | 5.9 | 0.07 | 0.06 | 0.04 | 0.17 |
| *Ficus vasta* | Moraceae | 2.3 | 2.5 | 6.5 | 1.6 | 0.8 | 1.7 | 4.1 | 0.04 | 0.03 | 0.03 | 0.1 |
| *Grevillea robusta* | Proteaceae | 1.4 | 1.2 | 2.4 | 4.7 | 2.8 | 1.9 | 2.4 | 7.1 | 0.05 | 0.04 | 0.04 | 0.13 |
| *Kaffir guajava* | Myrtaceae | 5.0 | 6.1 | 4.9 | 13.7 | 3.2 | 5.2 | 5.0 | 13.4 | 0.005 | 0.003 | 0.007 | 0.015 |
| *Psidium guajava* | Myrtaceae | 5.0 | 6.1 | 4.9 | 13.7 | 3.2 | 5.2 | 5.0 | 13.4 | 0.005 | 0.003 | 0.007 | 0.015 |
| *Jatropha curcas* | Euphorbiaceae | 1.0 | 0.5 | 1.1 | 3.7 | 2.9 | 1.9 | 2.3 | 7.2 | 0.02 | 0.02 | 0.02 | 0.06 |
| *Mangifera indica* | Anacardiaceae | 3.6 | 3.2 | 3.0 | 9.8 | 4.8 | 5.8 | 4.3 | 14.9 | - | - | - | - |
| *Olea europaea subsp. cuspidate* | Oleaceae | 1.4 | 1.0 | 2.3 | 4.8 | 1.0 | 0.5 | 1.9 | 3.5 | 0.02 | 0.01 | 0.02 | 0.05 |
| *Persea americana* | Lauraceae | 3.7 | 2.9 | 2.8 | 9.4 | 4.5 | 3.7 | 2.9 | 11.1 | - | - | - | - |
| *Psidium guajava* | Myrtaceae | 5.0 | 6.1 | 4.9 | 13.7 | 3.2 | 5.2 | 5.0 | 13.4 | 0.005 | 0.003 | 0.007 | 0.015 |
| *Rhamnus prinoides* | Rhamnaceae | 4.7 | 4.7 | 3.5 | 12.9 | 4.6 | 5.3 | 4.2 | 14.1 | 0.048 | 0.046 | 0.045 | 0.14 |
| *Rhus glutinosa* | Anacardiaceae | 1.0 | 0.6 | 2.2 | 3.8 | 1.2 | 0.6 | 1.7 | 3.5 | 0.03 | 0.03 | 0.03 | 0.1 |
| *Schinus molle* | Anacardiaceae | 0.8 | 0.5 | 1.4 | 2.6 | 1.4 | 0.8 | 2.0 | 4.2 | 0.02 | 0.015 | 0.02 | 0.055 |
| *Ziziphus spinosa-christi* | Rhamnaceae | 5.6 | 7.7 | 4.6 | 17.9 | 5.3 | 8.7 | 5.6 | 19.6 | 0.02 | 0.01 | 0.04 | 0.07 |

LE, Lower Elevation; ME, Middle Elevation; HE, Higher Elevation; RF, Relative Frequency; RD, Relative Density; RDo, Relative Dominancy; IVI, Important Value Index.

---

**Figure 4.** Radar chart illustrating farmers' perception on benefits of integrating trees on agricultural lands across an elevation gradient in North-eastern Ethiopia. Key: FC, Fuel, and Charcoals; SFM, Soil Fertility Maintenance; BCF, Building Construction, and Fence; FF, Food and Fodder; BK, Bee Keeping; Md, Medicinal use; IG, Income Generation.
indigenous AF systems dealt with the management of soil fertility. Besides, Asfaw and Agren (2007) showed the relevance of productivity and resilience of smallholder’s farming system from con-

4.2. Farmers’ role and ecological requirement of the life strategy of the species. Kewessa (2015) showed that studies that highlight the importance of farm plantations on agricultural fertility, get farm utilities, and livestock food and fodder. The perception surveyed farmers integrated trees into their farm system to improve soil

As reported by Alebachew (2012) in western Shewa Zone of central Ethiopia. The authors confirmed that soil available phosphorus under these tree species canopies was (34–50 %) higher than the corresponding soil away from the canopies. The integration of C. africana and Melillettia ferruginea for soil fertility mainte-

5. Conclusions

Agroforestry is a complex ecological-based natural resource management system with many benefits. Farmers in north Ethiopia have been integrating shrubs and trees into their agricultural systems to assure sustainability and productivity. However, tree species density and variability declined with increasing altitudinal gradient and many multi-

Table 5. Respondents’ (R1-R10; “key informants”) preference ranking for ten selected tree species based on the assumed maintenance of soil fertility. The rank was determined following the grading of ten most planted tree species to boost soil fertility; the largest value (10) was assigned to species considered to hold the greatest importance for soil maintenance, while the least contribution to soil maintenance was assigned (1).

| Tree species                        | R1 | R2 | R3 | R4 | R5 | R6 | R7 | R8 | R9 | R10 | Total | Rank |
|-------------------------------------|----|----|----|----|----|----|----|----|----|-----|-------|------|
| Acacia seyal (L.) Willd.            | 1  | 1  | 2  | 2  | 1  | 1  | 2  | 1  | 1  | 1   | 13    | 10   |
| Acacia seyal Delile                 | 4  | 4  | 3  | 4  | 5  | 4  | 5  | 4  | 5  | 3   | 41    | 7    |
| Albizia schimperiana Oliv.          | 3  | 3  | 4  | 3  | 2  | 3  | 3  | 2  | 4   | 30    | 8    |
| Cordia africana Lam.                | 8  | 9  | 8  | 8  | 9  | 10  | 8  | 10  | 8  | 8   | 88    | 2    |
| Cordia myxa Thwaites               | 6  | 6  | 5  | 6  | 6  | 6  | 7  | 4  | 7   | 5    | 56    | 5    |
| Croton macrostachyus Hochst. ex Delile | 7  | 7  | 8  | 7  | 9  | 7  | 6  | 9  | 6   | 7    | 73    | 4    |
| Ehretia cymosa Willd. ex Roem. & Schult. | 2  | 2  | 1  | 1  | 3  | 2  | 1  | 2  | 3   | 2    | 19    | 9    |
| Ficus vasa Forsk.                   | 9  | 8  | 7  | 9  | 7  | 10  | 8  | 7  | 9   | 9    | 83    | 3    |
| Olea europaea subspec. cupidana (Wall. & G.Don) Cif. | 5  | 5  | 6  | 5  | 4  | 5  | 5  | 6  | 4   | 6    | 51    | 6    |
| Ziziphus spina-christi (L.) Willd.  | 10 | 10 | 9  | 10 | 10 | 8  | 9  | 10 | 8   | 10   | 94    | 1    |

Table 5. Respondents’ (R1-R10; “key informants”) preference ranking for ten selected tree species based on the assumed maintenance of soil fertility. The rank was determined following the grading of ten most planted tree species to boost soil fertility; the largest value (10) was assigned to species considered to hold the greatest importance for soil maintenance, while the least contribution to soil maintenance was assigned (1).
Berhanu Abraha Tsegay: Conceived and designed the experiments; Wrote the paper.

Funding statement
This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability statement
Data included in article/supplementary material/referenced in article.

Declaration of interests statement
The authors declare no conflict of interest.

Additional information
Supplementary content related to this article has been published online at https://doi.org/10.1016/j.heliyon.2022.e09048.

Acknowledgements
The authors are thankful to the farmers, anonymous reviewers, and the editor for providing information and helpful comments.

References
Abebe, T., 2005. Diversity in home Garden Agroforestry Systems of Southern Ethiopia. Dissertation. Wageningen University, Netherlands.
Abebe, T., Sterck, F.J., Wiersum, K.F., Bongers, F., 2013. Diversity, composition and density of trees and shrubs in agroforestry homegardens in Southern Ethiopia. Agrofor. Syst. 87, 1283–1295.
Abebe, T., Wiersum, K.F., Bongers, F., 2010. Spatial and temporal variation in crop diversity in agroforestry home gardens of Southern Ethiopia. Agrofor. Syst. 78, 309–322.
Alebachew, M., 2012. Traditional agroforestry practices, opportunities, threats and research needs in the highlands of Oromia, Central Ethiopia. Int. J. Agric. Sci. Soil Sci. 2, 194–206.
Amarz, D., Wondie, M., Mekuria, W., Dar, D., 2019. Agroforestry of smallholder farmers in Ethiopia: practices and benefits. Small-Scale For. 18, 39–56.
ARWRF, 2020. Database for Meteorological Data Source (2009-2019/20 G.C.) of North Wollo, Ethiopia.
Amba, A., Stromsjoinder, L., de Graaff, J., 2017. Long-term dynamics in land resource use and the driving forces in the Beressa watershed, highlands of Ethiopia. J. Environ. Manag. 83, 443–459.
A slowdown, Z., Agnen, G.L., 2007. Farmers’ local knowledge and topsoil properties of agroforestry practices in Sidama, Southern Ethiopia. Agron. Syst. 71, 35–48.
Betamariam, M., Negash, M., Worku, A., 2020. Comparative analysis of carbon stocks in home garden and adjacent coffee based agroforestry systems in Ethiopia. Small-Scale For. 10, 319–334.
Birhan, B., Abebe, T., 2019. Diversity and floristic composition of rural and suburban home garden in Wadera district of Oromia region, Ethiopia. Int. J. Biodivers. Conserv. 11, 135–143.
Bishaw, B., Neufeldt, H., Mowo, J., Abdelkadir, A., Muriuki, J., Dalle, G., Aseefa, T., Guilbault, K., Kassa, H., Dawson, I.K., Luedeling, E., Mbow, C., 2013. Trees on farms and their contribution to soil fertility parameters in Badasena, Eastern Ethiopia. Biol. Fertil. Soils 42, 66–71.
Hailu, G., Lemenih, M., Sonboda, F., Itanna, F., Ian, F., 2017. Plant diversity and determinant factors across smallholder agricultural management units in Central Ethiopia. Agrofor. Syst. 91, 677–695.
Hammer, O., Harper, D.A.T., Ryan, P.D., 2001. Past: paleontological statistics software package for education and data analysis. Paleontol. Electron. 4 (1), 1–9.
Harrison, R.B., Reis, G.G., Reis, M.D.G.P., Bernardo, A.L., Firme, D.J., 2000. Effect of spacing and age on nitrogen and phosphorus distribution in biomass of Eucalyptus camaldulensis, Eucalyptus pellita and Eucalyptus urphylla plantations in Southeastern Brazil. For. Ecol. Manag. 133, 167–177.
Hasan, G., Ashraf, I., Mehmood, K., Sagheer, A., Irshad, M.Q., 2014. Present and future prospects of agroforestry as perceived by farmers in Punjab, Pakistan. TAJAR 2, 11–17.
Hedberg, I., Edwards, S., 1989. Flora of Ethiopia and Eritrea, Vol. 5, Pittosporaceae to Araliaceae. The National Herbarium, Addis Ababa and Uppsala.
Hedberg, I., Edwards, S., Nemomissa, S., 2003. Flora of Ethiopia and Eritrea. Vol. 4(1), Magnoliaceae Flacourtieae. The National Herbarium, Addis Ababa and Uppsala.
Jackson, B., Pagella, T., Sinclair, F., Orellana, B., Hanshaw, A., Reynolds, B., McIntyre, N., Whitaker, H., Eyzgot, A., 2013. Polycaper: a GIS mapping framework providing efficient and spatially explicit landscape-scale valuation of multiple ecosystem services. Landsc. Urban Plan. 112, 74–88.
Kassa, G., Abebe, T., Ewenetu, Z., 2015. Diversity, density and management of trees in different agroforestry practices of Yem special district, Southern Ethiopia. Sinet: Ethiop. J. Sci. 38, 1–16.
Kebebew, Z., Urgessa, K., 2011. Agroforestry perspective in land use pattern and farmers coping strategy: experience from Southwestern Ethiopia. World J. Agric. Res. 7 (1), 73–77.
Kent, M., Coker, P., 1992. Vegetation Description and Analysis. A Practical Approach. Belhaven Press, London.
Leganes, A., Negash, M., 2021. Species diversity, composition, structure and management in agroforestry systems: the case of Kachabira district, Southern Ethiopia. Heliyon 7, e06477.
Magurran, A.E., 1988. Biological Diversity and its Measurement. Springer, Dordrecht, Netherlands.
Mbow, C., Van Noordwijk, M., Prabhu, R., Simons, T., 2014. Knowledge gaps and research needs concerning agroforestry’s contribution to sustainable development goals in Africa. Curr. Opin. Environ. Sustain. 6, 162–170.
McVeery, J.A., Schroth, G., 2006. Agroforestry and biodiversity conservation—traditional practices, present dynamics, and lessons for the future. Biodivers. Conserv. 15, 549–554.
Molla, A., Kewessa, G., 2015. Woody species diversity in traditional agroforestry practices of Dellungena district, Southeastern Ethiopia: implication for maintaining native woody species. Int. J. Biodivers. 1–13, 2015.
Monge-González, M.L., Graven, D., Kromer, T., Castillo-Campos, G., Hernández-Sánchez, A., Guzmán-Jacob, V., Guerrero-Ramírez, N., Kreft, H., 2019. Response of tree diversity and community composition to forest use intensity along a tropical elevational gradient. Appl. Veg. Sci. 1–11, 00.
Nair, P.K.R., 1998. Directions in tropical agroforestry research: past, present, and future. In: Nair, P.K.R., Latt, C.R. (Eds.), Directions in Tropical Agroforestry Research. Forestry Sciences. Springer, Dordrecht, Netherlands.
Nagash, M., Yirdaw, E., Luukanen, O., 2012. Potential of indigenous multistraw agroforests for maintaining native floristic diversity in the south-eastern Rift Valley escarpment, Ethiopia. Agrofor. Syst. 85, 5–28.
Negash, M., Starr, M., 2015. Biodiversity and soil carbon stocks of indigenous agroforestry systems on the south-eastern Rift Valley escarpment, Ethiopia. Plant Soil 393, 95–107.
Nogueira-Braz, D., Araujo, M.B., Rosdul, T., Rabbee, B., 2008. Scale effects and human impact on the elevational species richness gradients. Nature 453, 216–219.
NWZAD, 2019. Socioeconomic, Land Use/Land Cover and Climatic Data of the Districts, Woldia, Ethiopia.
Pandey, R., Aretano, R., Gupta, A.K., Meena, D., Kumar, B., Alatalo, J.M., 2016. Agroforestry of smallholder farmers in Ethiopia. NWZAD, 2019. Socioeconomic, Land Use/land Cover and Climatic Data of the Districts, Woldia, Ethiopia.
Pandey, P.H., Pokhrel, P.N., Luitel, R.D., Acharya, K., Shah, K.K., 2021. Diversity of agroforestry species and uses in two ecological regions: A Case from Central Nepal. Adv. Agric. 2021, 1–9. Article ID 1198341.

Pinho, R.C., Miller, R.P., Sonia, S., 2012. Agroforestry and the improvement of soil fertility: a view from Amazonia. Appl Environ Soil Sci 1–11, 2012.

Reang, D., Hazarika, A., Sielski, G.W., Pandey, R., Das, A.K., Nath, A.J., 2021. Assessing tree diversity and carbon storage during land use transitioning from shifting cultivation to indigenous agroforestry systems: implications for REDD+ initiatives. J. Environ. Manag. 298, 113470.

Rejmanek, M., Randall, J., 1994. Invasive alien plants in California: 1993 summary and comparison with other areas in North America. Madrono 41, 161–177.

Sanou, J., Zougmore, R., Bayala, J., Teklehaimanot, Z., 2010. Soil infiltrability and water content as affected by Baobab (Adansonia digitata L.) and Néré (Parkia biglobosa (Jacq.) Benth.) trees in farmed parklands of West Africa. Soil Use Manag. 26, 75–81.

Sharma, C.M., Mishra, A.K., Tiwari, O.P., Krishan, R., Rana, Y.S., 2017. Effect of altitudinal gradients on forest structure and composition on ridge tops in Garhwal Himalaya. Energy Ecol. Environ. 2, 404–417.

Solefack, M.C.M., Fedoung, E.F., Temgoua, L.F., 2018. Factors determining floristic composition and functional diversity of plant communities of Mount Oku forests, Cameroon. J. Asia Pac. Bus. 11, 284–295.

Soto-Pinto, L., Villalvazo, V., Jiménez, G., Ramírez, N., Montoya, G., Sinclair, F., 2007. The role of local knowledge in determining shade composition of multistrata coffee systems in Chiapas, Mexico. Biodivers. Conservation 16, 419–436.

Thangataa, P.H., Hildebrand, P.E., 2012. Carbon stock and sequestration potential of agroforestry systems in smallholder agroecosystems of Sub-Saharan Africa: mechanisms for ‘reducing emissions from deforestation and forest degradation’ (REDD+). Agric. Ecosyst. Environ. 158, 172–183.

Tolera, M., Afew, Z., Lemenih, M., Karltun, E., 2008. Woody species diversity in a changing landscape in the South central highland of Ethiopia. Agric. Ecosyst. Environ. 128, 52–58.

Uelry, A.L., Graham, R.C., Chadwick, O.A., Wood, H.B., 1995. Decade-scale changes of soil carbon, nitrogen and exchangeable cations under chaparral and pine. Geoderma 65, 121–134.

Vlek, P.L.G., Le, Q.B., Tamene, L., 2010. Assessment of land degradation, its possible causes and threat to food security in Sub-Saharan Africa. In: Lal, R., Stewart, B.A. (Eds.), Food Security and Soil Quality. Taylor & Francis, USA.

Wondie, M., Mekuria, W., 2018. Planting of Acacia decurrens and dynamics of land cover change in Fagita Lekoma district in the Northwestern Highlands of Ethiopia. MRD 38 (3), 230–239.

Wondie, M., Schneider, W., Melesse, A.M., Teketay, D., 2011. Spatial and temporal land cover changes in the Simen Mountains National Park, a world heritage site in Northwestern Ethiopia. Rem. Sens. 3, 752–766.

Yengwe, J., Gebremikael, M.T., Buchan, D., Lungu, O., Neve, S.D., 2018. Effects of Faidherbia albida canopy and leaf litter on soil microbial communities and nitrogen mineralization in selected Zambian soils. Agrofor. Syst. 92, 349–363.